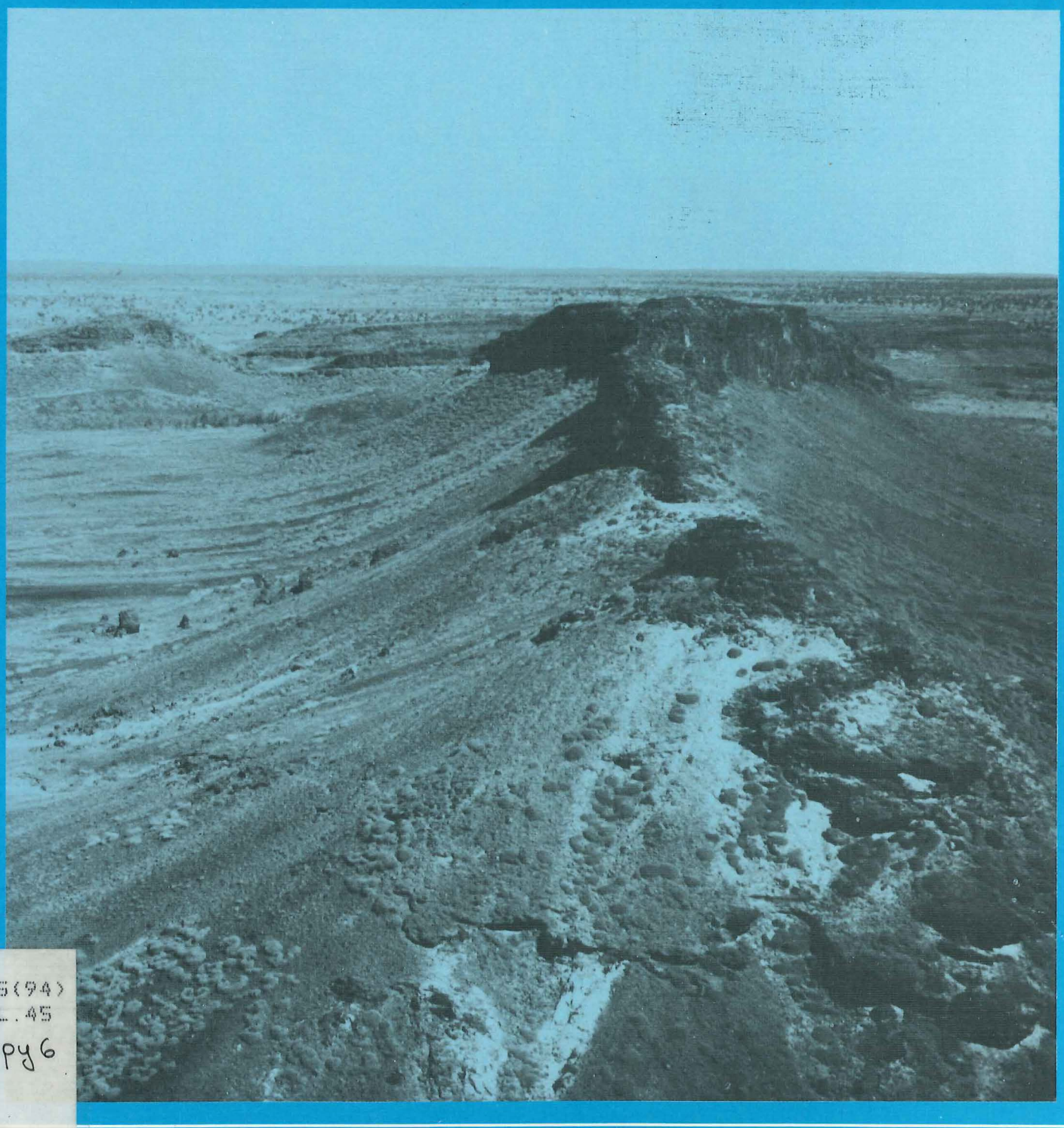
Geology of the onshore Canning Basin, Western Australia

BMR Bulletin
215

R.R.Towner D.L.Gibson



555(94)
BUL.45
Copy 6

DEPARTMENT OF NATIONAL DEVELOPMENT & ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN 215

Geology of the onshore Canning Basin, Western Australia

R. R. TOWNER & D. L. GIBSON

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA 1983

DEPARTMENT OF NATIONAL DEVELOPMENT & ENERGY

MINISTER: SENATOR THE HON. SIR JOHN CARRICK, K.C.M.G.

SECRETARY: A. J. WOODS

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

DIRECTOR: R. W. R. RUTLAND

Published for the Bureau of Mineral Resources, Geology and Geophysics by the Australian Government Publishing Service

© Commonwealth of Australia 1983

ISBN 0 644 01878 X
ISSN 0084-7089

This Bulletin was edited by J. S. Adkins

Printed by Graphic Services Pty Ltd, 516-518 Grand Junction Road, Northfield, SA 5085

CONTENTS

	Page
ABSTRACT	v
1. INTRODUCTION	1
Basin outline	1
Exploration history	1
Geological	1
Geophysical	1
Petroleum drilling	5
Non-petroleum drilling	5
Literature	5
Investigations, 1972–1977	5
2. STRATIGRAPHY	8
Precambrian	8
Phanerozoic	9
3. STRUCTURE AND TECTONICS	30
Basin boundaries	30
Basin structures	31
Faults and folds	32
Basin development	33
4. GEOLOGICAL HISTORY	33
5. MINERAL RESOURCES	33
Petroleum	33
Coal	41
Iron	41
Phosphate	41
Heavy-mineral sands	41
Salt	41
Diamonds	41
Lead and zinc	41
Construction materials	41
Water	41
6. REFERENCES	43

APPENDIXES (on microfiche)

1. BMR Record 1975/77: Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia.
2. BMR Record 1976/24: Permian depositional history of the Noonkanbah 1:250 000 Sheet area, W.A.
3. BMR Record 1976/95: Notes on the geology of the southern part of the Canning Basin.
4. BMR Record 1978/8: Permian and Mesozoic geology of the Derby and Mount Anderson 1:250 000 Sheet areas, Western Australia.
5. BMR Record 1980/30: Geology of Late Carboniferous and younger rocks of the onshore western Canning Basin, Western Australia.

TABLES

1. BMR and subsidised seismic surveys	2
2. Gravity surveys	4
3. Airborne and ground magnetic surveys	5
4. Drilling	6
5. Publications of the Canning Basin Survey (excluding Explanatory Notes)	8
6. Explanatory Notes for 1:250 000 Sheet areas	9
7. Stratigraphic table for 1:1 000 000 Canning Basin map	10
8. Precambrian basement lithologies penetrated by drillholes	30
9. Geological history	34

ACCOMPANYING MAPS

Plates 1 & 2 Geology of the Canning Basin, Western Australia; 1:1 000 000 scale

ABSTRACT

The Canning Basin is a large, intracratonic basin located between the Halls Creek Province and the Pilbara Block in the Great Sandy and Gibson Deserts region of Western Australia. Although blanketed by Cainozoic superficial sediments, reconnaissance mapping, drilling, and geophysical data have shown that the Canning Basin sequence is composed of faulted and folded Phanerozoic sedimentary rocks up to 18 km thick.

The geology of the onshore Canning Basin is characterised by five major periods of sedimentation; each period comprising a number of marine and continental phases, and each separated by major intervals of erosion with or without tectonism. The first period occurred during the Early Ordovician when predominantly marine sediments were deposited. The second period extended from possibly the Silurian through to the Early Carboniferous. Evaporitic marine, then continental-to-marine sediments were laid down, including a thick sequence of reef-carbonates during the Devonian. Tensional tectonism during this depositional phase formed the Fitzroy Trough and adjacent shelves and terraces in the northeast of the Canning Basin.

The third period of sedimentation began in the Late Carboniferous with both marine and continental sedimentation, initially under glacial conditions, and continued under a warmer climate into the Early Triassic, with marine and minor fluvial sediments accumulating.

This was followed by a major phase of compressional tectonism, probably during the Early Jurassic, which resulted in some right lateral shear and reverse movement along the Fenton Fault System at the southern margin of the Fitzroy Trough, and the folding of sediments within the Trough.

The fourth period of sedimentation commenced in late Early Jurassic times and continued until the Early Cretaceous with regional transgression from the northwest together with some fluvial influence, and ended with a minor transgression from the adjoining Officer Basin to the southeast.

The final major period of sedimentation was in the Cainozoic, during a wet climate, when a well-preserved dendritic palaeodrainage system developed on a land surface dominated by a duricrusted peneplain. As conditions became drier, salt lakes and sand dunes formed. Later, nearshore marine and continental sediments accumulated along the coast in response to a fluctuating sea level.

Good reservoir rocks and hydrocarbon source rocks are present within the Canning Basin sequences. Many potential petroleum trap structures have been tested with limited success. The best potential targets appear to be the Devonian reefs and the overlying Late Devonian to Early Carboniferous Fairfield Group. The Jurassic sandstones, Tertiary valley calcrete, and Quaternary alluvium are prospective for good quality groundwater.

1. INTRODUCTION

Basin outline

The onshore Canning Basin lies between latitudes 16° and 24°S and longitudes 119° and 128°E, in the northern part of Western Australia. It measures approximately 800 km from north to south, 950 km from east to west, and covers an area of 430 000 km^2. The Basin contains an aggregate maximum thickness of 18 000 m of predominantly Palaeozoic continental and shallow-marine clastic sediments. These are overlain by a thin cover of Mesozoic and surficial Cainozoic sediments.

Onshore, the Basin is intracratonic, lying between the stable Precambrian Halls Creek Province to the northeast, the Precambrian The Granites-Tanami Block and Arunta Block, and the Precambrian to Palaeozoic Amadeus Basin to the east, and the Precambrian Pilbara Block and Paterson Province to the southwest. The southern margin of the Canning Basin with the Officer Basin is arbitrarily taken as the crest of the Anketell Regional Gravity Ridge (see section on STRUCTURE AND TECTONICS). The Canning Basin extends offshore where, in the Mesozoic and Cainozoic, it developed in a similar way to the contiguous Carnarvon Basin to the southwest and the Browse Basin to the north (Gorter & others, 1979; Forman & Wales, 1981; Warris, 1976).

Exploration history

Geological

In the late 19th Century, a number of explorers crossed or travelled over parts of the Canning Basin (Feeken & others, 1970). Geological investigations of the Basin north of the Fitzroy River and along the southwestern margin began in the early 20th Century. Guppy & others (1958) and Traves & others (1956) give details of this work.

Following the start of aerial photographing of the Canning Basin in 1947, regional geological mapping began in earnest in the 1950s, mainly by the Bureau of Mineral Resources (BMR) with support from companies. Traves & others (1956), Brunnschweiler (1957), Guppy & others (1958), McWhae & others (1958), and Veevers & Wells (1961) reported the results of this early work. A long term investigation of the Devonian reef complexes along the northeastern margin of the Basin by the Geological Survey of Western Australia (GSWA) began in the early 1960s (Playford & Lowry, 1966). Numerous references within the previously mentioned regional geological reports refer to the detailed work on stratigraphy and palaeontology carried out at the same time as the regional mapping programs. A good knowledge of the Permian and Mesozoic stratigraphy resulted from this initial mapping phase, and a number of 1:253 440 scale (1 inch to 4 mile) geological maps and Explanatory Notes were produced.

In the early 1970s, a new phase of detailed mapping of the Devonian reef complexes was undertaken by GSWA (Playford, 1976, 1980), and BMR commenced a detailed sedimentological and palaeontological study of the Late Devonian to Early Carboniferous Fairfield Group in the northern Canning Basin (Radke, 1976; Druce & Radke, 1979; Nicoll & Druce, 1979).

Extensive reviews of the geology of the Canning Basin have been produced by Playford & others (1975), Gorter & others (1979), and Forman & Wales (1981).

Geophysical

Geophysical investigations within the Canning Basin commenced in 1952 when gravity and seismic surveys were conducted by BMR. In 1954, the first aeromagnetic survey within the Basin was made, also by BMR. From 1956 onwards, private exploration companies became involved in geophysical investigations, mainly seismic surveys. Following the introduction of the Petroleum Search Subsidy Acts in 1959, under which subsidy became available (until 1974) for up to 50 percent of the acceptable costs of approved geophysical operations and petroleum drilling, company investigations began in earnest. As a result of these Acts, a considerable quantity of company data became available, and these, together with BMR's work, have provided regional and some detailed coverage of the onshore Canning Basin, and provided information on the Ordovician to Permian stratigraphy.

BMR and subsidised seismic surveys are listed in Table 1. Of the 80 surveys listed, over 70 percent took place in the northwestern portion of the Basin; much of the Kidson Sub-basin, central Fitzroy Trough, and the eastern and southern areas adjacent to the Basin margins have very poor seismic coverage. Data quality from the surveys varies from poor to very good, depending on the data gathering and processing techniques involved. A thick weathering profile and extensive faulting appear to be responsible for some of these poor data. Although most of the seismic surveys were basically reconnaissance investigations, many subsurface structures have been outlined. Data on these structures were reviewed by Gorter & others (1979).

Gravity surveys conducted in the onshore Canning Basin are recorded in Table 2; the data are held in the BMR Gravity Data Bank. The gravity contours that appear on the face of the 1:1 000 000 map are based on survey data collected from 1954 to 1969, processed by Darby & Fraser (1969) and Fraser (1974), who named a number of gravity provinces and their subdivisions. The terminology of these features was slightly modified in a later paper by Fraser (1976) in which he named four provinces covering the Basin: the Fitzroy Regional Gravity Complex, the Munro Regional Gravity Platform, the South Canning Regional Gravity Low, and the Anketell Regional Gravity Ridge. The Bouguer gravity contours have been calculated using a rock density of 2.67 t.m^{-3}.

Nearly all of the onshore Canning Basin is covered by reconnaissance airborne magnetic surveys; however, some of the data are not available as some surveys were unsubsidised. Surveys for which data are available are listed in Table 3.

Using all the available data from BMR and company surveys, Gorter & others (1979) undertook a program to interpret:

(1) the main features of the magnetic field, the basement magnetic susceptibility data, and the gross

TABLE 1. BMR AND SUBSIDISED SEISMIC SURVEYS

Name of survey	*Date*	*Results*	*Reference*	*PSSA File*
Nerrima Dome	1952	Structure at depth of 2100 m bears no relation to surface anticline; major unconformity at 600 m	Vale & others (1953)	
Poole Range-Prices Creek area	1953	Thick section of sediment south of Pinnacle Fault	Smith (1955)	
Deep Well Anticline, Myroodah	1954	Reflections from a depth of 7300 m	Williams (1955)	
Poole Range-Christmas Creek area	1954	Thick sediment beneath Poole Range Anticline	Williams (1956)	
Broome area (preliminary investigation)	1954	Anticline at depth; thick sediments (in the order of 3800 m)	Vale & Williams (1955)	
Christmas Creek area	1955	A refractor (velocity 4600 m.s^{-1}) at about 2100 m unconformable with the overlying refractor is probably base Grant Group	Smith (1957)	
West of Langeys Crossing	1955	Thick sediments (up to 6000 m)	Vale & Smith (1956)	
Fenton Fault	1955	Fenton Fault at Barnes Flow (MOUNT ANDERSON) is a normal fault	Vale & Smith (1959)	
Near La Grange	1955	Sediment thickness ranges from about 1300 m to 2400 m	Smith (1960)	
Broome	1954–55	Thick folded sediments (up to 3000 m)	Smith (1961)	
Blue Hills-Logue	1959–60	Four pre-Permian anticlines and a possible salt structure	WAPET (1962a)	Publ. No. 36
Dampier Fault	1959–60	Five areas of interest with several probable closed structures	WAPET (1962b)	62/1520
The Sisters/Blackstone	1962	Anticline in The Sisters (DERBY) area is cut by a near-surface fault	Mines Adminstration (1962)	62/1598
Hawkstone Peak	1962	Hawkstone Peak structure defined	WAPET (1962c)	62/1608
Laurel Downs	1962	Gogo Anticline outlined; area has complex structure	WAPET (1962d)	62/1620
Goorda-Logue	1963	Inconclusive	WAPET (1963a)	63/1526
Gogo	1963	Northerly dip at north side of Gogo Anticline confirmed	WAPET (1963b)	63/1531
Sahara	1963–64	At least 3000 m of sediment likely	WAPET (1963c)	63/1539
Balgo-Lake Betty	1963	Coverage and data insufficient to determine closure of Balgo and Lake Betty Anticlines	WAPET (1964a)	63/1533
Parda	1964	Parda structure, and a sub-basin containing about 3000 m of sediment, separated from the Broome Arch by a fault, outlined	WAPET (1964b)	64/4524
St George Range	1964	Closed structure 1500 m beneath St George Ranges Anticline; area of closure mapped as 57 by 32 km	CONTINENTAL (1964)	64/4548
Poole Range	1965	Closure mapped about 4900 m beneath Poole Range Anticline	CONTINENTAL (1965a)	65/11001
Crossland	1965	Despite poor data, several anticlines delineated	CONTINENTAL (1965b)	65/11012
West Lennard	1965	Several inferred reef structures in the Kimberley Downs area	WAPET (1965a)	65/11016
Southeast Kidson	1965	About 4500 m thickness of sedimentary rocks	WAPET (1965b)	65/11014
Broome Swell	1965	Area has complex structure	CONTINENTAL (1965c)	65/11006
Barbwire Range	1965	A number of faulted anticlines	CONTINENTAL (1965d)	65/11041
Mowla	1965	Several possible closed structures	WAPET (1965d)	65/11040
Willara Hill	1966	Two anticlinal structures opening to west; definition of Willara Hill Structure improved	WAPET (1966a)	66/11081
Betty (detail)	1966	Permian structure with closure of about 100 m mapped beneath Lake Betty Anticline	WAPET (1966b)	65/11055
Dampierland	1966	Pender Terrace (part of Lennard Shelf) separated from the Fitzroy Trough by a fault; Tapper Ridge discovered	WAPET (1966c)	66/11099
West Meda	1966	Detailed evaluation of previously indicated reef structures failed to substantiate them	WAPET (1966d)	66/11100
Lower Fitzroy	1966	Barlee Anticline and another closed structure south of it indicated	Gewerkschaft Elwerath (1966)	66/11111
Roebuck	1966	Five possible structures; further investigation recommended	WAPET (1966e)	66/11115
McLarty	1967	Two small anticlines mapped, and recommended for drilling	French Petroleum (1968)	67/11145
Dakota	1967	Four structures mapped	AAP (1968)	67/11161
Baskerville	1968	Despite poor data, three probable closed structures mapped	WAPET (1968b)	68/3023
Lennard	1968	Probable reef structures at depth	WAPET (1968a)	68/3018

TABLE 1. BMR AND SUBSIDISED SEISMIC SURVEYS—*Continued*

Name of survey	*Date*	*Results*	*Reference*	*PSSA File*
Ryan	1968	Thick section west of STANSMORE may be easterly extension of Fitzroy Trough	AAP (1969a)	68/3026
Napier	1968	A continuous refractor with velocity of 5500 $m.s^{-1}$ to 6000 $m.s^{-1}$ mapped in Upper Devonian, and tied to Hawkstone Peak 1	Westralian Oil Ltd (1968)	68/3033
Contention Heights	1969	Eastern margin of Kidson Sub-basin delineated; several structural trends outlined	AAP (1969b)	69/3036
Matches Springs	1969	Edgar Range Anticline persists at depth	Total Exploration Australia (1969)	69/3028
Baron Range	1969	Eastern limit of Ordovician sediments and two anticlines mapped	AAP (1969c)	69/3052
Munro Arch	1969	No confirmation of gravity-indicated Munro Arch; Admiral Bay Fault extends to the east, contrary to previously suggested trend	WAPET (1969a)	69/3042
Alexander	1969	Too poor for reliable mapping	Lennard Oil N.L. (1969)	69/3057
Munro R-1	1969	Structures in Willara Sub-basin further investigated; Anketell Ridge detected	WAPET (1969c)	69/3081
Jurgurra Terrace	1969	Five structures mapped; two recommended for drilling	WAPET (1969d)	69/3075
King Sound (marine)	1970	Western extension of Lennard Shelf defined	WAPET (1970a)	70/218
Alexander II	1970	Poor data, but several structures may be worthwhile drilling; depth to basement ranges from about 600 to 2600 m	Lennard Oil N.L. (1970)	70/449
Helena	1970	Fault separates a basement high from the Fitzroy Trough in the north	WAPET (1970b)	70/504
Tabletop	1970	Tabletop Shelf outlined at the southern margin of Kidson Sub-basin	WAPET (1970c)	70/392
Stretch Range	1970	Large anticline partly outlined; unconformity at about 2000 m	AAP (1971)	70/600
Crossland	1970	Dummer Range Fault mapped between Barbwire Terrace and Broome Arch	WAPET (1971a)	70/687
Gogo Trig	1970	Four culminations of the Gogo Anticline	WAPET (1970d)	70/718
Lake Betty	1970	Area has complex faulted structure	WAPET (1970e)	70/657
Laurel	1970	Section thickens markedly to the south	WAPET (1970f)	70/763
Oscar	1970	Inconclusive over Oscar Ridge, but seven possible closed structures indicated	WAPET (1970g)	70/765
Anketell	1970	An anticlinal trend mapped on poor data	WAPET (1971b)	70/896
Broome-Samphire	1970	Broad structure with estimated closure of 60 m mapped on Broome Arch	WAPET (1970h)	70/857
Pender	1970	Lennard Shelf extends offshore	WAPET (1970i)	70/817
Munro (detail)	1971	Munro Fault and several structures further delineated	WAPET (1971c)	70/1000
Lake Auld	1971	Magnetic and gravity-indicated fault at southern margin of Kidson Sub-basin confirmed	WAPET (1970j)	70/933
Crossland Platform	1971	Several structures mapped and recommended for further investigation	WAPET (1971d)	71/150
North Broome	1971	Several small faulted anticlines mapped	WAPET (1971e)	71/252
Poulton	1971	A few structures beneath suspected base Permian	WAPET (1971f)	71/326
Munro D-2	1971	Structures in Munro area investigated in detail; drill site recommended	WAPET (1971g)	71/478
North Broome D-2	1972	Previously outlined structure investigated and recommended for drilling	WAPET (1972a)	72/961
East Canning	1972	Seven closed structures, some only poorly controlled, and Jones Range structure mapped	WAPET (1972b)	72/975
Lennard Shelf	1972	Four closed structures, some fault-controlled	WAPET (1972c)	72/1065
Dampier Downs-Collins	1972	Poor data; several structures partly delineated	WAPET (1972d)	72/2545
Hickey Hills	1972	Sedimentary section thickens to the north into the Kidson Sub-basin; possible pre-Ordovician salt structure indicated	AAP (1973)	72/2761

TABLE 1. BMR AND SUBSIDISED SEISMIC SURVEYS—*Continued*

Name of survey	*Date*	*Results*	*Reference*	*PSSA File*
Liveringa Ridge	1972	Five anticlinal axes mapped; some worth further investigation	WAPET (1972e)	72/2938
Thornton	1973	Several closed structures mapped at northern margin of Fitzroy Trough and along eastern extension of Broome Arch	Associated Australian Oilfields NL (1974)	72/3362
Sahara II	1973	Anticlinal trend with probably three culminations mapped	WAPET (1973a)	73/234
Crossland III	1973	Semi-detail coverage on previously indicated structures	WAPET (1973b)	73/244
Collins II	1973	Poor data; improved control on previously indicated structures	WAPET (1973c)	73/248
Jones Range-Hall Range	1973	Confirmed closure over Jones Range structure	WAPET (1974a)	73/255
Barbwire II	1973	Three anticlines partly delineated	WAPET (1974b)	73/263
Doran	1973	Poor data; detailed Doran structure	WAPET (1973d)	73/267
Liveringa II	1973	Two previously indicated structures further investigated	WAPET (1973e)	73/271

TABLE 2. GRAVITY SURVEYS

BMR survey Number	*Survey name*	*Year*	**Reference*	*PSSA File*	*Survey type*
5206	Fitzroy Basin	1952	Wiebenga & van der Linden (1953)		Traverses
5305	Onslow-Derby (regional)	1953	Dooley (1963)		Road traverse
5308	Kimberley (regional)	1953	*BMR		Road traverse
5309–10	Poole Range (detailed)	1953	Everingham (1962, 1965)		Traverses
5406	Halls Creek, Derby, Broome, and Kimberley	1954	*BMR		Road traverse
5407	Grant Range and Myroodah-Luluigui area	1954	*BMR		Road traverse
5408	Port Hedland	1954	*BMR		Road traverse
5505	Christmas Creek, Derby, Broome, and Anna Plains	1955	*BMR		Road traverse
5606	Billiluna, Anna Plains, Port Hedland, and Pilbara	1956	*BMR		Road traverse
5631–33	Canning Basin	1954–56	*WAPET		Grid
5707	Canning Basin	1957	*BMR		Traverse (helicopter)
5941	Barlee	1959	WAPET (1964c)	62/1903	Grid
6009	Canning and Fitzroy Basins	1960	Flavelle & Goodspeed (1962)		Grid (helicopter)
6206	Amadeus and South Canning Basin	1962	Lonsdale & Flavelle (1963, 1968)		Grid (helicopter)
6214	Poole Range	1962	*BMR		Road traverse
6237	Jurgurra Terrace	1962	WAPET (1962e)	62/1928	Grid
6238	Laurel Downs-Virgin Hills	1962	WAPET (1962e)	62/1928	Along seismic lines
6239	Napier Downs	1962	Oil Development NL (1962)	62/1931	Grid
6243	Alexander Creek	1962	Hawkstone Oil Co. Ltd (1962)	62/1934	Grid
6366	Lake Betty	1963	WAPET (1964d)	63/1909	
6344	Sahara (regional)	1963	WAPET (1963d)	63/1910	Grid
6349	Joanna Spring	1963/64	WAPET (1964e)	63/1908	Grid
6437	Stansmore Range	1964	Geosurveys (1964)	64/4807	Grid
6505–06	Canning Basin	1965	*BMR		Grid (helicopter)
6548	Dampierland (semi-detailed)	1965	WAPET (1965e)	65/4816	Reconnaissance
6549	Southeast Kidson	1965	WAPET (1965c)	65/4814	Grid (helicopter)
6706	Canning Basin	1967	Whitworth (1970)		Grid (helicopter)
6739	Jarmura	1967	French Petroleum (1967)	67/4832	Grid
6740	Noonkanbah	1967	Continental (1968)	67/4834	Grid
6742	McLarty	1967	French Petroleum (1968)	67/11145	Reconnaissance
6744	Dakota	1967	AAP (1968)	67/11161	Along seismic lines
6748	Munro Arch	1967	WAPET (1967)	67/4829	Grid
6804	Canning Basin	1968	*BMR		Grid (helicopter)
6837	Ryan	1968	AAP (1969a)	68/3026	Along seismic lines
6911–18	Canning Basin	1969	Darby & Fraser (1969)		Grid (helicopter)
7044	Stretch Range	1970	AAP (1971)	70/600	Reconnaissance and along seismic lines
7031	Tabletop	1970	*WAPET		

* Surveys referenced without date do not have accompanying reports, but the data are included in the BMR Gravity Data Bank

TABLE 3. AIRBORNE AND GROUND MAGNETIC SURVEYS

Name of survey	*Year*	*Reference*	*PSSA File*	*Altitude (m above MSL)*
Canning Basin Aeromagnetic Reconnaissance	1954	Quilty (1960)		460
South Canning Basin	1962	WAPET (1963e, 1966h)	62/1728	600
Stansmore Range	1963	Hackathorn New Zealand Oils Ltd and Australian Oil Corporation (1963)	63/1700	760
Gibson Desert	1965	Union Oil Co. of California (1965)	65/4610	760
Pollock Hills	1965	AAP (1965)	65/4619	800
Offshore Canning	1965	WAPET (1965f)	65/4614	460
King Sound	1966	WAPET (1966g)	66/4623	460
Lower Fitzroy	1966	Gewerkschaft Elwerath Inc. (1966)	66/11111	ground survey
Wallal	1969	WAPET (1969b)	69/3037	300
Billiluna-Helena	1971	Associated Australian Oilfields NL (1972)	71/422	670
White Hills	1971	AAP (1972)	71/508	670
Lennard Shelf	1972	WAPET (1972f)	72/1019	600
Control of Traverses Magnetic Map of Australia	1973	BMR		Various

tectonic elements of the Canning Basin as seen in the magnetic basement;

(2) the broad linear zones of west-northwesterly trending Bouguer anomaly highs;

(3) the possibility of detecting reef and salt structures from positive anomalies; and,

(4) with the aid of seismic velocities, the subsurface distribution of various formations.

Petroleum drilling

Petroleum exploration in the Canning Basin was initiated by the discovery of oil shows in a water bore at Prices Creek (southeast NOONKANBAH*) in 1919. Until early 1957, the search for oil was dominated by the Freney Kimberley Oil Company Ltd (Freney) and its daughter companies (often referred to as the Freney Period; Mayne, 1975). Sixteen wells were drilled by Freney, all of them in the Fitzroy Trough; some had slight shows of oil and gas (see Table 4).

West Australian Petroleum Pty Ltd (WAPET) began drilling operations in the Canning Basin in 1955 with WAPET Grant Range 1, followed by a number of other wells including a series of stratigraphic test holes for BMR during 1955–56. During this phase, exploration was extended by WAPET to include the other parts of the Basin, particularly the coastal portion.

Following the introduction of the Petroleum Search Subsidy Acts in 1959, drilling activity increased up until 1962, with a number of wells being drilled to test potential structures on the Lennard Shelf, Jurgurra Terrace, and Broome Arch. During this active phase a few gallons of excellent quality crude oil were recovered from WAPET Meda 1. However, after further tests in this well, the ratio of oil to salt water recovered did not improve, and the oil show was declared a non-commercial find. About the same time, the first salt dome to be drilled in Australia was penetrated in WAPET Frome Rocks 1.

After a short period of low exploration activity a number of other companies apart from WAPET began drilling operations in the Canning Basin. Continental Oil Company of Australia Ltd (Continental), Australian Aquitaine Petroleum Pty Ltd (AAP), Total Exploration Australian Pty Ltd (Total), Lennard Oil N.L., and Gewerkschaft Elwerath Inc. all entered the search for oil by drilling wells over various parts of the Basin, particularly during the period 1966–70. WAPET did not drill any wells in 1969 and 1970, but recommenced drilling in 1971. During the period 1971–1974, WAPET drilled 15 holes, including one unsubsidised well, involving mainly the Broome Arch and the terrace features. AAP, after several years of geophysical surveying, drilled a well in the eastern Kidson Sub-basin in 1973.

Drilling activity began to decline prior to the cessation of the Petroleum Search Subsidy Acts in 1974. Towards the end of the 1970s, a few more wells were drilled, mainly on the Lennard Shelf, and a number of other wells planned.

Non-petroleum drilling

Exploration for coal in the Canning Basin has been carried out since 1965. This included work by Premier Mining Pty Ltd from 1965 to 1966 (Baarda, 1967), Theiss Bros. Pty Ltd in 1966 (Pickering, 1967, 1968), Australian Inland Exploration from 1970 to 1972, Esso Exploration in conjunction with Dampier Mining Co. from 1973 to 1974 (Galloway & Howell, 1975), Dampier Mining Co. from 1973 to 1975, and Conzinc Riotinto of Australia Pty Ltd (CRA) in 1973 (Quinton, 1974). Although some coal seams and carbonaceous beds were penetrated, no commercial coal deposits were found.

Literature

The most recent major reference on the Canning Basin is by Forman & Wales (1981) which describes the petroleum geology of the Canning Basin. Other significant contributions have been made by Veevers & Wells (1961), Playford & others (1975), Druce & Radke (1979), Gorter (1978), Playford (1967, 1976, 1980), Burne & Kantsler (1977), and Burne & others (1979). A bibliography of the Canning Basin literature up until 1970 was prepared by Raine (1970); a more up to date bibliography, to 1977 with other references up to 1980, is included in Forman & Wales (1981).

Investigations, 1972–1977

In 1972, BMR, in cooperation with GSWA, embarked on a program to finalise the geological mapping and

* Names capitalised as such refer to 1:250 000 Sheet areas.

TABLE 4. DRILLING

Year	Name of well	Company	Location		Total depth (m)	Hydrocarbon shows	BMR File	Reference
			Latitude	Longitude				
1910–11	Myalls Bore	—	17°21′S	123°40′E	322	None	—	Playford (1957)
1922	Prices Creek 1	Freney Kimberley Oil Co. Ltd	18°40′30″S	125°55′30″E	392.2	Traces of oil	—	Blatchford (1922)
1922	Prices Creek 2	Freney Kimberley Oil Co. Ltd	18°40′40″S	125°55′55″E	103.6	Traces of oil	—	Blatchford (1922)
1922–3	Mount Wynne 1	Freney Kimberley Oil Co. Ltd	18°06′S	124°27′E	273.1	Asphalt and bitumen	—	Waterford (1941)
1923	Prices Creek 3	Freney Kimberley Oil Co. Ltd	18°41′02″S	125°55′55″E	271.3	Traces of oil	—	Blatchford (1929)
1923	Prices Creek 4	Freney Kimberley Oil Co. Ltd	18°40′55″S	125°54′05″E	121.9	None	—	Blatchford (1930)
1923	Mount Wynne 2	Freney Kimberley Oil Co. Ltd	18°06′S	124°27′E	18.3	None—hole abandoned	—	—
1923–5	Mount Wynne 3	Freney Kimberley Oil Co. Ltd	18°06′S	124°27′E	656.5	Globules of oil	—	Blatchford (1927)
1926	Poole Range 1	Freney Kimberley Oil Co. Ltd	18°52′S	125°48′E	121.9	None	—	Guppy & others (1958)
1926–7	Poole Range 2	Freney Kimberley Oil Co. Ltd	18°52′S	125°48′E	320.3	None	—	Waterford (1941)
1927–30	Poole Range 3	Freney Kimberley Oil Co. Ltd	18°53′06″S	125°47′20″E	994.9	Thick brown oil	—	Waterford (1941)
1931	Poole Range 4	Freney Kimberley Oil Co. Ltd	18°52′27″S	125°49′02″E		None—water bore for No. 5	—	Waterford (1941)
1932–3	Poole Range 5	Freney Kimberley Oil Co. Ltd	18°52′27″S	125°49′02″E	470.9	None	—	Waterford (1941)
1939–42	Nerrima 1	Freney Kimberley Oil Co. NL	18°28′16″S	124°24′02″E	1301.6	Slight gas shows	—	Reeves (1949)
1954–55	Grant Range 1	WAPET	18°00′48″S	124°00′22″E	3936.5	Bituminous material	—	WAPET (1956a)
1955	Nerrima 1	Associated Freney Oilfields NL	18°26′55″S	124°22′17″E	2765.1	Traces of oil	—	Hill (1955)
1955	Jurgurra Creek 1	BMR	18°20′04″S	123°43′05″E	512.1	None	—	Henderson & others (1963)
1955	Fraser River Corehole 1	WAPET	17°28′50″S	123°12′30″E	366.4	None	—	WAPET (1956b)
1955–6	Laurel Downs 2	BMR	18°07′06″S	125°20′05″E	1219.2	None	—	Henderson & others (1956a)
1955–6	Myroodah 1	Associated Freney Oilfields NL	18°16′15″S	124°11′27″E	1829.1	None	—	Hill (1956)
1955–6	Fraser River 1	WAPET	17°25′04″S	123°09′39″E	3091.9	None	—	WAPET (1956c)
1956	Prices Creek 3	BMR	18°39′44″S	125°54′00″E	211.5	None	—	Henderson (1956b)
1956	Dampier Downs 1	WAPET	18°18′S	123°06′E	922.9	None	—	McKellar (1957)
1956	Roebuck Bay 1	WAPET	18°09′34″S	122°27′28″E	1219.2	None	—	WAPET (1956d)
1956–7	The Sisters 1	Associated Freney Oilfields NL	17°43′31″S	124°25′09″E	2995.6	Small show of oil	—	Hill (1957)
1957	Wallal Corehole 1	WAPET	19°51′46″S	120°37′58″E	309	None	—	WAPET (1957)
1958	Wallal 4	BMR	19°44′12″S	120°44′25″E	429.8	None	—	Henderson & others (1963)
1958	Wallal 4A	BMR	19°44′12″S	120°44′25″E	679.1	None	—	Henderson & others (1963)
1958	Samphire Marsh 1	WAPET	19°31′08″S	121°10′51″E	2031.2	None	62/1002	Johnstone (1961)
1958	Meda 1	WAPET	17°24′00″S	124°11′32″E	2685.0	Few barrels of oil; several small gas shows	62/1022	Pudovskis (1962)
1958	Goldwyer 1	WAPET	18°22′47″S	122°22′58″E	1438.7	Traces of oil	—	Elliott (1959)
1959	Meda 2	WAPET	17°24′36″S	124°11′23″E	2325.0	Minor gas	—	WAPET (1959)
1959	Thangoo 1	WAPET	18°22′06″S	122°53′22″E	1059.2	Traces of oil	62/1054	Pudovskis & Willmott (1961)
1959	Frome Rocks 1	WAPET	18°11′48″S	123°38′42″E	1219.2	None	62/1029	Elliott & Willmott (1962)
1959	Frome Rocks 2	WAPET	18°15′15″S	123°39′35″E	2287.2	Globules of oil	62/1033	Elliott & Willmott (1962)
1959–60	Thangoo 1A	WAPET	18°21′52″S	122°53′09″E	1655.4	None	62/1054	Pudovskis & Willmott (1961)
1960	Barlee 1	WAPET	17°48′25″S	122°42′40″E	2469.1	Gas traces, some bitumen	62/1057	Pudovskis & Carter (1961)
1962	Babrongan 1	WAPET	18°23′23″S	123°35′37″E	1949.2	Methane gas, minor bitumen	62/1090	Gardner (1962); WAPET (1966i)
1962	Langoora 1	WAPET	17°18′07″S	124°06′48″E	1615.1	None	62/1094	Gardner (1963a); WAPET (1966i)
1962	Hawkstone Peak 1	WAPET	17°14′45″S	124°24′26″E	1187.8	None	62/1093	Gardner (1963b); WAPET (1966i)
1964	Tandalgoo 2	WAPET	21°07′S	123°27′E	152	None	—	WAPET (1964f)
1965	Sahara 1	WAPET	21°04′40″S	123°23′30″E	2120.2	None	64/4129	Singleton(1965); WAPET (1966f)
1965	Parda 1	WAPET	18°56′08″S	122°00′34″E	1906.8	Oil staining	65/4137	Williams (1965)
1965	Willara 1	WAPET	19°10′48″S	122°04′14″E	3903.3	Traces of oil and gas	65/4158	Johnson (1966a)
1965–6	St George Range 1	Continental Oil Co.	18°41′30″S	125°08′11″E	4437.3	Bitumen, several small gas shows	64/4170	Shannon & Henderson (1966)
1965–6	Point Moody 1	AAP	21°15′34″S	127°48′22″E	2133.6	Minor gas traces	65/4174	Labouysse & Michoud (1966)
1965–6	Kidson 1	WAPET	23°37′00″S	125°00′22″E	4431.5	None	65/4177	Johnson (1966b)
1967	May River 1	WAPET	17°14′50″S	124°05′01″E	1678.0	Minor oil stains	67/4252	Johson & Brownhill (1967)
1967	Blackstone 1	WAPET	17°35′14″S	124°21′01″E	3049.5	Minor gas and bitumen traces	67/4262	Johnson (1968)
1967	Yulleroo 1	Gewerkschaft Elwerath Inc.	17°51′16″S	122°54′25″E	4572.3	Gas shows	67/4249	Bischoff (1968)
1968	McLarty 1	Total Exploration Australia	19°23′45″S	123°39′30″E	2590.8	Minor bituminous material	68/2009	Jacque & others (1968b)
1968	Edgar Range 1	Total Exploration Australia	18°45′26″S	123°35′33″E	1968.1	Trace of oil	68/2041	Jacque & others (1968a)

Year	Name of well	Company	Location		Total depth	Hydrocarbon shows	BMR File	Reference
			Latitude	Longitude	(m)			
1968	Kemp Field 1	Total Exploration Australia	20°19′10″S	123°27′58″E	1181.1	None	68/2048	Jacque & others (1969a)
1968	Wilson Cliffs 1	AAP	22°16′39″S	126°46′55″E	3722.2	Slight trace of methane gas	68/2011	Creevey (1969)
1968	Doran 1	WAPET	18°10′56″S	123°29′06″E	763.2	Some bitumen	68/2033	Bird (1968)
1968	Willara Hill 1	WAPET	19°03′31″S	121°52′45″E	858.0	None	68/2044	Reid (1968)
1968	Chirup 1	WAPET	19°50′54″S	120°25′57″E	762.6	None	—	Bird (1969)
1969	Matches Springs 1	Total Exploration Australia	18°41′28″S	124°03′11″E	2834.6	None	69/2023	Jacque & others (1970)
1969	Mowla 1	Total Exploration Australia	18°43′50″S	123°42′35″E	762	None	69/2039	Jacque & others (1969b)
1969	Napier 1	Lennard Oil NL	17°12′20″S	124°31′36″E	1801.4	Traces of bitumen	69/2015	Newstead (1969)
1969	Napier 2	Lennard Oil NL	17°04′55″S	124°21′20″E	1606.9	Traces of methane gas and bitumen	69/2031	Watt & Newstead (1970)
1970	Napier 4	Lennard Oil NL	16°55′00″S	124°05′55″E	965.0	None	70/589	Temple (1970)
1970	Napier 5	Lennard Oil NL	17°06′30″S	124°28′06″E	1657.1	Minor methane gas traces	70/750	Watt & Temple (1971)
1970	*Lacepede 1A	BOC of Australia Ltd	17°05′18″S	121°26′41″E	2286	Minor methane gas traces	70/426	BOCAL (1970)
1971	Tappers Inlet 1	WAPET	16°51′38″S	122°35′22″E	2856.1	Slight traces of oil and gas	71/301	Crank (1971)
1971	Crossland 1	WAPET	19°43′10″S	125°14′50″E	913.2	None	71/465	Thomas & Caldwell (1971)
1971	Crossland 2	WAPET	20°00′45″S	124°59′36″E	914.4	None	71/465	Thomas & Caldwell (1971)
1971	Crossland 3	WAPET	20°12′12″S	125°45′39″E	915.3	None	71/465	Thomas & Caldwell (1971)
1971	Lake Betty 1	WAPET	19°34′10″S	126°19′52″E	3145.8	Minor methane gas show	71/441	Crank (1972)
1971	Munda 1	WAPET	19°28′27″S	122°17′32″E	1066.8	None	71/475	Moyes (1972)
1971	*Bedout 1	BOC of Australia Ltd	18°14′40″S	119°23′23″E	3073	None	71/435	BOCAL (1971)
1972	Pender 1	WAPET	16°40′48″S	122°50′06″E	911.7	None	72/2000	Meath (1972)
1972	Palm Springs 1	WAPET	17°48′56″S	124°53′08″E	1066.8	None	72/2002	Osborne (1972)
1972	Barbwire 1	WAPET	19°10′38″S	125°00′58″E	1071.4	None	72/2001	Young (1972)
1972	Munro 1	WAPET	19°51′47″S	122°28′28″E	2116	None	72/846	Williams (1972)
1972	Logue 1	WAPET	18°07′33″S	123°23′24″E	2699	Oil stain; minor gas show	71/479	Meath & Scott (1972)
1973	Thangoo 2	WAPET	18°26′32″S	122°54′33″E	1472	Minor oil stains	73/218	Young & O'Shaughnessy (1973a)
1973	Mimosa 1	WAPET	17°44′58″S	124°35′00″E	4117	Oil stains; minor gas shows	73/233	Osborne & O'Shaughnessy (1973)
1973	Mount Hardman 1	WAPET	18°00′38″S	124°54′48″E	3360	Oil stains; minor gas shows	73/259	Young & O'Shaughnessy (1973b)
1973	Contention Heights 1	AAP	22°25′36″S	127°13′31″E	1790.7	Slight traces of gas	73/230	Brown & Campbell (1974)
1973	*East Mermaid 1	Shell Development (Australia) Pty Ltd	17°10′01″S	119°49′21″E	4068	Slight traces of gas	73/1003	Shell (1973)
1973	*Wamac 1	Amax Petroleum (Australia) Inc.	17°14′26″S	121°29′30″E	2764	Slight traces of gas	73/246	Amax (1974)
1973	*Keraudren 1	Hematite Petroleum Ltd	18°54′27″S	119°09′15″E	3844	Slight traces of gas	73/240	Hematite (1974)
1973	Cornish 1	BMR	20°10′03″S	126°33′54″E	164	None	—	Yeates & others (1975a)
1973	Cornish 2	BMR	20°11′09″S	126°52′30″E	227	None	—	Yeates & others (1975a)
1973	Cornish 3	BMR	20°10′51″S	127°24′12″E	99	None	—	Yeates & others (1975a)
1973	Mount Bannerman 1	BMR	19°56′06″S	127°13′42″S	203	None	—	Yeates & others (1975a)
1973	Mount Bannerman 2	BMR	19°04′03″S	126°10′21″E	139	None	—	Yeates & others (1975a)
1973	Mount Bannerman 3	BMR	19°29′18″S	127°09′33″E	94	None	—	Yeates & others (1975a)
1973	Mount Bannerman 4	BMR	19°30′03″S	127°03′03″E	151	None	—	Yeates & others (1975a)
1973	Lucas 13	BMR	20°24′06″S	127°36′09″E	189	None	—	Yeates & others (1975a)
1973	Lucas 14	BMR	20°16′39″S	127°46′33″E	105	None	—	Yeates & others (1975a)
1973	Crossland 1	BMR	19°13′03″S	125°53′30″E	262	None	—	Yeates & others (1975a)
1973	Crossland 2	BMR	19°12′16″S	125°28′03″E	139	None	—	Yeates & others (1975a)
1973	Billiluna 1	BMR	19°56′33″S	127°51′55″E	123	None	—	Yeates & others (1975a)
1973	Billiluna 3	BMR	19°30′30″S	127°38′18″E	161	None	—	Yeates & others (1975a)
1974	Jones Range	WAPET	19°21′40″S	125°40′13″E	2540	Minor gas shows	—	Broad & McDermott (1974)
1974	*Minilya 1	BOC of Australia Ltd	18°19′28″S	118°43′57″E	—	Data confidential	74/116	—
1979	Ellendale 1	Amax Petroleum (Australia) Inc.	17°54′18″S	124°42′15″E	3190	Minor oil and gas shows	—	—
1979	Puratte 1	Esso Australia Ltd	17°05′16″S	123°14′18″E	3750	None	—	—
1980	Moogana 1	Esso Australia Ltd	16°56′17″S	122°41′28″E	2213	None	—	—
1980	Fitzroy River 1	Amax Petroleum (Australia) Inc.	18°29′39″S	124°52′50″E	3134	None	—	—
1981	Blina 1	Home Oil	17°37′24″S	124°30′05″E	2496	Oil discovery well	—	—
1981	Orange Pool 1	Home Oil	17°18′15″S	124°12′54″E	1171	None	—	—
1981	Yarrada 1	Home Oil	17°21′55″S	124°06′08″E	3295	None	—	—

*Offshore wells referred to on Plate 1 only.

TABLE 5. PUBLICATIONS OF THE CANNING BASIN SURVEY (EXCLUDING EXPLANATORY NOTES)

Authors	*Title*
(a) *Regional Geology*	
Yeates & others (1975a)	Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia.
Crowe & Towner (1976a)	Permian depositional history of the Noonkanbah 1:250 000 Sheet area, W.A.
Crowe (1975)	The classification, genesis and evolution of sand dunes in the Great Sandy Desert.
Crowe & Towner (1976b)	Environmental interpretation of the Permian Nura Nura Member of the Poole Sandstone, Noonkanbah Sheet area, Canning Basin; a gradation between fluviatile and shallow-water marine facies
Towner & others (1976)	Notes on the geology of the southern part of the Canning Basin.
Yeates & others (1976)	The Veevers Crater: a possible meteoritic feature.
Crowe & others (1978)	Permian and Mesozoic geology of the Derby and Mount Anderson 1:250 000 Sheet areas, Western Australia.
Towner & Gibson (1980)	Geology of Late Carboniferous and younger rocks of the onshore Western Canning Basin, Western Australia.
(b) *Stratigraphic Nomenclature*	
Yeates & others (1975b)	New and revised stratigraphic nomenclature, northeast Canning Basin, Western Australia.
Crowe & Towner (1976c)	Permian stratigraphic nomenclature, Noonkanbah 1:250 000 Sheet.
Crowe & Towner (1976d)	Definitions of some new and revised rock units in the Canning Basin.
(c) *Palaeontology*	
Dickins & Jell (1974)	Permian fossils from the Canning Basin, 1971 and 1972.
Dickins (in preparation)	Report on fossils collected in the northeast Canning Basin during 1973.
White & Yeates (1976)	Plant fossils from the northeastern part of the Canning Basin, Western Australia.
Dickins & others (1977)	A Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia.

interpretation at the scale of 1:250 000 for the entire onshore Canning Basin. Fieldwork was undertaken during the period 1972–1977, and involved Second Edition geological maps being produced for a number of the Sheet areas, particularly around the Basin margin.

Personnel involved in the fieldwork were: R. R. Towner (BMR), 1973–1977; D. L. Gibson (BMR), 1976–1977; R. W. A. Crowe (GSWA), 1972–1977; A. N. Yeates (BMR), 1972–1975; L. A. I. Wyborn (BMR), 1973; V. L. Passmore (BMR), 1972; and P. A. Jell (BMR), 1973. The mapping was carried out by traversing with four-wheel-drive vehicles. In the more inaccessible central, western, and southern Canning Basin, limited vehicle traversing was supplemented by helicopter surveys.

The survey was carried out using black and white aerial photographs of the RC9 (1:80 000) Series, except for JOANNA SPRING, SAHARA, and PATERSON RANGE where the older K17 (1:48 000) Series was used to obtain complete coverage of the Basin. Prior to each field season, the aerial photographs were examined; potentially good outcrops and other places of interest were marked and annotated on the photographs and on topographical base maps, which were available at either 1:100 000 or 1:250 000 scale. During the field seasons, these data points were used to plan vehicle and helicopter traverses. In 1972 and 1973, mapping was supplemented by shallow stratigraphic drilling and augering (Table 4). The 1:250 000 maps were prepared from information at visited localities and airphoto interpretation.

This Bulletin and accompanying maps are a synthesis of the geological information collected during the period 1972–1977. Local details on various areas and on individual Sheet areas can be found in the fieldwork reports (reproduced as Microfiche Appendixes 1–5 of this Bulletin), papers listed in Table 5, and Explanatory Notes listed in Table 6. **Where interpretation within this Bulletin differs from the earlier maps or reports, the Bulletin should be considered more up-to-date.**

With the exception of some of the Basin margins and a few ranges, e.g. the Stansmore, St George, and Grant Ranges, mapping in the Canning Basin is difficult, but not necessarily complex. Outcrops are widely separated and generally poor. Exposures of Phanerozoic rocks are generally less than 20 m thick, mostly flat-lying, and with little relief. Because of a lack of marker beds and macrofossils, the stratigraphic correlation between outcrops only a few kilometres apart, particularly in the central Basin region, may be difficult to establish. Lateritic weathering, especially in the central and southern Canning Basin, has destroyed many characteristic features of the bedrock, making airphoto interpretation difficult. The extensive cover of surficial deposits such as laterite, silcrete, and aeolian sand adds to mapping difficulties.

2. STRATIGRAPHY

The stratigraphy of the onshore Canning Basin is summarised in Table 7.

Precambrian

The nature of basement beneath most of the Canning Basin is largely unknown as it has only been penetrated in a few drillholes within the Basin (Table 8). The basement rocks could well be extensions of Precambrian rocks that are marginal to the Canning Basin, comprising igneous, metamorphic, and unmetamorphosed sedimentary rocks which crop out in the Halls Creek Province to the north (Dow & Gemuts, 1969), in The Granites-Tanami Block (Blake & others, 1979), the Arunta Block (Shaw & Stewart, 1975), and the Amadeus Basin (Wells & others, 1970) to the east, and in the Pilbara Block and Paterson Province (Wil-

TABLE 6. EXPLANATORY NOTES FOR 1:250 000 SHEET AREAS

Sheet			*Reference*
Pender		SE/51–2	Gibson (in preparation a)
Yampi		SE/51–3	Gellatly & Sofoulis (1973)
Broome		SE/51–6	Gibson (in preparation b)
Derby	First Edition	SE/51–7	Casey (1958a)
Derby	Second Edition	SE/51–7	Towner (1981)
Lennard River	First Edition	SE/51–8	Veevers (1958)
Lennard River	Second Edition	SE/51–8	Derrick & Playford (1973)
Lagrange		SE/51–10	Gibson (in preparation c)
Mount Anderson	First Edition	SE/51–11	Casey (1958b)
Mount Anderson	Second Edition	SE/51–11	Gibson & Crowe (1982)
Noonkanbah	First Edition	SE/51–12	Thomas (1958)
Noonkanbah	Second Edition	SE/51–12	Crowe & Towner (1981)
Mandora		SE/51–13	Towner (1982c)
Munro		SE/51–14	Towner (1982d)
McLarty Hills		SE/51–15	Gibson (1982)
Crossland		SE/51–16	Towner (1977)
Port Hedland	First Edition	SF/50–4	Low (1965)
Port Hedland-Bedout Island	Second Edition	SF/50–4 , SE/50–16	Hickman & Gibson (1982)
Yarrie	First Edition	SF/51–1	Wells (1959a)
Yarrie	Second Edition	SF/51–1	Hickman & others (in preparation)
Anketell	First Edition	SF/51–2	Casey (1957)
Anketell	Second Edition	SF/51–2	Towner (1982a)
Joanna Spring		SF/51–3	Towner (1982b)
Dummer		SF/51–4	Wyborn (1977)
Paterson Range	First Edition	SF/51–6	Wells (1959b)
Paterson Range	Second Edition	SF/51–6	Chin & others (1982)
Sahara		SF/51–7	Yeates & Towner (1978)
Percival		SF/51–8	Yeates (1978)
Rudall		SF/51–10	Chin & others (in preparation)
Tabletop	First Edition	SF/51–11	Wells (1960a)
Tabletop	Second Edition	SF/51–11	Yeates & Chin (1979)
Ural		SF/51–12	Towner (1978a)
Runton		SF/51–15	Crowe & Chin (1979)
Morris		SF/51–16	Crowe (1979)
Mount Ramsay		SE/52–9	Roberts & others (1968)
Mount Bannerman	First Edition	SE/52–13	Wells (1960b)
Mount Bannerman	Second Edition	SE/52–13	Yeates & Muhling (1977)
Billiluna	First Edition	SE/52–14	Wells (1962b)
Billiluna	Second Edition	SE/52–14	Blake & others (1977)
Cornish	First Edition	SF/52–1	Wells (1962c)
Cornish	Second Edition	SF/52–1	Crowe (1978)
Lucas	First Edition	SF/52–2	Wells (1962d)
Lucas	Second Edition	SF/52–2	Crowe & Muhling (1977)
Helena		SF/52–5	Yeates (1977)
Stansmore	First Edition	SF/52–6	Wells (1962a)
Stansmore	Second Edition	SF/52–6	Blake & Yeates (1976)
Wilson		SF/52–9	Towner (1978b)
Webb		SF/52–10	Blake (1977)
Ryan		SF/52–13	Towner (1978c)

liams & others, 1976) to the southwest of the Canning Basin. The sedimentary units within those marginal basement provinces are all steeply dipping and tightly folded; similar features probably occur in the basement of the Canning Basin. The top of the Precambrian basement is a weak seismic reflecting horizon appearing sporadically on some seismic sections.

Using magnetic and gravity data supplemented by seismic reflection data, Tucker (*in* Gorter & others, 1979) attempted to interpret the nature of basement lithology and to determine the thickness of unmetamorphosed Precambrian sedimentary rocks. Tucker's results showed that, in general, the basement is composed of two types of rock units, one made up predominantly of igneous and metamorphic rocks, and the other composed mainly of thick Precambrian unmetamorphosed folded sedimentary rocks overlying igneous and metamorphic rocks. The latter basement type appears to be confined to areas under the Kidson Sub-basin, and in the central areas of the Fitzroy Trough.

Phanerozoic

Extensive areas of Cainozoic terrestrial superficial units up to 25 m thick cover 80 percent of the Basin. The oldest exposed rocks are the Ordovician Prices Creek Group and Carranya beds, which crop out along the northern and northeastern margins of the Basin, on the Lennard Shelf and Billiluna Shelf respectively. Information on the various wholly subsurface formations, which range from Ordovician through to Carboniferous age, is based on geological data obtained from petroleum exploration wells and on geophysical data.

Details concerning variations within formations in any particular area can be found in the field work reports (Microfiche Appendixes 1–5 of this Bulletin) and in references listed in Table 7.

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
QUATERNARY	Qa	10?	Sand, silt, and clay; minor gravel		Fluvial
	Ql	20?	Clay, silt, and sand; minor gypsum		Lacustrine
	Qb (Black soil)	10?	Clay and silt		Fluvial and lacustrine
	Qs	10?	Sand and silt; minor gravel		Mixed fluvial and aeolian
	Qc (Coastal sediments)	25	Clay, silt, sand, and black organic clay; fine to coarse quartzose and calcareous sandstone; cross-bedded; minor salt	Recent corals, foraminifera, and shell fragments	Tidal flat, mangrove swamp, beach ridge, supratidal mud flat, and coastal aeolian dune
	Qz	20	Fine to medium, red quartz sand; minor silt		Aeolian
TERTIARY TO QUATERNARY	Calcrete Czk	15?	Calcrete; minor chalcedony		Lacustrine, pedogenic and evaporitic
	Warrimbah Conglomerate Czh	10?	Pebble and cobble gravel		Fluvial
	Lawford beds Czw	24 at type section	Calcrete, marl, sandy calcrete, and calcareous sandstone; minor chalcedony, calcareous breccia, and calcareous conglomerate	Stromatolites; fossil wood	Fluvial; partly evaporitic
	Lake Gregory beds Czg	99 in Cornish 3	Variegated clay, silt, and sand; minor gypsum and gravel; laminated to thin-bedded	Coquina of gastropods; fish bones	Lacustrine with fluvial influence; evaporitic in part
TERTIARY	Czs	2	Sand, silt, and ferruginous pisoliths; minor gravel and clay		Pedogenic
	Laterite Czl	10	Laterite; pisolitic or massive		Pedogenic
	Poondano Formation Tp	8	Pisolitic limonite, haematite, and goethite	Petrified wood	Fluvial, chemical, and pedogenic

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Superficial deposit	In creek areas (mainly in the north), claypans, and alluvial outwash fans adjacent to some mesas			
Superficial deposit	Includes deposits in Lake Waukarlycarly (PATERSON RANGE), Jones, Betty, Lanagan, McLernon, and Doman Lakes (MOUNT BANNERMAN), and chain lakes in PERCIVAL, SAHARA, TABLETOP, and McLARTY HILLS			
Superficial deposit	Occurs adjacent to major drainages, especially in NOONKANBAH, DERBY, and MOUNT ANDERSON; adjacent to outcrops of Devonian reefs (LENNARD RIVER, NOONKANBAH)		Forms flat or gently sloping areas in alluvial plains and overlying calcareous and argillaceous rocks	
Superficial deposit	Widespread in the northern Sheet areas; occurs mainly in drainage channels in southern Canning Basin		Forms plains characterised by mixed grass and spinifex	
Unconformable on older rocks	Coastal zone	Type locality for Bossut Formation is coastal area near Wallal Downs (MANDORA)	Includes Bossut Formation	Traves & others (1956); Lindner (1961)
Superficial deposit	Occurs extensively in central Canning Basin		Forms extensive sand plains and seif dunes	Crowe (1975)
Superficial deposit	Associated with the ancient drainage system, particularly in southern Canning Basin		Crops out as light-coloured low mounds	
Unconformably overlies Permian units	Mainly confined to within 15 km of Fitzroy River (NOONKANBAH, MOUNT ANDERSON)	None given	Forms scattered gravel plains between Myroodah (MOUNT ANDERSON) and Warrimbah (NOONKANBAH) homesteads; fossil kangaroo and crocodile bones at Alligator dam (NOONKANBAH) may come from this formation	Guppy & others (1958); Glauert (1921); Crowe & Towner (1981)
Unconformably overlies Precambrian rocks, Grant Group, Noonkanbah Formation, and Liveringa Group; top eroded	Restricted to area around Junction Creek and Salt Creek between Dean Hill and Bulka Swamp (MOUNT BANNERMAN)	15 km NE of Bulka Hills, on tributary of Christmas Creek (MOUNT BANNERMAN)	Present in pale-coloured, densely vegetated, low rubbly rises	Casey & Wells (1964); Yeates & others (1975a)
Unconformably overlies Permian and Triassic rocks	Gregory Salt Lake (CORNISH)	Cornish 3 between 0–99.1 m (CORNISH: 22°11′S, 127°24′E)	Probably still forming at present	Yeates & others (1975a)
Superficial deposit	Occurs over extensive areas in southern Canning Basin		Gravel plains overlying Czl	
Superficial deposit	Widespread over the Canning Basin; beneath Czs		Crops out as mesa cappings; forms low breakaways	
Unconformably overlies Callawa Formation and Precambrian rocks; top eroded	In northern and western PORT HEDLAND	'Type locality' is Poondano Well area, 5 km SW of Table Hill (PORT HEDLAND: 20°28′S, 118°49′E)	Occurs as mesa cappings; forms low-grade iron-ore deposits	Lindner & Drew (*in* McWhae & others, 1958); Harms & Morgan (1964); MacLeod (1966); Towner & Gibson (1980)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
TERTIARY	Oakover beds To	30	Calcareous sandstone containing limestone breccia and silica nodules, with ferruginous concretions and pisolitic ironstone; silicified limestone; chalcedony and common opal	Ostracods, not age diagnostic (Lloyd, 1963)	Lacustrine
	Fitzroy Lamproite fv		Leucite lamproite		Plugs and flows
CRETACEOUS TO TERTIARY	Lampe beds KTl	2	Medium to coarse sandstone; pebble and granule conglomerate; poorly sorted; intensely silicified		Fluvial
	Lake George beds KTg	5	Fine to coarse sandstone; granule conglomerate; poorly sorted; massive		Continental; partly pedogenic
MESOZOIC	Undivided M	10?	Sandstone, siltstone, and conglomerate		Probably continental
EARLY CRETACEOUS	Ke Bejah Claystone	14	Claystone; minor, very thin laminae of very fine sandstone and siltstone; massive to poorly bedded	Radiolaria *Lithocyclia exilis, Cenosphaera* sp.	Very quiet marine conditions
	Samuel Formation Ks	30	Fine to very fine sandstone interbedded with siltstone and claystone; laminated to thin-bedded	Pelecypods and gastropods; palynomorphs (*Dingodinium cerviculum* zone)	Shallow marine
	Anketell Sandstone Ka	70	Fine sandstone and siltstone, interbedded with coarse sandstone and granule conglomerate; laminated to thin-bedded; poorly sorted; cross-bedded; some scour-and-fill structures; minor bioturbation; minor intraformational claystone conglomerate	Foraminifera, rare wood fragments, and trace fossils including *Rhizocorallium*	Nearshore brackish-water
	Emeriau Sandstone Kr	About 30 in outcrop	Fine to coarse sandstone; minor conglomerate; poorly sorted; cross-bedded		Fluvial
	Frezier Sandstone Kf	About 20 in outcrop	Fine to coarse sandstone; minor granule conglomerate; feldspathic in part; poorly sorted; poorly bedded; some cross-bedding; minor bioturbation; commonly ferruginised or pedogenically altered	Rare bivalve (*Pseudavicula papyracea*)	Fluvial to deltaic
	Parda Formation Kp	30 in outcrop	Mudstone with fine sandstone lenses; thin-bedded or massive	Rare unidentified bivalves	Lagoonal or shallow marine

1:1 000 000 CANNING BASIN MAP— *Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Unconformably overlies Precambrian rocks and Paterson Formation; top eroded	Oakover River Valley (YARRIE, NULLAGINE)	'Type locality' is Oakover River Valley (YARRIE, NULLAGINE)	Forms flat-topped ridges; the silicified upper part is well exposed, but the underlying sediments are very soft and weather easily	Maitland (1904); Noldart & Wyatt (1962); Traves & others (1956); Towner & Gibson (1980)
Intrudes Palaeozoic and Mesozoic rocks	Occurs mainly in the Fitzroy Trough and Lennard Shelf (in DERBY, NOONKANBAH, and LENNARD RIVER)	None given	Forms small, low, rounded hills and sharp peaks resistant to erosion; Miocene (Wellman, 1973)	Thomas (1958); Wade & Prider (1940); Prider (1960); Derrick & Gellatly (1972); Kaplan & others (1967)
Unconformably overlies Precambrian rocks, Paterson and Samuel Formations, and Bejah Claystone; top eroded	Occurs mainly in MORRIS and RUNTON; small hill cappings occur in RYAN (not shown on 1:1 M map)	Mount Johnson (HERBERT: 25°24'S, 124°25'E) in the Officer Basin	Cappings on mesas and small rises	Towner & others (1976); Jackson & van de Graaff (1981)
Unconformably overlies Anketell Sandstone and Callawa Formation	SAHARA, PERCIVAL, TABLETOP, RUNTON, and URAL; small outcrop in JOANNA SPRING (shown on 1:3 M map)	8 km SE of Helen Hill (TABLETOP: 22°50'00"S, 123°42'55"E)	Forms mesa cappings; contains silicified pipe-like structures	Towner & others (1976)
Unconformably overlies Lightjack Formation and Precambrian rocks; relationships with other Mesozoic units unknown	Southeastern LUCAS, and northern STANSMORE		Crops out as low mounds, rises, and tor-like masses of sandstone	Blake & others (1973); Blake & Yeates (1976)
Conformably overlies Samuel Formation; unconformably overlain by Lampe beds	Occurs in southeastern RUNTON, at Traeger Hills (MORRIS), and southeastern MORRIS	Bejah Hill (RUNTON: 23°46'S, 124°09'E)		Veevers & Wells (1961); Lowry & others (1972); Towner & others (1976); Jackson & van de Graaff (1981)
Disconformably overlies Paterson Formation and Cronin Sandstone; interfingers with Anketell Sandstone; conformably overlain by Bejah Claystone; unconformably overlain by Lampe beds	Occurs in southeastern RUNTON, western RYAN, and most of MORRIS	Mount Charles (25°44'S, 126°11'E, BENTLEY) in the Officer Basin	Crops out in breakaways and forms low isolated hills	Lowry & others (1972); Towner & others (1976); Jackson & van de Graaff (1981); Kemp (1976)
Disconformably overlies Callawa Formation and Triwhite, Cronin, and Frezier Sandstones; passes laterally into Samuel Formation; unconformably overlain by Lake George beds	Occurs in SAHARA, URAL, WILSON, RYAN, ANKETELL, JOANNA SPRING, northeastern PATERSON RANGE, southern PERCIVAL, northern RUNTON, and MORRIS	Small hill 26 km E of Lake Auld (TABLETOP: 22°07'S, 124°01'E)	Crops out in mesas, breakaways, and isolated hills	Traves & others (1956); Veevers & Wells (1961); Playford & others (1975); Towner & others (1976); Towner & Gibson (1980)
Disconformably overlies Broome Sandstone and Melligo Sandstone; top eroded	Northern BROOME; PENDER	Emeriau Point (PENDER: 16°46'S, 122°34'E)	Forms low conical hills; exposed in coastal cliffs; commonly ferruginised	Brunnschweiler (1957); Playford & others (1975); Towner & Gibson (1980)
Disconformably overlies Parda Formation, and Broome and Melligo Sandstones; may pass laterally into Callawa Formation; disconformably overlain by Anketell Sandstone	Crops out in MUNRO, ANKETELL, southern LAGRANGE, western JOANNA SPRING, southwestern McLARTY HILLS, and northeastern PATERSON RANGE	Cape Frezier (LAGRANGE: 18°52'00"S; 121°36'20"E)	Forms small, isolated, hills with scree slopes	McWhae & others (1958); Veevers & Wells (1961); Playford & others (1975); Towner & Gibson (1980)
Disconformably overlies Melligo and Broome Sandstones, and Callawa Formation; disconformably overlain by Frezier Sandstone	Occurs in MUNRO, southern LAGRANGE, western ANKETELL, and northern YARRIE	Parda Hill (LAGRANGE: 18°56'10"S, 121°59'20"E)	Well exposed along the coast and in small hills and mesas; capped by laterite; displays a light-coloured pattern on aerial photographs	McWhae & others (1958); Veevers & Wells (1961); Playford & others (1975); Towner & Gibson (1980)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	Rock unit & symbol (1:1 M map)	Maximum thickness (m)	Lithology	Fossils	Depositional environment
EARLY CRETACEOUS	Melligo Sandstone Km	20 in outcrop	Fine to medium sandstone; well-sorted; laminated to thin-bedded; low angle cross-bedded; rare pebbles; silicified in part	Bivalves (including *Fissilunula clarkei*); belemnites (Aptian)	Beach
LATE JURASSIC TO CRETACEOUS	Broome Sandstone Kb	274 in Tappers Inlet 1	Fine to coarse sandstone; mudstone; minor conglomerate; strongly cross-bedded; ripple-marked; bioturbated in places	Microflora, plant fossils, bivalves, and dinosaur footprints	Shallow marine (tidal)
	Callawa Formation JKc	80?	Very fine to coarse sandstone; conglomerate; poorly sorted; cross-bedded; minor siltstone	Plant fossils (Late Jurassic or Early Cretaceous)	Fluvial
	Cronin Sandstone JKn	50?	Fine to coarse sandstone; moderately sorted; cross-bedded; bioturbated; minor pebble conglomerate; mudstone	Plant fossils including *Taeniopteris*, *Elatocladus*, and *Ptilophyllum*	Fluvial
	Mowla Sandstone JKo	15 in outcrop	Fine to very coarse sandstone; granule and clay pellet conglomerate; minor mudstone; poorly sorted; cross-bedded; ripple-marked; discontinuous basal conglomerate	Plant fossils	Fluvial to deltaic
	Jarlemai Siltstone JKr	259 in Barlee 1	Mudstone, massive, sandy in part; minor very fine to fine sandstone, massive to thin-bedded; glauconitic and partly phosphatic in the subsurface; bioturbated	Microfossils, pelecypods, belemnites, ammonites, and brachiopods	Shallow marine (sub-tidal)
	Barbwire Sandstone JKb	33 in outcrop	Fine to coarse sandstone; conglomerate; minor laminated to thin-bedded siltstone; poorly sorted; large scale planar and trough cross-bedding	Plant fossils including *Otozamites feistmanteli* and *Pagiophyllum peregrinum* which are Jurrassic or Early Cretaceous	Fluvial
LATE JURASSIC	Meda Formation Jd	9 exposed	Fine to coarse sandstone; granule and pebble conglomerate; minor siltstone; large scale trough cross-bedding; ripple-marked; poorly sorted; ferruginised	Wood fragments	Fluvial

1:1 000 000 CANNING BASIN MAP—*Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Conformably overlies Broome Sandstone; disconformably overlain by Frezier and Emeriau Sandstones, and Parda Formation	Occurs in northern parts of the Dampier Peninsula (PENDER, YAMPI, BROOME, and DERBY) and along the coast near Gourdon Bay (LAGRANGE)	Type area at Melligo Creek (PENDER: 16°34′S, 122°56′E)	Occurs as silicified hill cappings and cliffs inland and on east coast of Dampier Peninsula; unsilicified in cliffs along west coast	Brunnschweiler (1957); Veevers & Wells (1961); Skwarko (1967; 1970); Playford & others (1975); Towner & Gibson (1980)
Conformably(?) overlies the Jarlemai Siltstone; may pass laterally into Callawa Formation; probably equivalent to Mowla Sandstone; conformably overlain by Melligo Sandstone; disconformably overlain by Parda Formation, and Emeriau and Frezier Sandstones	Occurs over a wide area in northwestern Canning Basin	Gantheaume Point (BROOME: 17°58′30″S, 122°10′30″E)	Good exposures in coastal cliffs from Cape Leveque (PENDER: 16°24′S, 122°55′E) to Cape Gourdon (LAGRANGE); rare inland exposures in small hills and washaways; includes 'Leveque Sandstone' and part of 'Jowlaenga Formation' of Brunnschweiler (1957)	Reeves (1951); Veevers & Wells (1961); Playford & others (1975); Towner & Gibson (1980)
Unconformably overlies Precambrian rocks, Paterson Formation, Poole Sandstone, Noonkanbah Formation, and Triwhite Sandstone; disconformably or unconformably overlies Wallal Sandstone and Jarlemai Siltstone; may pass laterally into Broome, Frezier, and Cronin Sandstones; unconformably overlain by Lake George beds; disconformably overlain by Parda Formation and Anketell Sandstone	Occurs within 150 km of SW margin of Canning Basin in PORT HEDLAND, YARRIE, PATERSON RANGE, ANKETELL, and MANDORA; extends across southern Canning Basin in TABLETOP, SAHARA, URAL, WILSON, and PERCIVAL; possibly southern HELENA and RYAN	In hills NE of Callawa homestead (YARRIE: 20°32′S, 120°21′E)	Good exposures in hills near SW margin of Canning Basin	Reeves (1951); Traves & others (1956); Veevers & Wells (1961); Playford & others (1975); Towner & others (1976); Towner & Gibson (1980)
Unconformably overlies Precambrian rocks and Paterson Formation; may pass laterally into Callawa Formation; disconformably overlain by Anketell Sandstone and Samuel Formation	Confined to RUNTON in the southern Canning Basin	At Cronin Hills (RUNTON: 23°14′S, 123°23′E)	Crops out as isolated hills	Veevers & Wells (1961); Playford & others (1975); Towner & others (1976)
Conformably(?) overlies Jarlemai Siltstone; probably partly equivalent to Broome Sandstone; top eroded	Southern MOUNT ANDERSON and northeastern McLARTY HILLS	Near Mowla Bluff (MOUNT ANDERSON: 18°49′20″S, 123°43′50″E)	Forms ferruginised cappings on hills of Jarlemai Siltstone	Brunnschweiler (1954); Guppy & others (1958); Playford & others (1975); Crowe & others (1978); Towner & Gibson (1980)
Conformably overlies Alexander Formation; probably partly equivalent to Barbwire Sandstone; conformably(?) overlain by Broome and Mowla Sandstones; unconformably or disconformably overlain by Callawa Formation	Crops out in western DERBY, southern MOUNT ANDERSON, and northeastern McLARTY HILLS; present in subsurface over western third of Canning Basin	Mount Jarlemai (MOUNT ANDERSON: 18°42′55″S, 123°48′40″E)	Forms mesas and breakaways with steep sides and scree slopes; includes 'Langey Shale' of Brunnschweiler (1954) and part of 'Jowlaenga Formation' of Brunnschweiler (1957)	Brunnschweiler (1954); Guppy & others (1958); Veevers & Wells (1961); Playford & others (1975); Crowe & others (1978); Towner & Gibson (1980)
Unconformably overlies Hardman, Lightjack, and Noonkanbah Formations; probably partly equivalent to Wallal Sandstone, Alexander Formation, and Jarlemai Siltstone; top eroded	Barbwire and Worral Ranges (CROSSLAND, NOONKANBAH); isolated outcrops along Fenton Fault System (NOONKANBAH, MOUNT ANDERSON); central western CROSSLAND; western DUMMER(?)	Barbwire Range (NOONKANBAH: 18°58′S, 125°01′E)	Forms mesas and buttes in CROSSLAND and ferruginised hill cappings along Fenton Fault System; may correlate with Meda Formation	Guppy & others (1958); Yeates & others (1975a); Crowe & others (1978)
Unconformably overlies Erskine Sandstone; top eroded	Confined to northern and eastern DERBY	Erskine Range (DERBY: 17°50′S, 124°22′E)	Forms cappings on small isolated hills and the Erskine Range	Guppy & others (1958); Veevers & Wells (1961); Playford & others (1975); Crowe & others (1978)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
LATE JURASSIC	Alexander Formation Ja	92 in Samphire Marsh 1; 72 exposed in Edgar Ranges (MOUNT ANDERSON)	Fine to medium sandstone interbedded with mudstone and minor granule conglomerate; thin-bedded; ripple-marked; flaser and lenticular bedding; cross-bedded; bioturbated	Ammonoids, pelecypods, and brachiopods in outcrop; microflora and microfauna in subsurface; late Oxfordian to early Kimmeridgian	Shallow marine (tidal)
EARLY TO LATE JURASSIC	Wallal Sandstone Jl	364 in Barlee 1	Sandstone; minor siltstone, conglomerate, and lignite	Abundant microfauna and microflora (Toarcian to Oxfordian)	Continental to shallow marine
		20 in outcrop	*Jurgurra Sandstone Member:* medium to coarse sandstone; minor clay pellet conglomerate and mudstone; abundant large-scale trough cross-bedding and ripple cross-lamination	Rare pelecypods and plant fossils	Aeolian
		80	*Mudjalla Sandstone Member:* medium to coarse sandstone, poorly sorted; minor conglomerate and siltstone; trough and planar cross-bedded; overlain by very fine to medium sandstone (planar bedded, wavy bedded, and rippled)	Plant fossils	Fluvial
			MAJOR UNCONFORMITY		
LATE TRIASSIC	d		Dolerite, gabbro		Sills, plugs(?)
EARLY TO MIDDLE TRIASSIC	Culvida Sandstone Rc	207 in Cornish 2	Fine to coarse sandstone; siltstone; granule and pebble conglomerate; poorly sorted; cross-bedded; earthy red and green interbedded siltstone and fine sandstone at base in Cornish 2	Plant fossils indicate Middle Triassic; microflora belonging to Stage 3 (Evans, 1966) indicate late Early to Middle Triassic	Fluvial
	Erskine Sandstone Re	88 in outcrop; 269 in Myalls Bore (DERBY)	Very fine to fine sandstone; cross-bedded; minor clay pellet conglomerate and mudstone; laminated to thin-bedded; ripple-marked; interbedded very fine sandstone and siltstone in the upper part	Macroflora of equisetaleans and lycopods; microflora; Smithian to early Anisian	Fluvial
EARLY TRIASSIC	Blina Shale Rb	129 in outcrop; 311 in Blackstone 1; may reach 500 in central DERBY	Mudstone, sandy, micaceous, pyritic, and carbonaceous; minor very fine sandstone; laminated to thin-bedded; ripple-marked; small scour-and-fill structures; phosphatic near base; glauconitic; abundant burrows	Vertebrates, conchostracans, plant remains, brachiopods, and abundant microplankton (Scythian)	Shallow-marine tidal flat

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Conformably overlies Wallal Sandstone; probably partly equivalent to Barbwire Sandstone; conformably overlain by Jarlemai Siltstone	Exposed along west bank of Fitzroy River, 7 km SW of Yeeda homestead (DERBY); Edgar Ranges and Matches Springs area (MOUNT ANDERSON); central McLARTY HILLS; southwestern NOONKANBAH; present in western third of Canning Basin in subsurface	Mount Alexander (MOUNT ANDERSON: 18°41′00″S, 123°39′20″E)	Forms mesas and buttes with smooth, scree-covered slopes, as well as low hills and breakaways; difficult to recognise in some petroleum exploration wells, especially near the margins of the Canning Basin	Brunnschweiler (1954); Guppy & others (1958); Veevers & Wells (1961); Playford & others (1975); Crowe & others (1978); Towner & Gibson (1980)
Unconformably overlies Triassic and older rocks; probably partly equivalent to Barbwire Sandstone; conformably overlain by Alexander Formation; unconformably or disconformably overlain by Callawa Formation	Recognised over the western third of the Canning Basin in the subsurface	Between 276 m and 584 m in Wallal 4A (MANDORA: 19°44′12″S, 120°44′25″E)	Members differentiated on 1:250 000 maps, but not on 1:1 M map (Plate 1)	McWhae (*in* Johnstone, 1961); Playford & others (1975); Burne & Crowe (1977); Crowe & others (1978); Towner & Gibson (1980); Gibson & Crowe (1982)
Lower boundary not recognised; conformably overlain by Alexander Formation	Crops out in Edgar Ranges area (MOUNT ANDERSON); subsurface extent unknown	Geegully Creek near Mount Alexander (MOUNT ANDERSON: 18°41′S, 123°39′E)	Crops out in creek beds only	Brunnschweiler (1954); Burne & Crowe (1977); Crowe & others (1978); Gibson & Crowe (1982)
Unconformably overlies Liveringa Group and Noonkanbah Formation; conformably(?) overlain by Alexander Formation	Crops out near west bank of Fitzroy River in northern MOUNT ANDERSON and southern DERBY; subsurface extent unknown	MOUNT ANDERSON: 18°02′S, 123°46′E	Deposited by westerly-flowing rivers	Guppy & others (1958); Crowe & others (1978); Gibson & Crowe (1982)
	MAJOR UNCONFORMITY			
Intrudes Palaeozoic rocks	Occurs in NW Fitzroy Trough, in Fraser River 1 and Barlee 1 (DERBY, BROOME)			Gibson (in preparation b)
Conformably overlies Erskine Sandstone; top eroded	Restricted to within 20 km radius of the type area (CORNISH); encountered in the subsurface only in Cornish 2	1 km S of Culvida Soak (CORNISH: 20°14′00″S, 126°56′00″E)	Forms small exposures in the Minnie Range and Culvida Soak area (CORNISH)	Casey & Wells (1964); Playford & others (1975); Yeates & others (1975a); White & Yeates (1976)
Disconformably overlies Blina Shale; unconformably overlies Permian rocks; unconformably overlain by Meda Formation and Wallal Sandstone; conformably overlain by Culvida Sandstone	Occurs in Myroodah Syncline (northeastern MOUNT ANDERSON); wide area of DERBY; in NW-trending belt across MOUNT BANNERMAN, eastern CORNISH, and western LUCAS	Erskine Range (DERBY: 17°50′S, 124°22′E)	Forms scarps in The Sisters area and Erskine Range (DERBY), Bishop Range (CORNISH), and at Point Alphonse (LUCAS)	Brunnschweiler (1954); Guppy & others (1958); Veevers & Wells (1961); Playford & others (1975); Crowe & others (1978)
Passes laterally into, and conformably overlies Millyit Sandstone; disconformably overlies Liveringa Group and Chirup Formation; disconformably overlain by Erskine Sandstone; unconformably overlain by Wallal Sandstone	Confined to the Fitzroy Trough, parts of the Lennard Shelf, and in subsurface in western MANDORA	Erskine Range (DERBY: 17°51′25″S, 124°21′40″E)	In general, crops out very poorly, except in Erskine Range (DERBY), Bishop Range (CORNISH), and Bababaru Rockhole, 6 km SE of Bishops Dell (LUCAS); identified on aerial photographs by light colour with trend lines visible as streaky patterns	Reeves (1951); Brunnschweiler (1954); Guppy & others (1958); McKenzie (1961); Veevers & Wells (1961); Playford & others (1975); Yeates & others (1975a); Crowe & others (1978); Towner & Gibson (1980)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
EARLY TRIASSIC	Millyit Sandstone Rm	90 in Lucas 13	Medium to fine sandstone; minor siltstone; thin-bedded; cross-bedded; ripple-marked; quartz-pebble conglomerate at base; in LUCAS, cycles up from conglomerate, to medium to coarse sandstone, to fine sandstone and siltstone	Fossil plants indicate Late Permian to Early Triassic; palynology indicates Early Triassic	Fluvial
			MINOR UNCONFORMITY/DISCONFORMITY		
	Undivided Pz		Sandstone and siltstone; minor limestone		
LATE PERMIAN	Chirup Formation Pi	38 in Chirup 1	Interbedded grey to black carbonaceous shale and fine to conglomeratic sandstone; lignite; partly pyritic	Abundant microflora (Balme, 1969) (Late Permian)	Shallow marine, possibly lagoonal
	Godfrey beds Pf	90 in outcrop	Basal beds of medium to coarse, poorly sorted sandstone, partly conglomeratic; overlain by fine to medium micaceous sandstone interbedded with siltstone; clay pellet conglomerate; laminated to thin-bedded; small scale cross-bedding; ripple-marks	Plant fossils (Permo-Triassic)	Shallow marine (tidal flat), possibly lagoonal
EARLY TO LATE PERMIAN	Liveringa Group Pl	1000?	Interbedded sandstone and mudstone; minor conglomerate	Abundant macrofauna and macroflora	
	Hardman Formation Ph	100	*Cherrabun Member:* grades from mudstone, with minor sandstone and limestone near base, to mainly sandstone with cross-bedding near top; minor coal	Abundant deltaic brachiopods, pelecypods, and plant fossils (*Glossopteris*); palynomorphs (Tatarian)	Regressive marine
		325	*Hicks Range Sandstone Member:* lower part of mudstone (and minor sandstone and coal) with ripple marks and mud cracks; upper part of sandstone and minor siltstone; cross-bedded	Trace fossils and palynomorphs	Shallow marine
		300	*Kirkby Range Member:* lower part of mudstone and fine sandstone with minor limestone; upper part of cross-bedded sandstone	Abundant deltaic brachiopods and pelecypods; palynomorphs (Tatarian)	Regressive marine
	Condren Sandstone Pr	130 in Stansmore Range (STANSMORE)	Fine to medium sandstone, micaceous, well-sorted; thin-bedded; planar cross-bedded; ripple-marked; in the southeast, rhythmically bedded, fine to medium, some coarse sandstone with beds of siltstone and conglomerate (minor thin coal beds)	Plant fossils include *Gangamopteris* & *Glossopteris*; microflora indicates Late Permian, possibly Kazanian age (Price, 1973)	Low-energy fluvial or deltaic with some swampy conditions

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Unconformably overlies Hardman Formation; passes laterally into, and is conformably overlain by Blina Shale; disconformably overlies Godfrey beds and Condren Sandstone	Occurs in McLarty and Millyit Range Synclines (NOONKANBAH, CROSSLAND); exposed between Lake Jones (MOUNT BANNERMAN), and Minnie Range (CORNISH); south-western and north-western LUCAS	Head of Spring Creek (CROSSLAND: 19°12′00″S, 125°33′30″E)	Low strike ridges; low breakaways give good exposures in CORNISH	Elliott (*in* McWhae & others, 1958); Veevers & Wells (1961); Playford & others (1975); Yeates & others (1975a); Crowe & others (1978)
	MINOR UNCONFORMITY/DISCONFORMITY			
	Palaeozoic units overlying Precambrian rocks on eastern Canning Basin margin (LUCAS, STANSMORE, and WEBB)		Not considered part of Canning Basin	Blake & others (1973)
Unconformably overlies Grant Group; unconformably overlain by Wallal Sandstone; disconformably overlain by Blina Shale	Occurs in Wallal 4A and Chirup 1 in Wallal Embayment (MANDORA)	Between 499 m and 537 m in Chirup 1 (MANDORA: 19°51′S, 120°26′E)	May correlate with upper part of Hardman Formation	Gorter & others (1979); Henderson & others (1963); Towner & Gibson (1980)
Disconformably overlies Condren Sandstone; disconformably overlain by Millyit Sandstone	Around Twin Heads and Crown Head (CORNISH), and in Stretch Range (LUCAS)	Near Godfreys Tank, 3 km ENE of Twin Heads (CORNISH: 20°14′30″S, 126°33′00″E)	Forms prominent breakaways, ranges, and isolated peaks (CORNISH) and low rises (LUCAS)	Casey & Wells (1964); Veevers & Wells (1961); Playford & others (1975); Yeates & others (1975a)
	See under various formations	At Liveringa Ridge (MOUNT ANDERSON: 17°52′57″S, 123°55′00″E)	Subdivided into Hardman Formation, Condren Sandstone, and Lightjack Formation	Guppy & others (1958); Playford & others (1975); Yeates & others (1975a)
Possibly disconformable on Hicks Range Sandstone Member; unconformably overlain by Millyit Sandstone(?) and Barbwire Sandstone; disconformably overlain by Blina Shale	Hardman Formation: extensive in the Fitzroy Trough	Hardman Formation: Mount Hardman (NOONKANBAH: 18°18′45″S, 124°38′52″E) Cherrabun Member: Spring Creek (CROSSLAND: 19°11′00″S, 125°33′06″E)	Hardman Formation: recognised mainly from subsurface information; crops out as gravel plains and low strike ridges; ranges in CROSSLAND provide good exposures	Guppy & others (1958); Playford & others (1975); Yeates & others (1975a); Crowe & others (1978); Towner & Gibson (1980)
Conformable on Kirkby Range Member; possibly disconformably overlain by Cherrabun Member		Hicks Range (CROSSLAND: 19°13′48″S, 125°53′42″E)		
Disconformable on Lightjack Formation and Condren Sandstone; conformably overlain by Hicks Range Sandstone Member		Millyit Range (CROSSLAND: 19°09′39″S, 125°34′24″E)		
Conformably overlies Lightjack Formation; conformably overlain by Hardman Formation; disconformably overlain by Godfrey beds, Blina Shale, and Millyit Sandstone	Confined to northwest trending belt in south-eastern Fitzroy Trough, extending from STANSMORE to CROSSLAND, and in western LUCAS; thins out to the northwest	At Condren Pinnacles (LUCAS: 20°06′S, 127°39′E)	Well exposed in breakaways, cliff-faces, strike ridges, mesas, buttes, and low hills	Casey & Wells (1964); Veevers & Wells (1961); Playford & others (1975); Yeates & others (1975a)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
EARLY TO LATE PERMIAN	Lightjack Formation Pj	Over 250 in Stansmore Range (STANSMORE)	Upper part: interbedded mudstone and fine sandstone; ripple-marked; coal; minor coarse sandstone Middle part: medium quartz sandstone; well-sorted; laminated to thin-bedded; trough cross-bedded; ripple-marked Lower part: interbedded fine sandstone and mudstone with lenses of clay pellet conglomerate and coarse sandstone; laminated to thin-bedded; ripple-marked	Pelecypods, brachiopods, trace fossils, and plant fragments; *Atomodesma exerata* and *Stutchburia muderongensis* are characteristic and indicate late Artinskian to early Kazanian age	Shallow marine to lagoonal
	Triwhite Sandstone Pt	77 in Kidson 1	Fine to medium micaceous sandstone interbedded with siltstone and intraformational claystone conglomerate; laminated to thin-bedded; ripple-marked; flaser and lenticular bedding; planar cross-bedding	Fossils including *Astartila blatchfordi* and *Atomodesma mytiloides* indicate Early Permian	Shallow regressive marine
	Noonkanbah Formation Pn	410 in The Sisters 1	Grey, micaceous, pyritic mudstone interbedded with fine to medium calcareous sandstone; laminated to thin bedded; minor finely crystalline fossiliferous limestone interbeds; coquinite bed crops out in LUCAS	Rich fauna of brachiopods, bryzoans, corals, crinoids, and molluscs (Artinskian)	Unrestricted marine with shallower conditions in some areas
EARLY PERMIAN	Poole Sandstone Pp	At least 250 exposed in the Grant Range; 350 in Nerrima 1	Mainly fine sandstone, some medium to coarse towards base; interbeds of siltstone; laminated to thin-bedded; ripple cross-bedding; lenticular and flaser bedding; clay-pellet conglomerate lenses; bioturbated; calcareous sandstone, sandy limestone, and minor mudstone at base	See below	Shallow water, possibly lagoonal
		25	*Christmas Creek Member:* poorly sorted sandstone and conglomerate; cross-bedded; ripple-marked	Trace fossils	Fluvial
		325	*Tuckfield Member:* very fine and fine sandstone with minor siltstone; clay-pellet conglomerate lenses; abundant small-scale cross-bedding and wave-formed ripple marks; thin-bedded; traces of coal	Plant fossils, trace fossils and palynomorphs (early Artinskian)	Shallow water, possibly lagoonal
		110	*Nura Nura Member:* in east, poorly sorted, cross-bedded sandstone and conglomerate; further to west, thin-bedded sandstone and siltstone; calcareous; ripple-marked	Brachiopods, ammonites, bryozoa, foraminifera, pelecypods, conodonts, crinoids, ostracods and conulariids; leaf and root fossils (late Sakmarian)	Braided river to marine; represents a possible barrier bar in eastern MOUNT ANDERSON

1:1 000 000 CANNING BASIN MAP— *Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Conformable between Noonkanbah Formation and Condren Sandstone; partly equivalent to Triwhite Sandstone; disconformably overlain by Hardman Formation; unconformably overlain by Barbwire Sandstone	Occurs extensively throughout the Fitzroy Trough from DERBY to STANSMORE	At Lightjack Hill (NOONKANBAH: 18°59′S, 125°50′E)	Forms prominent strike ridges, breakaways, mesas, and hills particularly in the southeast Fitzroy Trough; low strike ridges and rubble plains occur to the northwest; the middle sandstone unit is resistant to erosion and develops good cliff-like exposures	Guppy & others (1958); Casey & Wells (1964); Veevers & Wells (1961); Playford & others (1975); Yeates & others (1975a); Crowe & others (1978)
Conformably overlies Noonkanbah Formation; equivalent to part of Lightjack Formation; unconformably overlain by Callawa Formation; disconformably overlain by Anketell Formation	Confined to Kidson Sub-basin and eastern part of Anketell Shelf in southern Canning Basin	1.6 km E of Dunn Soak (TABLETOP: 22°04′S, 123°10′E)	Forms good exposures at Scott Bluff, Triwhite Hills, and mesas east of Lake Dora (TABLETOP); occurs along parts of the Percival Lakes (PERCIVAL); crops out as low mounds and hills in southeastern PATERSON RANGE	Traves & others (1956); Playford & others (1975); Towner & others (1976); Towner & Gibson (1980)
Conformable between Poole Sandstone and Triwhite Sandstone or Lightjack Formation; unconformably overlain by Wallal Sandstone, Callawa Formation, and Barbwire Sandstone	Confined mainly to Kidson Sub-basin and Fitzroy Trough; has been removed from parts of the Broome Arch and Willara Sub-basin by post-Permian erosion	Near Bruten Hill (NOONKANBAH: 18°44′35″S, 125°37′30″E)	Exposures very poor; crops out as low mounds and small cliffs near edge of claypans, as rubble adjacent to deflation plains and claypans, and on plains where strikes of more resistant beds are readily recognisable on aerial photographs	Wade (1938); Guppy & others (1952); Playford & others (1975); Yeates & others (1975a); Towner & others (1976); Crowe & Towner (1976a); Crowe & others (1978); Towner & Gibson (1980)
Unconformably (in Fitzroy Trough) or disconformably (elsewhere) overlies Grant Group and Paterson Formation; conformably overlain by Noonkanbah Formation; unconformably overlain by Callawa Formation	Mainly confined to Fitzroy Trough, northern Broome Arch, and Kidson Sub-basin; probably removed from western part of Broome Arch and from the Willara Sub-basin, Anketell Shelf, Tabletop Shelf, and Betty Terrace by post-Permian erosion	Southeastern Grant Range (MOUNT ANDERSON: 18°04′30″S, 124°08′30″E)	Well exposed in flanks of Poole and St George Ranges (NOONKANBAH); Grant Range and Mount Wynne (MOUNT ANDERSON); South Esk Tableland (CORNISH); Stansmore Range (STANSMORE); elsewhere, exposures are scree-covered	Wade (1936); Guppy & others (1952); Playford & others (1975); Yeates & others (1975a); Towner & others (1976); Crowe & Towner (1976a, 1976b); Crowe & others (1978); Towner & Gibson (1980)
Overlies Tuckfield Member with interfingering contact; underlies Noonkanbah Formation (contact not seen)	Crops out only in NOONKANBAH	Mount Piper (NOONKANBAH: 18°54′00″S, 125°47′30″E)	Occurs only in NOONKANBAH	
Conformably and disconformably overlies Nura Nura Member; conformably overlain by Christmas Creek Member and Noonkanbah Formation	Crops out only in Fitzroy Trough; identified elsewhere in the subsurface	Mount Tuckfield (NOONKANBAH: 18°42′15″S, 124°53′35″E)		
Conformably and disconformably overlain by Tuckfield Member; unconformably overlies Carolyn Formation	Crops out only in DERBY, MOUNT ANDERSON, and NOONKANBAH	Nura Nura Ridge (MOUNT ANDERSON: 18°′02S, 124°28′E)		

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
EARLY PERMIAN	Paterson Formation Pa	Up to 150	Claystone and siltstone; laminated, varved, or massive; very poorly sorted; contains abundant dropstones up to boulder size; overlain by cross-bedded coarse and conglomeratic sandstone and siltstone, with lenses of pebbles and boulders	Microfossils (Sakmarian)	Initially lacustrine and then fluvial under the influence of a glacial climate
	Lillybooroora Conglomerate Py	Up to 60	Boulder and cobble conglomerate; sandstone; boulders have chatter marks		Fluvial
LATE CARBONIFEROUS TO EARLY PERMIAN	Grant Group Pg	415	*Carolyn Formation:* Fine to coarse, feldspathic sandstone; conglomerate; massive, large scale cross-bedding; overlain by fine to medium, calcareous sandstone and mudstone, with dropstones, laminated to very thinly bedded; overlain in turn by mainly medium sandstone with minor mudstone; cross-bedded; ripple-marked	Marine macrofossils, (including *Eurydesma*, and *Deltopecten lyonensis*) and palynomorphs (Sakmarian)	Non-marine and marine glacial
		278 in The Sisters 1	*Winifred Formation:* siltstone, grey, sandy, carbonaceous, and pyritic; thin interbeds of very fine sandstone	Crinoids and bryzoans; microflora (Sakmarian)	Possible deep marine or lagoonal
		1714 in Grant Range 1	*Betty Formation:* fine to coarse sandstone; minor conglomerate and siltstone; basal polymict conglomerate present in some areas	Macrofossils; palynology gives a Late Carboniferous to Sakmarian age	Shallow-water glacial environment
			MAJOR UNCONFORMITY		
EARLY CARBONIFEROUS	Anderson Formation Ca	2551 in Yulleroo 1; may reach over 4000 in central Fitzroy Trough	Alternating sandstone, siltstone, and shale; minor limestone, dolomite, and anhydrite	Microflora (Tournaisian to Visean)	Continental and marine
LATE DEVONIAN TO EARLY CARBONIFEROUS	Fairfield Group DCf	649 in Lake Betty 1	*Laurel Formation:* basal part: limestone, shale, and minor dolomite; upper part: grey calcareous shale	Rich biota of algae, brachiopods, bryzoans, pelecypods, ostracods, microflora, and conodonts (Tournaisian)	Shallow marine
		327 in Napier 1	*Yellow Drum Sandstone:* Sandstone and dolomite; minor shale and siltstone; rare limestone beds	Spores indicate latest Devonian to earliest Carboniferous	Intertidal to supratidal, with some fluvial influence
		369 in Meda 1	*Gumhole Formation:* Limestone interbedded with siltstone, shale, and claystone; colour laminated; thick-bedded; cross-stratified	Brachiopods, pelecypods, bryzoans, conodonts, and ostracods (late Famennian)	Subtidal and intertidal

1:1 000 000 CANNING BASIN MAP—*Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Unconformably overlies Precambrian rocks, Devonian rocks, and possibly Ordovician rocks; disconformably overlain by Poole Sandstone, probably interfingers with Grant Group; unconformably overlain by Callawa Formation, Cronin Sandstone, Oakover beds, and Lampe beds; disconformably overlain by Samuel Formation	Crops out along the southwestern and southeastern margin of Canning Basin	In the Paterson Range (PATERSON RANGE: 21°45′00″S, 122°10′00″E)	Exposures, particularly of the mudstone part, are very poor; glaciated pavements in RUDALL	Talbot (1920); Traves & others (1956); Veevers & Wells (1961); Playford & others (1975); Towner & others (1976); Towner & Gibson (1980); Jackson & van de Graaff (1981)
Unconformably overlies Precambrian rocks; possibly passes laterally laterally into Grant Group	Discontinuous belt near Lillybooroora and Townshend Rivers (YAMPI)	None known	Rounded boulder-strewn hills, flat topped mesas, and valley sides; benches flanking Proterozic sandstone ridges	Gellatly & Sofoulis (1973)
Grant Group; unconformably overlies pre-Permian rocks; probably interfingers with Paterson Formation on the southern margin, and Lillybooroora Conglomerate in the north; unconformably (in Fitzroy Trough) or disconformably (elsewhere) overlain by Poole Sandstone; unconformably overlain by Chirup Formation and Wallal Sandstone	Grant Group: present over most of Canning Basin	Grant Group type locality: Grant Range (MOUNT ANDERSON: 18°02′00″S, 124°05′00″E); Carolyn Formation Composite Section: (NOONKANBAH: 18°44′20″S, 124°55′52″E and 18°41′53″S, 124°54′30″E)	Carolyn Formation is well exposed in Grant Range (MOUNT ANDERSON), Poole and St George Ranges (NOONKANBAH), French Hills and Fisher Bluff (CORNISH), and isolated hills and ridges in NOONKANBAH, MOUNT RAMSAY BILLILUNA, MOUNT BANNERMAN, CORNISH, and HELENA	Guppy & others (1952); Playford & others (1975); Veevers & Wells (1961); Crowe & Towner (1976a,c,d); Towner & others (1976); Crowe & others (1978); Towner & Gibson (1980)
		Winifred Formation: (TABLETOP: 22°52′40″S, 123°36′20″E)	Winifred Formation forms scree-covered hills near Lake Winifred (TABLETOP)	
		Betty Formation: Between 1058 and 1657 m in Lake Betty 1 (MOUNT BANNERMAN: 19°34′10″S, 126°19′52″E)	Betty Formation not exposed	
MAJOR UNCONFORMITY				
Disconformably(?) overlies Fairfield Group; unconformably overlain by Grant Group	Confined in subsurface to the Fitzroy Trough	Between 2408 m and 3936 m in Grant Range 1 (MOUNT ANDERSON: 18°00′48″S, 124°00′22″E)	Sandstone outcrop containing *Leptophloema austreole* near Bohemia Downs (MOUNT RAMSAY) may belong to Anderson Formation	McWhae & others (1958); Veevers & Wells (1961); Playford & others (1975)
Fairfield Group: Disconformably(?) overlies Late Devonian reef complex (Dr); conformably overlies Luluigui Formation; unconformably overlain by Grant Group; disconformably(?) overlain by Anderson Formation	Crops out in belt SW of Napier and Oscar Ranges (LENNARD RIVER); in subsurface, occurs in Fitzroy Trough in Lake Betty 1 (MOUNT BANNERMAN)	Two sections: 3 km NW of Twelve Mile Bore (LENNARD RIVER: 17°55′S, 125°14′30″E); and 5 km SE of Twelve Mile Bore (LENNARD RIVER: 17°58′S, 125°02′E)	Good exposures in vicinity of Twelve Mile Bore (20 km SW of Leopold Downs homestead)	Guppy & others (1958); Thomas (1959); Veevers & Wells (1961); Playford & Lowry (1966); Druce & Radke (1979)
	Confined predominantly to the Lennard Shelf; penetrated in Yulleroo 1 in Fitzroy Trough	Low ridge 1 km NE of Yellow Drum Bore, 25 km WNW of Fitzroy Crossing (NOONKANBAH: 18°04′35″S, 125°25′00″E)	Poorly exposed	
	Crops out and subcrops in the Lennard Shelf area; recognised in Frome Rocks 2 on the Jurgurra Terrace	Along Great Northern Highway (NOONKANBAH: 18°07′30″S, 125°27′25″E)	Poorly exposed	

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	Rock unit & symbol (1:1 M map)	Maximum thickness (m)	Lithology	Fossils	Depositional environment
SILURIAN(?) TO DEVONIAN	Undivided D	3000?	Sandstone, siltstone, limestone and evaporites	Unknown	Unknown
	Conglomerate Do	Less than 300	Boulder and pebble conglomerate (subrounded to rounded) and minor feldspathic sandstone		Alluvial fans laid down in front of active fault scarps
LATE DEVONIAN	Dr (Carbonate reef complex)				
	Di (Marginal-slope & basin facies)	>1200	*Napier Formation:* Calcarenite, calcirudite, and megabreccia; some interbedded siltstone, shale, calcareous sandstone, and conglomerate	Conodonts, goniatites, brachiopods, and foraminifera (early Frasnian to late Famennian)	Shallow marine
		At least 600	*Virgin Hills Formation:* Siltstone, shale, calcarenite, calcilutite, calcirudite, and megabreccia	Conodonts and ammonoids (middle Frasnian to to middle Famennian)	Shallow marine
		<180	*Bugle Gap Limestone:* Calcarenite, calcirudite, and megabreccia; medium to thickly bedded	Sparse fauna of brachiopods and conodonts (Famennian)	Shallow marine
		<300?	*Piker Hills Formation:* Calcarenite and calcirudite in forereef facies; interbedded shale, siltstone, calcarenite, and calcirudite in inter-reef facies	Ammonoids, conodonts, and brachiopods (late Famennian)	Shallow marine
	Dp (Platform facies)	Between 90 and 150	*Windjana Limestone:* Limestone, massive to thickly bedded; framework of algae and stromatoporoids	Algae, brachiopods, and corals (late Givetian to late Famennian)	Shallow marine, water depth <10 m
		At least 410	*Pillara Limestone:* Limestone; minor dolomite, sandstone, and siltstone; limestone is stromatoporoid, fenestral, and oolitic; massive to poorly bedded	Brachiopods, atrypids, bivalves, corals, and bryzoans (late Givetian to late Famennian)	Shallow marine, water depth <10 m
		Up to 300	*Nullara Limestone:* Medium-bedded biostromal limestone and interbedded oolite, grading down to coarse calcarenite and quartz-pebble sandstone	Conodonts and foraminifera (late Famennian)	Shallow marine, water depth <10 m

1:1 000 000 CANNING BASIN MAP—*Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Unknown	Confined in subsurface to the Fitzroy Trough and part of Jurgurra Terrace		Includes Thangoo Calcarenite (McWhae & others, 1958), and Devonian units intersected in Yulleroo 1 in the Fitzroy Trough	Playford & others (1975)
Unconformably overlies Precambrian basement; overlies and interfingers with formations of the Late Devonian reef complex (Dr)	Confined to the Lennard Shelf; crops out in Van Emmerick Range, Mount Behn, and Stony Creek areas (LENNARD RIVER), Virgin Hills area (NOONKANBAH), and Sparke Range (MOUNT RAMSAY)	Bobs Bore Conglomerate: southern flank of Virgin Hills (NOONKANBAH: 18°30′12″S, 125°52′10″E); Stony Creek Conglomerate: (LENNARD RIVER: 17°57′S, 125°56′E); Behn Conglomerate: at Mount Behn (LENNARD RIVER: 17°29′S, 125°05′E); Van Emmerick Conglomerate: Van Emmerick Range (LENNARD RIVER: 17°03′S, 124°37′E)	Forms low rounded hills and ranges with complex drainage patterns; includes Van Emmerick, Behn, Bobs Bore, and Stony Creek Conglomerates	Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975)
See under Di, Dp, and Dd			Composed of Di, Dp, and Dd	
Interfingers with or abuts Windjana or Pillara Limestones; lateral equivalent of Gogo, Sadler, Virgin Hills, and Piker Hills Formations, and Bugle Gap Limestone; conformably overlain by Nullara Limestone	Crops out in Napier, Oscar, and Geikie Ranges area (LENNARD RIVER, NOONKANBAH)	Along Barker River in Napier Range (LENNARD RIVER: 17°16′S, 124°44′E)		Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975)
Conformably overlies Gogo Formation; laterally equivalent to Napier Formation; conformably overlain by and equivalent to Bugle Gap Limestone, Windjana and Nullara Limestones, and Piker Hills Formation	Restricted to Hull Range, Virgin Hills, Mount Pierre, and Lloyd Hill areas (NOONKANBAH, MOUNT RAMSAY)	About 8 km north of Mount Pierre (NOONKANBAH: 18°16′30″S, 125°52′00″E)	Red colour of sediments is a characteristic feature	Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Overlies and equivalent to upper part of Virgin Hills Formation; equivalent to Piker Hills Formation; lateral equivalent of Napier Formation; interfingers with Windjana Limestone; unconformably overlain by Grant Group	Confined to southern end of Bugle Gap (MOUNT RAMSAY)	5 km SE of Lloyd Hill (MOUNT RAMSAY: 18°42′S, 126°04′E)		Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Conformably overlies Virgin Hills Formation; equivalent to Bugle Gap Limestone and Napier Formation; interfingers with or abuts Windjana or Pillara Limestones; unconformably overlain by Grant Group	Confined to area between Mount Pierre (NOONKANBAH), Piker Hills, and Burramundi Range (MOUNT RAMSAY)	At Piker Hills (MOUNT RAMSAY: 18°04′30″S, 126°05′30″E)		Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Interfingers with Nullara Limestone, and Napier, Virgin Hills, Bugle Gap, and Piker Hills Formations; disconformably overlain by Fairfield Group; unconformably overlain by Grant Group	Crops out discontinuously along Napier and Oscar Ranges (LENNARD RIVER, NOONKANBAH), and south of Burramundi Range (MOUNT RAMSAY)	Windjana Gorge, where Lennard River cuts through Napier Range (LENNARD RIVER: 17°24′30″S, 124°57′30″E)		Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Unconformably overlies Ordovician and Precambrian sediments, Tandalgoo Sandstone, and Poulton and Gap Creek Formations; equivalent to Gogo Formation, Sadler Limestone, Piker Hills Formation, and Napier Formation	Crops out along Lennard Shelf	Menyous Gap in the Pillara Range (NOONKANBAH: 18°24′S, 125°56′E)		Playford & Lowry (1966); Read (1973 a, b); Playford & others (1975); Playford (1980)
Conformably overlies Napier and Virgin Hills Formations; laterally equivalent to Windjana Limestone; disconformably overlain by Fairfield Group	Confined to Lennard Shelf; crops out in Napier Range and NW Oscar Range (LENNARD RIVER, NOONKANBAH)	2 km south of Mount Percy (LENNARD RIVER: 17°40′S, 124°56′30″E)		Read (1973a, b); Playford (1980)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
LATE DEVONIAN	Dd (Marginal slope & basin facies)	At least 300	*Sadler Limestone:* Calcarenite, calcirudite, and minor megabreccia, with interbeds of calcareous siltstone and shale; thinly bedded	Brachiopods, ammonoids, conodonts, corals, and algae (late Givetian to early Frasnian)	Fore-reef
		At least 600	*Gogo Formation:* Dark shale and siltstone, with thin interbeds of limestone; characterised by layers of calcareous concretions	Mainly pelagic forms, including ammonoids, conodonts, nautiloids, fish, and crustaceans (late(?) Givetian to early Frasnian)	Shallow marine
	Knobby Sandstone Duk	About 200	Fine to coarse sandstone with interbeds of siltstone and pebble conglomerate; poorly sorted; large scale cross-bedding	Plant fossils, and placoderm fish including *Bothriolepis* and *Asterolepis* (Late Devonian)	Fluvial
	Luluigui Formation Dl	1055 in Mount Hardman 1	Interbedded siltstone, shale, limestone, and fine-grained sandstone	Microfossils, conodonts, and ostracods (Famennian)	Marine
	Clanmeyer Siltstone Dc	1067 in Logue 1	Grey-green siltstone, shale, and minor limestone	Ammonoids (Glenister, 1962) and microspores (Balme, 1962) (middle to late Famennian)	Marine
	Babrongan beds Dd	An incomplete section of 213 in Babrongan 1	Shale, siltstone (in part calcareous), grading into minor limestone and dolomite	Palynomorphs	Marine
MIDDLE TO LATE DEVONIAN	Mellinjerie Limestone Dm	266 in Kidson 1	Limestone, dolomite, and dolomitic shale; minor sandstone interbeds; minor anhydrite	Microflora and conodonts (Givetian to Frasnian)	Shallow marine
EARLY TO MIDDLE DEVONIAN	Poulton Formation Dn	401 in Napier 1	Red-brown to red siltstone; minor shale and sandstone; traces of dolomite	Microflora (Middle Devonian)	Shallow marine
	Tandalgoo Sandstone Dt	733 in Kidson 1	Red-brown, medium sandstone; minor interbeds of siltstone and shale; rare limestone	Fish scales give Early Devonian (Dittonian) age	Continental, mainly as aeolian dunes; minor fluvial
SILURIAN? TO EARLY DEVONIAN	Carribuddy Formation Sc	1709 in Kidson 1	Dolomite, dolomitic siltstone, and claystone; evaporites; minor sandstone	Sparse spores and pollen—no accurate age can be determined	Shallow sea with restricted circulation

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
Equivalent to Pillara Limestone and Napier Formation; interfingers with and conformably overlain by Gogo Formation	Confined to SE Lennard Shelf around Emanuel, Pillara, Hull, and Oscar Ranges, and Bugle Gap (NOONKANBAH, MOUNT RAMSAY, and LENNARD RIVER)	In Emanuel Range (NOONKANBAH: 18°36′S, 125°56′E)	Soft terrigeneous sediments, poorly exposed; brachiopods are commonly silicified	Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Unconformably overlies Precambrian rocks and Ordovician sediments; interfingers with and conformably overlies Sadler Limestone; equivalent to Pillara Limestone and Napier Formation; conformably overlain by Virgin Hills Formation	Restricted in outcrop to Bugle Gap (MOUNT RAMSAY), and Emanuel and Pillara Ranges areas (NOONKANBAH); has been intersected in wells on the Jurgurra and Barbwire Terraces (Gorter & others, 1979)	Near Menyous Gap in Pillara Range (NOONKANBAH: 18°36′S, 125°26′E)	Poorly exposed	Guppy & others (1958); Playford & Lowry (1966); Playford & others (1975); Playford (1980)
Unconformably overlies Carranya beds; unconformably overlain by Grant Group	Confined in outcrop to the Billiluna Shelf in western BILLILUNA and northern LUCAS	In Knobby Hills (BILLILUNA: 19°24′24″S, 127°45′44″E)	Forms small hills and rises	Casey & Wells (1964); Veevers & Wells (1961); Yeates & others (1975a)
Conformably overlies Clanmeyer Siltstone; passes laterally into Late Devonian reef complex (Dr); conformably overlain by Fairfield Group; unconformably overlain by Grant Group	Penetrated in wells in DERBY, MOUNT ANDERSON, LENNARD RIVER, and NOONKANBAH	Between 1084 m and 1909 m in Frome Rocks 2 (MOUNT ANDERSON: 18°15′15″S, 123°39′35″E)	Not exposed	Willmott (1962, 1966); Playford & others (1975); Gorter & others (1979)
Conformably overlies Babrogan beds; passes laterally into Late Devonian reef complex (Dr); conformably overlain by Luluigui Formation	Penetrated in wells along margin of Fitzroy Trough in DERBY, MOUNT ANDERSON, and NOONKANBAH	Between 713 m and 1736 m in Babrongan 1 (MOUNT ANDERSON: 18°23′23″S, 123°35′37″E)	Not exposed	Willmott (1966); Playford & others (1975); Gorter & others (1979)
Base of unit not known but probably unconformably overlies Carribuddy Formation; conformably overlain by Clanmeyer Siltstone; passes laterally into Late Devonian reef complex (Dr)	Penetrated only in Logue 1 and Babrongan 1 on Jurgurra Terrace (MOUNT ANDERSON)	Between 1736 m and 1949 m in Babrongan 1 (MOUNT ANDERSON: 18°23′23″S, 123°35′37″E)	Not exposed	Playford & others (1975); Gorter & others (1979)
Disconformably(?) overlies Tandalgoo Sandstone; unconformably overlain by Grant Group	Appears to be confined to the Kidson Sub-basin, and southeastern Barbwire Terrace and Broome Arch	Between 931 m and 1128 m in Sahara 1 (SAHARA: 21°04′40″S, 123°23′30″E)	Not exposed	Koop (1966); Playford & others (1975); Towner & others (1976)
Unconformably overlies Precambrian rocks and Ordovician rocks (Gap Creek Formation(?)); unconformably overlain by Pillara Limestone	Penetrated only in wells in the northwestern Lennard Shelf, including Blackstone 1, Meda 1, Napier 1, and Napier 2 (DERBY and LENNARD RIVER)	Between 1941 m and 2220 m in Blackstone 1 (DERBY: 17°35′14″S, 124°21′01″E)	Not exposed; an increase in salinity of drilling fluid in Blackstone 1 was considered to be due to dissolution of salt from the formation	Playford & others (1975); Gorter & others (1979)
Conformably overlies Carribuddy Formation; disconformably(?) overlain by Mellinjerie Limestone; unconformably overlain by Grant Group	Penetrated in wells in the Kidson Sub-basin, and in Matches Springs 1 and Barbwire 1	Between 1128 m and 1727 m in Sahara 1 (SAHARA: 21°04′40″S, 123°23′30″E)	Not exposed; name changed from 'Tandalgoo Red Beds' to conform with the New Stratigraphic Code	Koop (1966); Playford & others (1975); Towner & others (1976)
Disconformably overlies Nita and Goldwyer Formations; conformably overlain by Tandalgoo Sandstone; unconformably overlain by Grant Group, Paterson Formation, Late Devonian reef complex, and probably Babrogan beds	Appears to be confined to the Kidson Sub-basin, eastern Willara Sub-basin, and parts of the Broome Arch	Between 1727 m and 2120 m (total depth) in Sahara 1 (SAHARA: 21°04′40″S, 123°23′30″E)	Not exposed; diapiric salt dome in Frome Rocks 1	Koop (1966); Playford & others (1975); Towner & others (1976)

TABLE 7. STRATIGRAPHIC TABLE FOR

Age	*Rock unit & symbol (1:1 M map)*	*Maximum thickness (m)*	*Lithology*	*Fossils*	*Depositional environment*
EARLY ORDOVICIAN	Undivided O		Limestone, dolomite, shale, siltstone, and sandstone		
	Nita Formation On	240 in Matches Springs 1	Limestone, dolomite, interbedded shale, and minor anhydrite	Conodonts and microflora (Llanvirnian to Llandeilian)	Shallow marine, probably subtidal to intertidal
	Prices Creek Group Op	192 at type section	*Gap Creek Formation:* (Og): Dolomite with interbedded siltstone and sandstone	Brachiopods; conodonts give late Arenigian to earliest Llanvirnian age	Intertidal to possibly supratidal in parts
		746 composed of outcrop and Prices Creek 3 section	*Emanuel Formation:* (Oe): Interbedded grey nodular limestone and calcareous shale, overlying sandy dolomite and sandstone	Brachiopods, trilobites, graptolites, and conodonts (latest Tremadocian(?) to Arenigian)	Shallow subtidal
	Goldwyer Formation Oo	736 in Willara 1	Shale, grey to black, calcareous, and pyritic; interbedded limestone and dolomite; minor siltstone lenses	Abundant trilobites, graptolites, brachiopods, conodonts, and ostracods (Llanvirnian)	Subtidal
	Willara Formation Ow	532 in Willara 1	Limestone, dolomitic, finely crystalline; minor shale, siltstone, and fine sandstone	Conodonts, graptolites, and microflora (Arenigian to early Llanvirnian)	Subtidal to intertidal
	Wilson Cliffs Sandstone Oi	656 in Wilson Cliffs 1	Fine to medium sandstone; minor siltstone, shale, and limestone; dolomite interbeds in upper part	Trilobites, graptolites, bivalves, conodonts, and microflora (Arenigian)	Intertidal with some subtidal
	Nambeet Formation Ot	775 in Samphire Marsh 1	Grey to green shale with interbedded limestone, and dolomite; basal very fine to medium sandstone	Graptolites, trilobites, brachiopods, conodonts, and gastropods (Tremadocian(?) to Arenigian)	Intertidal to shallow subtidal
	Carranya beds Oc	135 measured in outcrop	Fine to medium sandstone; pebble and clay-pellet conglomerate; thin to medium-bedded; cross-bedded	Trilobites and gastropods (Arenigian)	Intertidal sandflats
	PRECAMBRIAN pЄ		Igneous, metamorphic, and sedimentary rocks		

1:1 000 000 CANNING BASIN MAP— *Continued*

Stratigraphic relationship	*Distribution*	*Type section*	*Remarks*	*References*
			Section only	
Conformably overlies Goldwyer Formation; disconformably overlain by Carribuddy Formation; unconformably overlain by Grant Group and Poulton Formation	Appears to be restricted mainly to the Broome Arch, Barbwire and Jurgurra Terraces, and the Willara Sub-basin; intersected in Blackstone 1 on Lennard Shelf; may be present in western Kidson Sub-basin	Between 1165 m and 1269 m in Parda 1 (LAGRANGE: 18°56′08″S, 122°00′34″E)	Not exposed; includes Roebuck Dolomite of McWhae & others (1958)	Playford & others (1975); McTavish & Legg (1976)
Conformably overlies Emanuel Formation; probably passes laterally into Willara Formation; unconformably overlain by Pillara Limestone and Poulton Formation	Prices Creek Group: occurs in the Prices Creek area around the Emanuel Range (NOONKANBAH) on the Lennard Shelf	Near Gap Creek (NOONKANBAH: 18°35′S, 125°55′E)	Crops out as strike ridges displaying well-marked bedding	Guppy & Öpik (1950); Guppy & others (1958); Veevers & Wells (1961); Playford & others (1975); McTavish & Legg (1976)
Unconformably overlies Precambrian rocks; possibly passes laterally into Nambeet Formation; conformably overlain by Gap Creek Formation		Near Gap Creek (NOONKANBAH: 18°39′S, 125°55′E)	Poorly exposed; best exposures in Emanuel Creek, near Emanuel Range (NOONKANBAH)	
Conformable between overlying Nita Formation and underlying Willara Formation and Wilson Cliffs Sandstone; unconformably overlain by Grant Group; disconformably overlain by Carribuddy Formation	Extends over most of Canning Basin; eastern limit is uncertain	Between 848 m and 1060 m in Thangoo 1A (LAGRANGE: 18°21′52″S, 122°53′09″E)	Not exposed	Elliott (1961); Playford & others (1975); McTavish & Legg (1976)
Conformable between overlying Goldwyer Formation, and underlying Wilson Cliffs Sandstone, Nambeet Formation, and Carranya beds; unconformably overlies Precambrian rocks in northwestern Broome Arch; probably laterally equivalent to Gap Creek Formation; unconformably overlain by Grant Group	Penetrated in wells in western Canning Basin, south of Fenton Fault; may be present in Fitzroy Trough and Lennard Shelf	Between 2610 m and 3142 m in Willara 1 (MUNRO: 19°10′48″S, 122°04′14″E)	Not exposed	Playford & others (1975); McTavish & Legg (1976)
Unconformably overlies older rocks in Wilson Cliffs 1; passes laterally into Nambeet Formation; conformably overlain by Goldwyer and Willara Formations	Penetrated in Wilson Cliffs 1 (WILSON) and McLarty 1 (McLARTY HILLS)	Between 2847 m and 3503 m in Wilson Cliffs 1 (WILSON: 22°16′39″S, 126°46′55″E)	Not exposed	McTavish & Legg (1976)
Unconformably overlies Precambrian rocks; passes laterally into Wilson Cliffs Sandstone, and possibly Carranya beds and Emanuel Formation; conformably overlain by Willara Formation; unconformably overlain by Grant Group in western Willara Sub-basin	Penetrated in many wells, suggesting that it may have extended over most of Canning Basin, except the southern shelf areas	Between 1240 m and 2015 m in Samphire Marsh 1 (MANDORA: 19°31′08″S, 121°10′51″E)	Not exposed	Johnstone (1961); Koop (1966); Playford & others (1975); McTavish & Legg (1976)
Unconformably overlies Precambrian rocks; possibly passes laterally into Nambeet Formation; unconformably overlain by Knobby Sandstone and Grant Group; probably conformably overlain by Willara Formation in subsurface	Crops out as low-lying rises along Canning Basin margin on Billiluna Shelf (BILLILUNA and MOUNT BANNERMAN)	In BILLILUNA: 19°10′S, 127°40′E approx.	Poorly exposed	Veevers & Wells (1961); Casey & Wells (1964); Playford & others (1975); Yeates & others (1975a); McTavish & Legg (1976)
Basement of Canning Basin	Penetrated in a number of wells (see Table 8)		Isolated exposures around Pillara Range; probable extension of Precambrian rocks marginal to Canning Basin	Gorter & others (1979); Forman & Wales (1981)

TABLE 8. PRECAMBRIAN BASEMENT LITHOLOGIES PENETRATED BY DRILLHOLES
(after Gorter & others, 1979)

Well name	*Total depth BSL (m)*	*Amount of basement penetrated*	*Lithology*
Tappers Inlet 1	2834	22	Metabasalt
Pender 1	888	5	Mica schist
Goldwyer 1	1357	18	Granite
Thangoo 1A	1482	101	Biotite phyllite
Thangoo 2	1279	34	Chlorite-muscovite gneiss
Edgar Range 1	1832	52	Quartz-mica schist
Napier 4	874	23	Quartzite
May River 1	1658	36	Oligoclase-epidote-actinolite schist
Langoora 1	1591	18	Quartz-chlorite-biotite schist
Meda 1	2655	44	Quartz-chlorite schist
Napier 2	1521	19	Mica schist
Napier 5	1583	8	Granite gneiss
Napier 1	1727	28	Granite gneiss
Hawkstone Peak 1	1136	13	Quartzite
Prices Creek 1	53	31	Biotite schist
Wilson Cliffs 1	3277	219	Silty shale, siltstone, sandstone
Munro 1	2056	10	Granite
Parda 1	1800	130	Chlorite gneiss
Samphire Marsh 1	2022	17	Granite
Wallal 4 & 4A	669	1	Gneiss

3. STRUCTURE AND TECTONICS

Simplified structural and solid geology maps of the Canning Basin are shown on Plate 2 and should be interpreted in conjunction with the legend columns on the same plate.

Almost all of the information concerning the Canning Basin structure is based on the interpretation of geophysical surveys conducted in and around the area. The reconnaissance gravity surveys provided information on the large-scale structures; aeromagnetic surveys have been used to delineate basement blocks and intra-basin structural divisions; and seismic surveys combined with geological drilling have allowed more detailed interpretation and definition of the subsurface structures. Many structures can be, and have been, predicted beneath and within the sedimentary basin sequences (Gorter & others, 1979) on the basis of geophysical discontinuities such as changes in the gradients, directions, and patterns of gravity anomaly contours.

The joint mapping program by BMR/GSWA, together with the geophysical information, has delineated the main depocentres, thickness variation, and lateral stratigraphic changes as well as significant breaks in the tectonic and sedimentary history of the Basin. The structural subdivisions are those of the present day and, strictly speaking, are divisions of pre-Ordovician basement. The legend columns (Plate 2) give some idea of the developmental history of the subdivisions (also section on GEOLOGICAL HISTORY).

Within this broad structural entity, four distinct periods of sedimentation occur within the Palaeozoic and Mesozoic Eras and one occurs in the Cainozoic Era. Within each period, the resulting set of strata have their own structural history, and are separated by regional unconformities, the origin of which may be either tectonic or simply a depositional hiatus. Each set could be identified as a separate basin which could be related to some distinct stage of crustal history (GSA, 1971; Doutch & Nicholas, 1978); the broad main structural subdivisions have been superimposed on these sets.

Basin boundaries

The onshore Canning Basin boundaries are erosional except in the south where the boundary approximates to a basement high. During the Early Cretaceous, the shallow sea which covered much of the Officer Basin to the south transgressed into the area of the south Canning Basin indicating that the two basins at that time were one entity. Prior to the Late Permian, these two basins, Canning and Officer, were apparently separated by a basement high coincident with the Anketell Regional Gravity Ridge (Fraser, 1976). Seismic survey results in the southern Canning Basin (AAP, 1969a) indicate shallowing of pre-Permian sediments against a magnetic basement high (Goodeve, 1961) which corresponds to the Anketell Regional Gravity Ridge. This regional gravity ridge is considered to form part of an important late Precambrian structural trend, the 'Paterson-Musgrave Trend' (Austin & Williams, 1978) which can be traced along the southern margin of the Amadeus Basin, westward along the gravity ridge and thence along the Late Proterozoic(?) Paterson Province at the southwestern margin of the Canning Basin.

The boundary between the Canning and Amadeus Basins from Early Permian onwards is the trace of the unconformity between Permian sediments and the older Amadeus Basin sequences. Gravity data have defined an elongated north-trending basement high along the southeastern Canning Basin margin, and magnetic and magnetotelluric evidence indicates a shallowing of basement as the gravity high is approached from the west. Some workers (e.g. Webby, 1978) suggest that, during Early Ordovician times, the Canning and Amadeus Basins were either openly connected, or joined by a narrow passage. Seismic evidence in the southeast Canning Basin area shows the 'Late Ordovician' marker pinching out and being overlapped by the 'Carribuddy' marker. These data, together with the palaeogeographic information from the Amadeus Basin (Cook *in* Wells & others, 1970) strongly suggest that, if a connection did exist between the two basins, it was only a narrow passage which was closed late in the Early Ordovician.

To the northwest, the boundary of the offshore Canning Basin cannot be mapped. Playford & others (1975) and Gorter & others (1979), have arbitrarily chosen the edge of the continental shelf as the northwest margin. The thick Jurassic-Cretaceous sequence whose main depocentres are located in the Bedout Sub-basin (in the offshore portion of the Canning Basin) onlaps the onshore Canning Basin, extending inland for some 150 kilometres. For details of the offshore Canning Basin, see Forman & Wales (1981).

Basin structures

The structural subdivisions proposed below for the onshore Canning Basin are based on present day basement configuration (see major structural subdivision, Plate 2). They are the northern shelf area, comprising the Lennard and Billiluna Shelves; the northern basin and adjoining terraces, consisting of the Fitzroy Trough, and Betty, Barbwire, and Jurgurra Terraces; a central high, the Broome Arch; the southern basins, consisting of the Kidson and Willara Sub-basins; and the southern shelf area consisting of the Anketell, Tabletop, and Ryan Shelves. Some of these structural features can be traced offshore, and most of them are illustrated in the cross-sections on Plate 2.

Very little structural information can be obtained from surface exposures. Extensive seismic surveys, particularly along the northern margin and in the central region of the Basin, supported by deep drilling, have supplied some information on faulting and depth to basement.

The *Lennard Shelf*, a narrow shelf characterised by a number of high and low Bouguer anomalies of relatively small amplitude, occurs along most of the northeastern side of the Basin. The Shelf is a shallow basement feature overlain by up to 3000 m of sediments of predominantly Ordovician, Devonian, and Permian age. The northeastern boundary of the Lennard Shelf, which is the northeastern boundary of the Canning Basin, is the exposed unconformity between the Phanerozoic sediments of the Basin and the Precambrian rocks of the Halls Creek Province. The southwestern margin of the Lennard Shelf is marked by the Pinnacle Fault System in the southeast, which is well mapped in outcrop, and the Beagle Bay Fault System in the northwest, which has no surface expression and is mapped solely on seismic evidence. These faults are coincident with a pronounced gravity gradient.

The *Billiluna Shelf* is separated from the Lennard Shelf by the Precambrian basement rocks around Bulka Hills (MOUNT BANNERMAN). The Billiluna Shelf is a basement feature which seismic results show to be extensively faulted. It is most clearly defined by aeromagnetic data. The Shelf is coincident with part of a major gravity low (Mount Bannerman Gravity Trough; Flavelle & Goodspeed, 1962) and is overlain by about 3000 m of mainly Devonian and Ordovician sediments. The Shelf's southwestern boundary is the Mueller Fault, and its northwestern, northern, and eastern boundaries, which are the same as the Basin boundaries, are the exposed unconformities between Phanerozoic rocks of the Canning Basin and Precambrian basement rocks of the Halls Creek Province and The Granites-Tanami Block.

The *Betty Terrace* (WAPET, 1970c) is an area comprising a series of structural high and low features within the basement which are reflected in aeromagnetic and gravity data (Paten & others, 1972). The Betty Terrace varies in depth from 3000 to 6000 m below sea level. Seismic evidence supported by drilling indicates that the overlying sedimentary section, which thickens southwestwards, is composed of Ordovician to Permian rocks. The Stansmore Fault, which on the surface can be mapped from the Stansmore Range (STANSMORE) northwest into CORNISH, forms part of the southwestern margin of the Betty Terrace. Seismic evidence indicates that this fault extends farther to the northwest, into central MOUNT BANNERMAN. Displacement on the fault appears to decrease to the northwest. The character of the rest of the southwestern margin farther to the northwest is not known.

The *Fitzroy Trough*, situated southwest of the Lennard Shelf and Betty Terrace, is characterised by an extensive, elongated gravity low, the dominant feature of the Fitzroy Regional Gravity Complex, and is coincident with an aeromagnetic low. Combined geophysical evidence suggests a thick pile of sediments, which have not been completely penetrated by drilling. Seismic evidence suggests that basement depths are generally about 8000 m, with a maximum depth of 18 000 m in the southeast. The Fitzroy Trough contains a thick sequence of Ordovician, Devonian, Carboniferous, and Permian clastic sediments. The correlatives of the Ordovician are the same thickness outside the Trough, but those of the Devonian, Carboniferous, and Early Permian outside the Trough are much thinner or have not been deposited.

The southwestern boundary of the Fitzroy Trough is the Fenton Fault System, which is coincident with a steep gravity gradient. The maximum movement on this fault system is about 4000 m down to the northeast. However, the northwestern and southeastern ends of the Fenton Fault System are poorly defined. In fact, seismic evidence suggests that the throw on the Fenton Fault System decreases to the southeast where displacement is taken up by steep monoclinical flexuring (WAPET, 1970b).

The *Barbwire* and *Jurgurra Terraces* are two relatively narrow shelf-like basement areas separated from the Fitzroy Trough by the Fenton Fault System. The southwestern boundary of the Jurgurra Terrace is the Dampier Fault System; and for the Barbwire Terrace, the Dummer Range Fault System. The Dampier and Dummer Range Fault Systems do not crop out, and it appears from limited seismic information that the ends of these two fault systems merge with the Fenton Fault System. Geophysical data indicate that both basement areas have been subjected to block faulting. The sediments above the Jurgurra Terrace are about 2000 m to 4500 m thick; those on the Barbwire Terrace are 1500 m thick in the northwest, increasing to more than 4500 m in the southeast (WAPET, 1970b). The sequence on the Terraces comprises Palaeozoic rocks veneered by Mesozoic rocks on the Jurgurra Terrace and part of the Barbwire Terrace. An unusual feature of the sedimentary sequence overlying the Jurgurra Terrace is the occurrence of a salt dome, composed of salt from the Silurian(?) to Early

Devonian Carribuddy Formation which intruded during or prior to the Early Jurassic.

All the major faults paralleling the northwest-trending Fitzroy Trough are steeply dipping towards their downthrown sides, and all of them appear to be major gravity faults with long histories of growth (Forman *in* Gorter & others, 1979). Seismic evidence has shown that anticlines parallel to the faults may be present on their down-dip sides, together with antithetic faulting.

The *Broome Arch* ('Broome Swell' of Veevers & Wells, 1961; 'Broome Platform' of Koop, 1966; 'Crossland Platform' of WAPET, 1970b), centrally located in the Canning Basin, is a broad area of relatively shallow basement, overlain by 1000 to 3000 m of sediments of predominantly Palaeozoic age, although some Mesozoic rocks are present in the northwest. The Broome Arch lies within the Munro Regional Gravity Platform, an area of moderate Bouguer anomaly (Flavelle, 1974). The regional dip of the sediments on the Arch is to the southwest. In the west, the Admiral Bay Fault System forms the southern margin of the Arch. The Admiral Bay Fault System, detected only by geophysical methods, has a normal displacement of up to 500 m down to the south, essentially affecting the pre-Permian and basement rocks; farther to the southeast, no clear boundary exists between the Arch and Sub-basins to the south. The Broome Arch may be an area which did not downwarp as rapidly as the Fitzroy Trough and the Terraces to the northeast and Sub-basins to the southwest. Alternatively, it may be an uplifted area marginal to the Fitzroy Trough, similar to uplifts marginal to rift zones in the northwest Africa–Red Sea area.

The *Kidson* and *Willara Sub-basins* are two contiguous basement depressions southwest of the Broome Arch. The Willara Sub-basin, which has a maximum estimated depth of 4500 m, coincides with the Munro Regional Gravity Platform (Fraser, 1976), and is filled with Palaeozoic sediments overlain by Mesozoic sediments which thicken northwestwards. The Kidson Sub-basin coincides with the South Canning Regional Gravity Low. There is reasonable correlation between the gravity and aeromagnetic data, which together suggest that the Kidson Sub-basin has a maximum depth of 10 000 m (WAPET, 1963d,e; Darby & Fraser, 1969). Information from boreholes indicates thick Palaeozoic rocks dominated by a thick evaporite sequence of Silurian(?) to Early Devonian age, with a thin cover of Mesozoic rocks.

Seismic data show little evidence of strong deformation, and it is probable that the Sub-basins are the result of gentle downwarping of the basement. The two Sub-basins are considered to be separated from each other by a low basement rise, the 'Munro Arch', which appears to have developed near the end of the Ordovician.

The *Samphire Embayment* (formerly Samphire Depression; Veevers & Wells, 1961), situated immediately to the southwest of the Willara Sub-basin, near the coastline, is a small basement depression separated from the Willara Sub-basin by an area of relatively shallow basement. Limited seismic evidence together with aeromagnetic results confirm that the Embayment is bounded on its southwestern margin by a northwest-trending fault which has affected only the pre-Permian rocks.

A poorly delineated shelf, which laps around the north of the Pilbara Block and adjoins the Officer Basin, lies along the southern margin of the Canning Basin; the shelf coincides with the northern margin of the Anketell Regional Gravity Ridge. Little is known about the shelf owing to the absence of wells and the paucity of seismic data, which is of very poor quality when available. The shelf is covered by a veneer of Late Palaeozoic and Mesozoic rocks less than 700 m thick. In the review of the Canning Basin by Gorter & others (1979), this shelf feature has been referred to in three parts—*Anketell*, *Tabletop*, and *Ryan Shelves*, depending on location. Although these names have been retained here, the validity of such nomenclature subdivision must be questioned owing to the paucity of information.

The *Wallal Embayment* is a small structural embayment within the basement of the Anketell Shelf, and is characterised by a gravity low. Seismic results and drilling show that the Wallal Embayment is a small, shallow, half-graben bounded in the northeast by a fault and in the southeast by the pinching out of the sedimentary section. The Embayment contains Ordovician, overlain by Permian, and thin Triassic rocks.

Faults and folds

Faulting predominates in the Canning Basin, and most of the folds are related to faulting although a few isolated drape structures are known (Gorter & others, 1979). The Fitzroy Trough contains many north-northwest-trending transverse faults arranged en-echelon between the two boundary fault systems. These en-echelon faults are predominantly normal faults, although a few reverse faults occur and there are several low-angle thrust faults in the Poole Range (NOONKANBAH) that may mark the soles of gravity slide blocks in the upper part of the Grant Group. The normal faults have an average dip of 70°. Slickensides indicate that movements were essentially vertical. The maximum throw on the en-echelon faults observed in the St George Ranges (NOONKANBAH) is 200 m.

Folds are common in the northwest of the Fitzroy Trough and are arranged in en-echelon fashion with axes generally orientated west to west-northwest. Some appear to be slightly asymmetrical, and their axial planes dip slightly to the south. There is evidence (Galloway & Howell, 1975; Crowe & Towner, 1976a) that the major anticlines have acted alternately as positive and negative features during their history: for instance, the Poole Sandstone is markedly thicker in the axial region of the St George Ranges–Poole Range Anticlines than to the north and south, suggesting that faster subsidence occurred in that area at the time when the Poole Sandstone was deposited.

Joints are particularly prominent in the Grant Group, especially in the Fitzroy Trough. In the St George Ranges Anticline, the master joints occur roughly parallel to the fold axis, and the minor joints appear to be parallel to faults.

The intrusion of mafic igneous rocks is associated with the faulting and folding, in the northwest Fitzroy Trough.

Minor faults and folds have affected the Jurassic rocks especially in MOUNT ANDERSON. Smith & Williams (1955) considered the folds to be drape structures caused by differential compaction over an irregular pre-Jurassic topography, although this origin was questioned by Crowe & others (1978). Gibson (in preparation b) discusses a post-Early Cretaceous broad anticlinal warp present in the Dampier Peninsula in BROOME.

Basin development

The area now known as the Canning Basin, which developed on a floor of Precambrian rocks, appears to have undergone a long period of erosion lasting till the Ordovician, when the area was mainly of low relief, a gently downwarped surface on Precambrian rocks.

The initial development of the structural subdivisions began in Silurian(?) to Early Devonian times with downwarping of the Kidson Sub-basin during the deposition of Carribuddy Formation and Tandalgoo Sandstone. In the Middle Devonian, main movements along the Dampier, Dummer Range, Beagle Bay, Pinnacle, and Fenton Fault Systems, and the Stansmore and Mueller Faults, initiated the Fitzroy Trough and adjacent terraces as well as the Broome Arch. Continued movement on the faults during deposition of sediments in the Late Devonian and Early Carboniferous resulted in great thicknesses of sediment in the Trough compared with that on the adjacent terraces and the Broome Arch. Pre-Permian units in and around the Fitzroy Trough are extensively faulted, and this probably reflects the tensional tectonic regime that operated in the Devonian and Carboniferous.

The Fitzroy Trough and the Kidson and Willara Sub-basins continued to be major depocentres with respect to the rest of the Basin (mainly the Broome Arch) during the Permian; some minor movements along bounding faults of the Trough occurred during this time. These movements are represented by small breaks in sedimentation within the Fitzroy Trough and in the Samphire Embayment and by possible non-deposition over the rest of the Canning Basin.

In the Late Triassic or Early Jurassic, compression between the Canning Basin and Halls Creek Province (Rattigan, 1967; Smith, 1968; Forman *in* Gorter & others, 1979) is thought to have caused right-lateral shear in the Fitzroy Trough, causing movements along the major faults including reverse movement along the Fenton Fault System, and folding and faulting in the Trough itself. A set of east-trending en-echelon anticlines and synclines and north-northwest-trending fault blocks developed within the thick sediments of the Trough. Folding within the Trough was probably assisted by salt movement and decollement at depth (Gorter & others, 1979), and dolerite was intruded in the northwest. This deformation and subsequent erosion over the entire Basin resulted in the regional unconformity at the base of the Jurassic units.

There has been only minor deformation since the Early Jurassic. Some downwarping probably occurred in the Late Jurassic in the northwest Fitzroy Trough, where Late Jurassic units are thicker than in adjacent areas. Jurassic to Cretaceous rocks are gently folded and faulted in MOUNT ANDERSON, although it is not clear whether this deformation is due to a tectonic event or compaction over an irregular surface. Gentle doming probably took place in the Dampier Peninsula during the Tertiary (Brunnschweiler, 1957; Gibson, in preparation b).

4. GEOLOGICAL HISTORY

The geological history of the Basin is summarised in Table 9; the time intervals Late Carboniferous through to Early Cretaceous inclusive are depicted on sketch maps on Plate 2. The history should be considered in conjunction with the reference diagram also on Plate 2.

5. MINERAL RESOURCES

Petroleum

Petroleum exploration had not revealed any commercially exploitable accumulations of hydrocarbons until the 1981 Home Oil Blina 1 oil discovery (being evaluated at the time of writing). Eighty-four petroleum exploration and stratigraphic wells were drilled between 1920 and late-1981 (see Plate 1). Only four of these wells (see Table 4) have yielded hydrocarbons on test: Gewerkschaft Elwerath Yulleroo 1, which produced more than 890 m^3 of gas; Continental St George Range 1; WAPET Meda 1 (Horstman & others, 1976), which yielded several gallons of 38° API gravity paraffin-base crude (Powell & McKirdy, 1976) on drill stem test of a sandstone in the Early Carboniferous Laurel Formation; and Home Oil Blina 1.

A possible explanation for this disappointing record has been suggested by the analyses of levels of organic metamorphism and thermal histories of the rocks (Burne & Kantsler, 1977). Burne & Kantsler concluded that sediments which now lie at a depth where present temperatures are between 50° and 70°C are the most likely to be generating hydrocarbons. They concluded, however, that the great age, slow subsidence, and often low geothermal gradient in the Canning Basin downgraded possibilities of finding petroleum.

Since large regions of the central, southern, and eastern portions of the Canning Basin are still relatively unexplored, Smith (1977) suggested that high-quality seismic coverage is required, followed by several stratigraphic wells to improve knowledge of the area's geological history and its hydrocarbon potential.

Burne & others (1979) attempted to explain the poor exploration record of the area and assess its hydrocarbon potential by examining the source rock potential; to do this they analysed the total organic carbon and determined the amount of, and nature of, the extractable organic matter present in some of the Palaeozoic rocks. They concluded that:

TABLE 9. GEOLOGICAL HISTORY

Time	Structural subdivision	Anketell/ Tabletop/Ryan Shelves	Willara and Kidson Sub-basins	Broome Arch and Jurgurra and Barbwire Terraces	Fitzroy Trough including Betty Terrace and Billiluna Shelf	Lennard Shelf	Remarks
QUATERNARY	Holocene	Beach ridge, supratidal flat, and intertidal zone development; continued alluvial deposititon					Sea level fluctuating about present level, or slight regression; younger(?) beach ridges and associated coastal deposits forming
	Pleistocene	Deposition of calcarenite and calcilutite along the coast; alluvial deposition in north and east					Slight rise in sea level
		Weathering and erosion of laterite; deposition of aeolian sand					Arid climate with winds from an easterly direction; extensive sand plains developed
	Late Tertiary	Erosion; alluvial deposits choke rivers					Change from humid to semi-arid climate; continental deposition of Lawford beds and Warrimbah Conglomerate; continued sedimentation in lakes
					Intrusion and extrusion of lamproite		Fitzroy Lamproite
	Late Cretaceous to Late(?) Tertiary	Deep chemical weathering; deposition of fluvial gravel, sand, and silt; development of soil profile (including laterite); deposition of carbonates, clay, and sand in lakes; some chemical sedimentation in far SW					Development of drainage systems probably under high rainfall and subtropical temperatures; fluvial deposition of Lampe beds and Lake George beds; lacustrine deposition of Oakover beds and Lake Gregory beds; chemical sedimentation of Poondano Formation in SW; humid climate
				Gentle deformation			Gentle folding and faulting of Jurassic and Cretaceous rocks
	Early Cretaceous	Erosion					Total regression of sea from area
		Deposition of shallow marine mud					Bejah Claystone; see Map 14
		Deposition of shallow marine silt and sand					Transgression from south (Officer Basin); Anketell Sandstone and Samuel Formation; see Map 14

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
		Deposition of fluvial and deltaic sand and gravel					Withdrawal of sea followed by continental deposition; Emeriau Sandstone on Lennard Shelf; Frezier Sandstone elsewhere; see Map 13
		Deposition of mud and fine sand in shallow sea or lagoon					Transgression in SW (Parda Formation); see Map 12
Early Cretaceous					Deposition of beach sand in NW		Regression in north (Melligo Sandstone); see Map 12
		Deposition of fluvial sand, gravel, and silt in SW and south		Deposition of marine (tidal) sand and mud flanked on eastern margin by deltaic and fluvial sand and gravel			Regression; marine Broome Sandstone; rivers flowing north and east off Pilbara Block (Callawa Formation) and over plains of Jarlemai Siltstone and Permian sediments (Mowla Sandstone); see Map 11
		Erosion(?)					Possible erosion of Jarlemai Siltstone and Wallal Sandstone
Late Jurassic to Early Cretaceous		Deposition of marine mud flanked in NE and SE by fluvial sand, gravel, and silt					Continued transgression from NW (Jarlemai Siltstone); rivers flowing west from higher ground (Barbwire Sandstone and Meda Formation); rivers flowing north and east off Pilbara Block (Callawa Formation and Cronin Sandstone); see Map 10
Late Jurassic		Deposition of tidal sand and mud in NW (flanked along eastern margin by fluvial gravel and sand)					Transgression from NW (Alexander Formation); continental deposition to the east (Barbwire Sandstone); see Map 9
Early(?) to Late Jurassic		Deposition of fluvial, aeolian, deltaic, and shallow marine sand, silt, and gravel					Wallal Sandstone; confined to western Canning Basin; see Map 9

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
Middle Triassic to Early(?) Jurassic		Erosion	Gentle deformation; erosion	Salt dome emplacement	Dolerite intrusion; Faulting, folding, uplift, and erosion		Tectonism; wrench movements along Fenton and Pinnacle Fault Systems of Fitzroy Trough producing E-W anticlinal structures, and N-S faults; Triassic and older rocks eroded; development of unconformity at base of Jurassic sequence; dolerite and gabbro intrusions as plugs and sills in Fitzroy Trough; possible time of salt dome emplacement on Jurgurra Terrace
Early to Middle Triassic					Deposition of deltaic and fluvial sand, gravel and minor silt		Regression; Erskine and Culvida Sandstones; see Map 8
Early Triassic		Deposition of tidal-flat mud in Wallal and Samphire Embayments			Deposition of tidal-flat mud		Continued shallow transgression; Blina Shale; see Map 7
					Deposition of fluvial sand, silt and minor gravel in SE; shallow marine mud in NW		Transgression in NW (basal Blina Shale); Millyit Sandstone in SE; see Map 7
latest Permian to earliest Triassic		Minor deformation; erosion; Regression			Regression		Development of unconformity/disconformity between the Late Permian and Early Triassic units
Late Permian		Deposition of mud and fine sand in shallow marine conditions, mainly in Wallal and Samphire Embayments			Deposition of deltaic mud, sand, and minor gravel in NW; shallow tidal flats in SE		Transgression confined to Fitzroy Trough and Lennard Shelf (Hardman Formation in NW, Godfrey beds in SE) and Willara Sub-basin (Chirup Formation in SW); see Map 6
					Deposition of fluvial and deltaic sand		Continental deposition (Condren Sandstone); possible erosion of earlier Permian units; see Map 5

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
Early to Late Permian			Deposition of shallow marine fine sand and mud		Depositional of shallow marine and lagoonal fine sand and mud		Regression; Lightjack Formation in north; Triwhite Sandstone in south; see Map 4
			Deposition of marine mud, carbonates, and minor sand				Rise in sea level; open marine (Noonkanbah Formation); see Map 3
			Deposition of carbonates, silt, and sand in shallow sea, followed by fine sand and silt				Marine transgression over most of the Basin; deposition initially in open marine environment then in restricted conditions, possibly lagoonal (Poole Sandstone); see Map 2
					Minor faulting, folding and erosion		Movement along the Pinnacle Fault and Fenton Fault Systems; development of unconformity/disconformity between Grant Group and Poole Sandstone
Early Permian			Deposition of shallow marine sand and mud; pebbles rafted in by ice				Shallow marine deposition followed by regression (Carolyn Formation); climate initially cold, but becoming warmer; see Map 1
		Deposition of fluvial sand and gravel		Deposition of marine mud and fine sand			Sea-level rise (Winifred Formation); warm climate indicated by shell fossils—possibly interglacial phase; continental deposition on southern margin (Paterson Formation); see Map 1
		Deposition of lacustrine silt and clay, followed by fluvial sand		Deposition of sand, gravel, and silt in shallow sea		Deposition of gravel in NW	Transgression; continental deposition in north (Lillybooroora Conglomerate) and in south (Paterson Formation); marine deposition elsewhere (Betty Formation); cold climate; see Map 1

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
Late Carboniferous					Deposition of sand and gravel in shallow sea		Glaciation of land surface; striated pavements in Precambrian rocks to north and SW of Basin margin; transgression, initially in Fitzroy Trough (basal part of Betty Formation of Grant Group); see Map 1
		Erosion					Unconformity between Anderson Formation and Grant Group
Early Carboniferous					Deposition of shallow marine and continental sand, silt, and minor carbonates		Regression; mainly continental deposition (Anderson Formation); data lacking for this time period
Late Devonian to Early Carboniferous				Deposition of quiet open-marine to platform carbonates, sand, and silt	Deposition of terrigenous clastics	Deposition of open marine passing up into supratidal carbonates, sand, silt, and mud	Shallowing of sea in Fitzroy Trough and adjacent shelves (Fairfield Group); Fitzroy Trough units poorly known (undivided D)
Late Devonian				Deposition of carbonates and mud	Deposition of clastics in Trough and fluvial gravel, sand, and silt in SE	Growth of carbonate reefs, and bioherms	Gradual deepening of sea; continued reef and carbonate bank development (Devonian carbonate complex); Clanmeyer Siltstone and Luluigui Formation south of Fitzroy Trough; undivided D units in Fitzroy Trough; Knobby Sandstone on Billiluna Shelf
				Deposition of mud	Probable deposition of deep water marine clastics and carbonates	Carbonate reef growth continued	Continued development of Devonian carbonate complex; Babrongan beds on Jurgurra Terrace
Middle to Late Devonian			Deposition of carbonates, silt, and minor salt on supratidal and intertidal flats		Probable deposition of deep water marine clastics and carbonates	Initiation of deposition of carbonates and assorted clastics	Marine transgression; Mellinjerie Limestone in south; Devonian reef carbonate complexes on Lennard Shelf; undivided D in Fitzroy Trough

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
	Middle(?) Devonian		Downwarping		Major tectonism		Movement along Pinnacle, Beagle Bay, Fenton, Dummer Range, and Dampier Fault Systems; initiation of Fitzroy Trough, adjacent shelves, and terraces; some block faulting on Lennard Shelf
	Early to Middle Devonian		Deposition of sand and minor silt under desert conditions		Probable clastic deposition	Deposition of silt and minor sand in shallow sea along NE margin	Regression in south; deposition of Tandalgoo Sandstone forming extensive sand sheets with aeolian dunes; continued deposition in north (undivided D, and Poulton Formation)
	Silurian(?) to Early Devonian		Deposition of carbonates, fine clastics, and evaporites in shallow sea		?—?—?—?	No information —possibly no deposition	Trangression by sea with restricted circulation, particularly in south; successive periods of evaporation, precipitation, and recharge with concentrated brines (Carribuddy Formation in south; undivided D in north)
	Late Ordovician to Silurian(?)		Erosion				Land surface lowered
ORDOVICIAN	late Llanvirnian to early Llandeilian		Deposition of subtidal to intertidal carbonates and silt; some anhydrite in NE		?—?—?—?		Possible change from humid to semi-arid climate implied by anhydrite; regression of sea towards NW (Nita Formation); distribution is tentative owing to lack of information
	late Arenigian to Llanvirnian		Deposition of subtidal to intertidal clastics and carbonates				Continuation of shallow marine transgression (Goldwyer Formation)
	late Arenigian		Deposition of subtidal carbonate, mud, and minor sand				Continued transgression (Willara Formation); Gap Creek Formation on Lennard Shelf

TABLE 9. GEOLOGICAL HISTORY—*Continued*

Time	*Structural subdivision*	*Anketell/ Tabletop/Ryan Shelves*	*Willara and Kidson Sub-basins*	*Broome Arch and Jurgurra and Barbwire Terraces*	*Fitzroy Trough including Betty Terrace and Billiluna Shelf*	*Lennard Shelf*	*Remarks*
ORDOVICIAN	early Arenigian		Deposition of intertidal to subtidal mud and sand		Deposition of intertidal to subtidal mud, carbonate, and sand; sand and gravel on intertidal sand flats in SE		Marine transgression; Nambeet Formation over much of area; Wilson Cliffs Sandstone in central Broome Arch and SE Kidson Sub-basin; Emanuel Formation on Lennard Shelf; Carranya beds on Betty Terrace and Billiluna Shelf; palaeomagnetic data suggest warm, humid climate (Embleton, 1973)
Pre-Ordovician		Erosion of Precambrian rocks					Formation of Canning Basin floor with low topographical relief

(i) good source rocks exist at suitable levels of organic metamorphism, but are not at optimum positions in the sedimentary sequence to enable migration into the best known reservoir rocks;

(ii) the slow rate of burial of the sediments means that, by the time maturation has occurred, primary porosity has been lost in many potential reservoirs;

(iii) extensive periods of uplift, erosion, and groundwater flushing have adversely affected the prospectiveness of the area.

Their study also confirmed that the Fairfield Group on the Lennard Shelf contains good source rocks, but that the prospectiveness of this sequence is limited by the poor porosity and the small size of potential Fairfield Group reservoirs.

In the petroleum geology study of the Canning Basin, Gorter & others (1979) agreed with Burne & others (1979) that 'all exploration in the area must now be regarded as a high risk', and also indicated that 'the best potential rests with the testing of Devonian reef trends, Permian Poole Sandstone plays in the southeast Fitzroy Graben, and Lower Devonian Tandalgoo Red Beds [now Tandalgoo Sandstone] plays in areas of suspected seal and source'.

Coal

Coal occurs in many parts of the Basin but, as yet, no commercial deposits are known. In DERBY, Dampier Mining intersected coal seams up to 10 m thick during exploration in 1980; however, the seams were discontinuous and the coal was of low rank.

In 1974, Esso Exploration carried out extensive drilling (up to 50 holes) in western NOONKANBAH, and showed that the Permian Lightjack Formation contains the most widespread and thickest coal seams (maximum thickness 2 m) but that the coal is of low rank (sub-bituminous to bituminous) and contains thin sandstone interbeds (Galloway & Howell, 1975). CRA obtained similar results in the Meda River-Lennard River area, northeast and east of Derby (Quinton, 1974). Drilling by BMR (Yeates & others, 1975a) intersected coal seams less than 10 cm thick in northwestern MOUNT BANNERMAN. Carbonaceous material is present within the Permian Poole Sandstone in the eastern Canning Basin (Yeates & others, 1975a), and has been reported from the same stratigraphic level elsewhere in the Basin. Thin laminae of coal have been reported in a number of petroleum exploration wells, particularly in the Jurassic and Permian sandstones.

Iron

The Lightjack Formation contains lenses of limonitic oolite near its base. Although the oolite-bearing interval is extensive, it is not considered to be an economic deposit of iron ore (Edwards, 1953). Iron is also associated with phosphatic intervals in the Permian and Jurassic rocks.

An estimated reserve of 3.5 million tonnes of iron ore at an average grade of about 57% Fe and with low phosphorus content occurs in Tertiary pisolitic goethite and limonite of the Poondano Formation in PORT HEDLAND (de la Hunty, 1962).

Phosphate

Phosphate occurs in a number of formations, especially the Noonkanbah Formation, Blina Shale, and Jarlemai Siltstone. The average P_2O_5 values range from 3% to 15%. The phosphatic beds are thin, composed of clastic rocks, and often occur as phosphatic ironstones. They are not considered to be favourable for economic exploitation (Freas & Zimmerman, 1965; Howard, 1972; Yeates & others, 1975a; Towner & Gibson, 1980).

Heavy-mineral sands

Heavy-mineral sands are present on the coast between Broome and Cape Leveque (Baxter, 1977; Gardiner, 1977; Towner & Gibson, 1980). The most common minerals are magnetite and magnetite-ilmenite compounds with subordinate zircon, rutile, and tourmaline. To date, the deposits have not been mined.

Salt

Thick sequences of evaporites (mainly halite and gypsum) are present in the Carribuddy Formation (Glover, 1973). Deposits of salt up to several centimetres thick occur in slight depressions on the mudflats around Broome and Derby, and in the surfaces of some of the large dry lakes in the central and eastern parts of the Canning Basin. Salt is currently commercially produced by evaporation in pans on coastal mudflats near Port Hedland.

Diamonds

Following a suggestion by Prider (1960), that the Fitzroy Lamproite may be genetically related to kimberlite, aeromagnetic, radiometric, drilling, and surface sampling surveys were carried out in the north of the Canning Basin, but no diamonds or indicator minerals were found. However, in 1978, a number of new kimberlite plugs were discovered east of Derby. At the time of writing, bulk sampling of these pipes was in progress, aimed at defining any potentially economic diamondiferous areas.

Lead and zinc

Two lead-zinc ore bodies were mined intermittently from 1906 to 1964 in the Devonian Napier Formation at Narlarla near Old Napier homestead in LENNARD RIVER (Halligan, 1965). Exploration for Mississippi Valley-type lead-zinc deposits in the Devonian reef complex is continuing in this area at the time of writing.

Construction materials

There are large deposits of lateritic materials, especially in the south Canning Basin, which have been used for surfacing dirt roads and airstrips. Widespread areas of sand are present along the coastal strip and in the central portion of the Basin. The sand is relatively free of organic matter but is locally clayey. Beach ridge sand contains considerable amounts of shells and so is probably unsuitable for concrete.

In the Dampier Hill region (DERBY), sandstone from the Melligo Sandstone has been quarried and used in local buildings.

Water

Because of the unreliable seasonal rainfall, and the semi-arid climate, surface water is inadequate for

pastoral use. Large rivers, such as the Fitzroy, Margaret, and Sturt Rivers in the north, and the Nullagine, Oakover, and De Grey Rivers in the south, have large semi-permanent pools of water but may become completely dry if the rainy season is poor for several years in succession. Elsewhere in the Canning Basin, particularly in the desert areas, small rockholes located on mesas and breakaways contain a small supply of water following periods of heavy rainfall. In southwest McLARTY HILLS, there is a small permanent freshwater soak. Most salt lakes and claypans hold water only for a short time after heavy rain.

The pastoral industry, missions, and townships, therefore, do not rely on surface water, but use it to supplement groundwater obtained from water-bores. The water-bores are locally concentrated around the various cattle and sheep properties in the northern portion of the Canning Basin and along part of the coast. Away from these areas, in the desert regions of the Basin, temporary water-bores were drilled to provide water for the drilling of petroleum exploration wells and the various seismic surveys. The groundwater potential in some areas is excellent. However, the only region where the groundwater has been adequately and systematically tested is near the southwestern margin of the Basin. There, drilling and pump tests indicate the presence of two aquifer systems, one in the Wallal Sandstone and the other within the Callawa Formation and Quaternary sequence (Leech, 1974, 1979).

Salinity measurements (Crowe & Towner, 1981; Gibson & Crowe, 1982; Towner, 1981) from numerous station bores and wells, particularly in the north, indicate that good water may be present in the Grant Group, parts of the Liveringa Group, Erskine Sandstone, and in some parts of the Devonian reef complex. Other water-bearing formations, e.g. Tandalgoo Sandstone, are too deep to be of interest as a water source for stock.

Valley calcrete bodies in the west and south of the Basin are also attractive targets for water. They are easy to locate on the ground and on aerial photographs because they occur along present-day and relict drainages; their thicknesses rarely exceed a few tens of metres, and the water is normally contained in fractures and vughs. Some calcretes cap and confine aquifers immediately below them. The calcrete bodies were the site for many of the Canning Stock Route wells, the conditions of which are reported in Yeates & others (1975a) and Towner & others (1976).

6. REFERENCES

AAP (Australian Aquitaine Petroleum Pty Ltd), 1965—Pollock Hills aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4619 (unpublished).

AAP, 1968—Dakota seismic and gravity survey, W.A., final report. *Bureau of Mineral Resources, Australia*, File 67/11161 (unpublished).

AAP, 1969a—Ryan seismic and gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 68/3026 (unpublished).

AAP, 1969b—Contention Heights seismic refraction survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3036 (unpublished).

AAP, 1969c—Baron Range seismic and gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3052 (unpublished).

AAP, 1971—Stretch Range seismic and gravity survey. *Bureau of Mineral Resources, Australia*, File 70/600 (unpublished).

AAP, 1972—White Hills area high sensitivity aeromagnetic survey. *Bureau of Mineral Resources, Australia*, File 71/508 (unpublished).

AAP, 1973—Hickey Hills reflection seismic survey. *Bureau of Mineral Resources, Australia*, File 72/2761 (unpublished).

Amax Petroleum (Australia) Inc., 1974—Wamac No. 1 well completion report. *Bureau of Mineral Resources, Australia*, File 73/246 (unpublished).

Associated Australian Oilfields NL, 1972—Billiluna-Helena aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 71/422 (unpublished).

Associated Australian Oilfields NL, 1974—Thornton seismic survey. *Bureau of Mineral Resources, Australia*, File 72/3362 (unpublished).

Austin, P. M., & Williams, G. E., 1978—Tectonic development of Late Precambrian to Mesozoic Australia through plate motions possibly influenced by the Earth's rotation. *Journal of the Geological Society of Australia*, 25(1), 1-22.

Baarda, F. D., 1967—Geological report on coal investigations, West Kimberley area, Western Australia—Temporary Reserves Nos 3426H-3434H and 3754H. *Premier Mining Pty Ltd, Company Report* (unpublished).

Balme, B. E., 1962—Palynological report on samples from Frome Rocks No. 2 well. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 8, 23-25.

Balme, B. E., 1969—The Permian-Triassic boundary in Australia. *Geological Society of Australia, Special Publication* 2, 99-112.

Baxter, J. L., 1977—Heavy mineral sand deposits of Western Australia. *Geological Survey of Western Australia, Mineral Resources Bulletin* 10.

Bird, K. J., 1968—Doran No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 68/2033 (unpublished).

Bird, K. J., 1969—Chirup No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

Bischoff, G., 1968—Yulleroo No. 1 well completion report (Gewerkschaft Elwerath Inc.). *Bureau of Mineral Resources, Australia*, File 67/4249 (unpublished).

Blake, D. H., 1977—Webb, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-10.

Blake, D. H., & Yeates, A. N., 1976—Stansmore, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-6.

Blake, D. H., Hodgson, I. M., & Muhling, P. C., 1973—Geology of The Granites and Precambrian parts of Billiluna, Lucas and Stansmore 1:250 000 Sheet areas, Northern Territory and Western Australia. *Bureau of Mineral Resources, Australia, Record* 1973/171 (unpublished).

Blake, D. H., Passmore, V. L., & Muhling, P. C., 1977—Billiluna, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/52-14.

Blake, D. H., Hodgson, I. M., & Muhling, P. C., 1979—Geology of The Granites-Tanami region, Northern Territory and Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 197.

Blatchford, T., 1922—Petroleum indications in the Kimberley Division. *Geological Survey of Western Australia, Annual Report for 1921*, 19-24.

Blatchford, T., 1927—The geology of portions of the Kimberley Division, with special reference to the Fitzroy Basin and the possibilities of the occurrence of mineral oil. *Geological Survey of Western Australia, Bulletin* 93.

Blatchford, T., 1929—Boring for mineral oil at Poole Range (Freney Kimberley Oil Co.). *Geological Survey of Western Australia, Annual Report for 1928*, 5.

Blatchford, T., 1930—Boring for mineral oil at Poole Range. *Geological Survey of Western Australia, Annual Report for 1929*, 10.

BOCAL (Burmah Oil Company of Australia Ltd), 1970—Lacepede No. 1A well completion report. *Bureau of Mineral Resources, Australia*, File 70/426 (unpublished).

BOCAL, 1971—Bedout No. 1 well completion report. *Bureau of Mineral Resources, Australia*, File 71/435 (unpublished).

Broad, D. S., & McDermott, R. J., 1974—Jones Range No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

Brown, R., & Campbell, N., 1974—Contention Heights No. 1 well completion report (Australian Aquitaine Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 73/230 (unpublished).

Brunnschweiler, R. O., 1954—Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. *Journal of the Geological Society of Australia*, 1, 35-54.

Brunnschweiler, R. O., 1957—The geology of Dampier Peninsula, Western Australia. *Bureau of Mineral Resources, Australia, Report* 13.

Burne, R. V., & Crowe, R. W. A., 1977—Aeolianites in the Jurassic Jurgurra Sandstone, Canning Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics*, 2(4), 314-317.

Burne, R. V., & Kantsler, A. J., 1977—Geothermal constraints on the hydrocarbon potential of the Canning Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics*, 2(4), 271-288.

Burne, R. V., Gorter, J. D., & Saxby, J. D., 1979—Source rocks and hydrocarbon potential of the Palaeozoic in the onshore Canning Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics*, 4, 125-133.

Casey, J. N., 1957—Anketell—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-2.

Casey, J. N., 1958a—Derby—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-7.

Casey, J. N., 1958b—Mt Anderson—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-11.

Casey, J. N., & Wells, A. T., 1964—The geology of the north-east Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Report* 49.

Chin, R. J., Hickman, A. H., & Towner, R. R., 1982—Paterson Range, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-6.

Chin, R. J., Williams, I. R., & Williams, S. J., in preparation—Explanatory notes on the Rudall 1:250 000 Geological Sheet. *Geological Survey of Western Australia, Record* (unpublished).

CONTINENTAL (CONTINENTAL OIL COMPANY OF AUSTRALIA LTD), 1964—St George Range seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 64/4548 (unpublished).

CONTINENTAL, 1965a—Poole Range detail 'Vibroseis' project, final report. *Bureau of Mineral Resources, Australia*, File 65/11001 (unpublished).

CONTINENTAL, 1965b—Crossland seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/11012 (unpublished).

CONTINENTAL, 1965c—Broome Swell seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/11006 (unpublished).

CONTINENTAL, 1965d—Barbwire Range seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/11041 (unpublished).

CONTINENTAL, 1968—Noonkanbah gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 67/4834 (unpublished).

CRANK, K., 1971—Tappers Inlet No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 71/301 (unpublished).

CRANK, K., 1972—Lake Betty No. 1 well competion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 71/441 (unpublished).

CREEVEY, K. J., 1969—Wilson Cliffs No. 1 well completion report (Australian Aquitaine Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 68/2011 (unpublished).

CROWE, R. W. A., 1975—The classification, genesis and evolution of sand dunes in the Great Sandy Desert. *Geological Survey of Western Australia, Annual Report for 1974*, 46-49.

CROWE, R. W. A., 1978—Cornish, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-1.

CROWE, R. W. A., 1979—Morris, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-16.

CROWE, R. W. A., & CHIN, R. J., 1979—Runton, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-15.

CROWE, R. W. A., & MUHLING, P. C., 1977—Lucas, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-2.

CROWE, R. W. A., & TOWNER, R. R., 1976a—Permian depositional history of the Noonkanbah 1:250 000 Sheet area, W.A. *Bureau of Mineral Resources, Australia, Record* 1976/24 (unpublished).

CROWE, R. W. A., & TOWNER, R. R., 1976b—Environmental interpretation of the Permian Nura Nura Member of the Poole Sandstone, Noonkanbah Sheet area, Canning Basin: a gradation between fluviatile and shallow-water marine facies. *Geological Survey of Western Australia, Annual Report for 1975*, 59-62.

CROWE, R. W. A., & TOWNER, R. R., 1976c—Permian stratigraphic nomenclature, Noonkanbah 1:250 000 Sheet. *Geological Survey of Western Australia, Annual Report for 1975*, 56-58.

CROWE, R. W. A., & TOWNER, R. R., 1976d—Definitions of some new and revised rock units in the Canning Basin. *Geological Survey of Western Australia, Record* 1976/24 (unpublished).

CROWE, R. W. A., & TOWNER, R. R., 1981—Noonkanbah, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-12.

CROWE, R. W. A., TOWNER, R. R., & GIBSON, D. L., 1978—Permian and Mesozoic geology of the Derby and Mount Anderson 1:250 000 Sheet areas, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1978/8 (unpublished).

DARBY, F., & FRASER, A. R., 1969—Reconnaissance helicopter gravity survey, Canning Basin, W.A., 1968. *Bureau of Mineral Resources, Australia, Record* 1969/37 (unpublished).

DE LA HUNTY, L. E., 1962—Report on some limonitic iron ore deposits in the vicinity of Port Hedland, Pilbara Goldfield, W.A. *Geological Survey of Western Australia, Annual Report for 1960*, 15-21.

DERRICK, G. M., & GELLATLY, D. C., 1972—New leucite lamproites from the West Kimberley, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 125, 103-120.

DERRICK, G. M., & PLAYFORD, P. E., 1973—Lennard River, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-8.

DICKINS, J. M., in preparation—Report on fossils collected in the northeast Canning Basin during 1973.

DICKINS, J. M., & JELL, P. A., 1974—Permian fossils from the Canning Basin, 1971 and 1972. *Bureau of Mineral Resources, Australia, Record* 1974/77 (unpublished).

DICKINS, J. M., TOWNER, R. R., & CROWE, R. W. A., 1977—A Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia. *Journal of the Palaeontological Society of India*, 20, 275-278.

DOOLEY, J. C., 1963—Onslow/Derby regional gravity traverse, W.A., 1953. *Bureau of Mineral Resources, Australia, Record* 1963/13 (unpublished).

DOUTCH, H. F., & NICHOLAS, E., 1978—The Phanerozoic sedimentary basins of Australia and their tectonic implications. *Tectonophysics*, 48, 365-388.

DOW, D. B., & GEMUTS, I., 1969—Geology of the Kimberley region, Western Australia: the east Kimberley. *Bureau of Mineral Resources, Australia, Bulletin* 106.

DRUCE, E. C., & RADKE, B. M., 1979—The Geology of the Fairfield Group, Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 200.

EDWARDS, A. B., 1953—Oolitic iron formation from northwest Western Australia. *CSIRO, Melbourne, Mineragraphic Investigations Report* 540.

ELLIOTT, R. M. L., 1959—Goldwyer No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

ELLIOTT, R. M. L., 1961—New and amended Formation names. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 14, 37-43.

ELLIOTT, R. M. L., & WILLMOTT, S. P., 1962—Frome Rocks No. 1 and No. 2 wells, Western Australia, of West Australian Petroleum Pty Limited. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 8.

EMBLETON, B. J. J., 1973—The palaeolatitude of Australia through Phanerozoic time. *Journal of the Geological Society of Australia*, 19, 475-482.

EVANS, P. R., 1966—Mesozoic stratigraphic palynology in Australia. *Australasian Oil and Gas Journal*, 12, 58-63.

EVERINGHAM, I. B., 1962—Poole Range gravity survey, Western Australia 1953. *Bureau of Mineral Resources, Australia, Record* 1962/91 (unpublished).

EVERINGHAM, I. B., 1965—Poole Range gravity survey, Western Australia 1953. *Bureau of Mineral Resources, Australia, Report* 97.

FEEKEN, E. H. J., FEEKEN, G. E. E., & SPATE, D. H. K., 1970—THE DISCOVERY AND EXPLORATION OF AUSTRALIA. *Nelson, Sydney*.

FLAVELLE, A. J., 1974—Canning Basin gravity surveys 1953-1962. *Bureau of Mineral Resources, Australia, Record* 1974/181 (unpublished).

FLAVELLE, A. J., & GOODSPEED, M. J., 1962—Fitzroy and Canning Basins, reconnaissance gravity surveys, Western Australia 1952-1960. *Bureau of Mineral Resources, Australia, Record* 1962/105 (unpublished).

FORMAN, D. J., & WALES, D. W. (Compilers), 1981—Geological evolution of the Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 210.

FRASER, A. R., 1974—Reconnaissance helicopter gravity survey of the northwest of Western Australia, 1969. *Bureau of Mineral Resources, Australia, Record* 1974/27 (unpublished).

FRASER, A. R., 1976—Gravity provinces and their nomenclature. *BMR Journal of Australian Geology & Geophysics*, 1(4), 350-352.

FREAS, D. H., & ZIMMERMAN, D. O., 1965—Geological evaluation for phosphate exploration of the Canning, Ord River and Bonaparte Gulf Basins of northwestern Australia. *IMC Development Corporation, Report No.* 7 (unpublished).

FRENCH PETROLEUM (FRENCH PETROLEUM COMPANY (AUSTRALIA) PTY LTD), 1967—Jarmura helicopter and land gravity survey, final report. *Bureau of Mineral Resources, Australia,* File 67/4832 (unpublished).

FRENCH PETROLEUM, 1968—Geograph reflection/refraction seismograph and gravity survey of McLarty prospect, Western Australia. *Bureau of Mineral Resources, Australia,* File 67/11145 (unpublished).

GALLOWAY, M. C., & HOWELL, D. J., 1975—Relinquishment report of TR5851H to 5856H, 5878H to 5880H, Fitzroy Trough, Western Australia. *Esso Exploration and Production Australia Incorporated, and Dampier Mining Company, Company Report* (unpublished).

GARDINER, J. E., 1977—Heavy-mineral sand deposits along the coast of Western Australia. *Bureau of Mineral Resources, Australia, Record* 1977/34 (unpublished).

GARDNER, W. E., 1962—Babrongan No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 62/1090 (unpublished).

GARDNER, W. E., 1963a—Langoora No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 62/1094 (unpublished).

GARDNER, W. E., 1963b—Hawkstone Peak No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 62/1093 (unpublished).

GELLATLY, D. C., & SOFOULIS, J., 1973—Yampi, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-3.

GEOSURVEYS, 1964—Stansmore Range gravity survey, final report. *Bureau of Mineral Resources, Australia,* File 64/4807 (unpublished).

GEWERKSCHAFT ELWERATH INC., 1966—Lower Fitzroy reflection seismic and magnetometer survey, final report. *Bureau of Mineral Resources, Australia,* File 66/11111 (unpublished).

GIBSON, D. L., 1982—McLarty Hills, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-15.

GIBSON, D. L., in preparation a—Pender, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-2.

GIBSON, D. L., in preparation b—Broome, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-6.

GIBSON, D. L., in preparation c—Lagrange, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-10.

GIBSON, D. L., & CROWE, R. W. A., 1982—Mount Anderson, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-11.

GLAUERT, L., 1921—Pleistocene fossil vertebrates from the Fitzroy River, West Kimberley, W.A. *Journal of the Royal Society of Western Australia,* 7, 85-86.

GLENISTER, B. F., 1962—*Clymenia* and conodonts from Frome Rocks No. 2 well. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 8, 32-34.

GLOVER, J. E., 1973—Petrology of the halite-bearing Carribuddy Formation, Canning Basin, Western Australia. *Journal of the Geological Society of Australia,* 20(3), 343-359.

GOODEVE, P. E., 1961—Rawlinson Range–Young Range aeromagnetic reconnaissance survey, W.A. 1960. *Bureau of Mineral Resources, Australia, Record* 1961/137 (unpublished).

GORTER, J. D., 1978—Triassic environments in the Canning Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics,* 3, 25-33.

GORTER, J. D., RASIDI, J. S., TUCKER, D. H., BURNE, R. V., PASSMORE, V. L., WALES, D. W., & FORMAN, D. J., 1979—Petroleum Geology of the Canning Basin. *Bureau of Mineral Resources, Australia, Record* 1979/32 (unpublished).

GSA (GEOLOGICAL SOCIETY OF AUSTRALIA), 1971—Tectonic map of Australian and New Guinea 1:5 000 000. *Geological Society of Australia Incorporated, Sydney.*

GUPPY, D. J., & ÖPIK, A. A., 1950—Discovery of Ordovician rocks, Kimberley Division, W.A. *Australian Journal of Science,* 12(6), 205-206.

GUPPY, D. J., LINDNER, A. W., RATTIGAN, J. H., & CASEY, J. N., 1952—The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. *Nineteenth International Geological Congress, Algeria, Gondwana Symposium,* 101-114.

GUPPY, D. J., LINDNER, A. W., RATTIGAN, J. H., & CASEY, J. N., 1958—The geology of the Fitzroy Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 36.

HACKATHORN NEW ZEALAND OILS LTD & AUSTRALIAN OIL CORPORATION, 1963—Stansmore Range aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia,* File 63/1700 (unpublished).

HALLIGAN, R., 1965—The Narlarla lead-zinc deposits, Barker River area, West Kimberley Goldfield. *Geological Survey of Western Australia, Annual Report for 1964,* 43-45.

HARMS, J. E., & MORGAN, B. D., 1964—Pisolitic limonite deposits in northwest Australia. *Proceedings of the Australasian Institute of Mining and Metallurgy,* 212, 91-124.

HAWKSTONE OIL CO. LTD, 1962—Alexander Creek gravity meter survey, final report. *Bureau of Mineral Resources, Australia,* File 62/1934 (unpublished).

HEMATITE PETROLEUM PTY LTD, 1974—Keraudren No. 1 well completion report. *Bureau of Mineral Resources, Australia,* File 73/240 (unpublished).

HENDERSON, S. D., 1956a—Lithological log, Bore BMR 2, Laurel Downs, Fitzroy Basin, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1956/49 (unpublished).

HENDERSON, S. D., 1956b—Stratigraphic bore BMR 3, Prices Creek, Fitzroy Basin, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1956/96 (unpublished).

HENDERSON, S. D., CONDON, M. A., & BASTIAN, L. V., 1963—Stratigraphic drilling, Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Report* 60.

HICKMAN, A. H., & GIBSON, D. L., 1982—Port Hedland-Bedout Island, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/50-4 and part SE/50-16.

HICKMAN, A. H., CHIN, R. J., & GIBSON, D. L., in preparation—Yarrie, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-1.

HILL, W. G., 1955—Final report on the Nerrima No. 1 exploration well. *Associated Freney Oilfields NL, Company Report* (unpublished).

HILL, W. G., 1956—Myroodah No. 1 exploration well, final report. *Associated Freney Oilfields NL, Company Report* (unpublished).

HILL, W. G., 1957—Final report on The Sisters No. 1 exploration well. *Associated Freney Oilfields NL, Company Report* (unpublished).

HORSTMAN, E. L., LYONS, D. A., NOTT, S. A., & BROAD, D. S., 1976—Canning Basin, onshore. *In* LESLIE, R. B., EVANS, H. J., & KNIGHT, C. L. (Editors)—ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA—3. PETROLEUM. *Australasian Institute of Mining and Metallurgy, Monograph* 7, 170-184.

HOWARD, P. F., 1972—Exploration for phosphate in Australia. *Economic Geology*, 67, 1180-1192.

JACKSON, M. J., & VAN DE GRAAFF, W. J. E., 1981—Geology of the Officer Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 206.

JACQUE, M., LESLIE, W., & TRICOT, P., 1968a—Edgar Range No. 1 well completion report (Total Exploration Australia Pty Ltd). *Bureau of Mineral Resources, Australia*, File 68/2041 (unpublished).

JACQUE, M., SWEENEY, P. J., & TRICOT, P., 1968b—McLarty No. 1 well completion report (Total Exploration Australia Pty Ltd). *Bureau of Mineral Resources, Australia*, File 68/2009 (unpublished).

JACQUE, M., LESLIE, W., SWEENEY, P. J., & TRICOT, P., 1969a—Kemp Field No. 1 well completion report (Total Exploration Australia Pty Ltd). *Bureau of Mineral Resources, Australia*, File 68/2048 (unpublished).

JACQUE, M., STOBEL, P., & SWEENEY, P. J., 1969b—Mowla No. 1 well completion report (Total Exploration Australia Pty Ltd). *Bureau of Mineral Resources, Australia*, File 69/2039 (unpublished).

JACQUE, M., STOBEL, P., & SWEENEY, P. J., 1970—Matches Springs No. 1 well completion report (Total Exploration Australia Pty Ltd). *Bureau of Mineral Resources, Australia*, File 69/2023 (unpublished).

JOHNSON, N. E. A., 1966a—Willara No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources Australia*, File 65/4158 (unpublished).

JOHNSON, N. E. A., 1966b—Kidson No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 65/4177 (unpublished).

JOHNSON, N. E. A., 1968—Blackstone No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 67/4262 (unpublished).

JOHNSON, N. E. A., & BROWNHILL, M. H., 1967—May River No. 1 well competion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 67/4252 (unpublished).

JOHNSTONE, M. H., 1961—Samphire Marsh No. 1 well, Western Australia, of West Australian Petroleum Pty Ltd. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 5.

KAPLAN, G., FAURE, D., ELLOY, R., & HEILAMMER, R., 1967—Contribution a l'etude de l'origine des lamproites. *Centre de Recherches de Pau, Bulletin* 1, 153-159.

KEMP, E., 1976—Palynological observations in the Officer Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 160, 23-39.

KOOP, W. J., 1966—Recent contributions to Palaeozoic geology in the South Canning Basin, Western Australia. *APEA Journal*, 6, 105-109.

LABOUYSSE, M., & MICHOUD, P., 1966—Point Moody No. 1 well completion report (Australian Aquitaine Petroleum). *Bureau of Mineral Resources, Australia*, File 65/4174 (unpublished).

LEECH, R. E. J., 1974—West Canning Basin groundwater investigation progress report. *Geological Survey of Western Australia, Record* 1974/18 (unpublished).

LEECH, R. E. J., 1979—Geology and groundwater resources of the southwestern Canning Basin, Western Australia. *Geological Survey of Western Australia, Record* 1979/9 (unpublished).

LENNARD OIL N.L., 1969—Alexander seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3057 (unpublished).

LENNARD OIL N.L., 1970—Alexander II seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/449 (unpublished).

LINDNER, A. W., 1961—Definitions of new formation names. Bossut Formation. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 5, 15.

LLOYD, A. R., 1963—Probable radiolaria from the Lower Cretaceous Bejah Beds, Gibson Desert, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1963/30 (unpublished).

LONSDALE, G. F., & FLAVELLE, A. J., 1963—Amadeus and South Canning Basins reconnaissance gravity survey using helicopters, NT and WA 1962. *Bureau of Mineral Resources, Australia, Record* 1963/152 (unpublished).

LONSDALE, G. F., & FLAVELLE, A. J., 1968—Amadeus and south Canning Basins gravity survey, Northern Territory and Western Australia 1962. *Bureau of Mineral Resources, Australia, Report* 133.

LOW, G. H., 1965—Port Hedland, Western Australia—1:250 000 Geological Series. *Geological Survey of Western Australia, Explanatory Notes* SF/50-4.

LOWRY, D. C., JACKSON, M. J., VAN DE GRAAFF, W. J. E., & KENNEWELL, P. J., 1972—Preliminary results of geological mapping in the Officer Basin, Western Australia, 1971. *Geological Survey of Western Australia, Annual Report for 1971*, 50-56.

MACLEOD, W. N., 1966—The geology and iron deposits of the Hamersley Range area, Western Australia. *Geological Survey of Western Australia, Bulletin* 117.

MAITLAND, A. G., 1904—Preliminary report on the geological features and mineral resources of the Pilbara Goldfields. *Geological Survey of Western Australia, Bulletin* 15.

MAYNE, S. J., 1975—History of petroleum search in the Canning Basin, Western Australia, to 31 December 1974. *Bureau of Mineral Resources, Australia, Record* 1975/109 (unpublished).

MCKELLAR, M. G., 1957—Dampier Downs No. 1 geological well summary. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

MCKENZIE, K. G., 1961—Vertebrate localities in the Triassic Blina Shale of the Canning Basin, Western Australia. *Journal of the Royal Society of Western Australia*, 44(3), 69-76.

MCTAVISH, R. A., & LEGG, D. P., 1976—The Ordovician of the Canning Basin, Western Australia. *In* BASSETT, M. G. (Editor)—THE ORDOVICIAN SYSTEM. *University of Wales Press and Natural Museum of Wales, Cardiff*, 447-478.

MCWHAE, J. R. H., PLAYFORD, P. E., LINDNER, A. W., GLENISTER, B. F., & BALME, B. E., 1958—The stratigraphy of Western Australia. *Journal of the Geological Society of Australia*, 4(2).

MEATH, J. R., 1972—Pender No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 72/2000 (unpublished).

MEATH, J. R., & SCOTT, R. J., 1972—Logue No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 71/479 (unpublished).

MINES ADMINISTRATION PTY LTD, 1962—Blackstone seismic survey, The Sisters area, final report. *Bureau of Mineral Resources, Australia*, File 62/1598 (unpublished).

MOYES, C. P., 1972—Munda No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 71/475 (unpublished).

NEWSTEAD, P. G., 1969—Napier No. 1 well completion report (Lennard Oil NL). *Bureau of Mineral Resources, Australia*, File 69/2015 (unpublished).

NICOLL, R. S., & DRUCE, E. C., 1979—Conodonts from the Fairfield Group, Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 190.

NOLDART, A. J., & WYATT, J. D., 1962—The geology of portion of the Pilbara Goldfield covering the Marble Bar and Nullagine 4 mile map sheets. *Geological Survey of Western Australia, Bulletin* 115.

OIL DEVELOPMENT NL, 1962—Napier Downs gravity meter survey, final report. *Bureau of Mineral Resources, Australia*, File 62/1931 (unpublished).

OSBORNE, D. G., 1972—Palm Springs No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 72/2002 (unpublished).

OSBORNE, D. G., & O'SHAUGHNESSY, P. R., 1973—Mimosa No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 73/233 (unpublished).

PATEN, R. J., EVANS, G. R., & BROWN, L. N., 1972—Exploration Permits E.P. 58 and 59 (W.A.). Report on the 1972 field mapping programme. *Mines Administration Pty Ltd, Company Report* (unpublished).

PICKERING, R., 1967—Report on coal exploration in Temporary Reserves 3517H, 3518H, 3570H, 3571H, West Kimberley District, Western Australia. *Theiss Brothers Pty Ltd, Company Report* (unpublished).

PICKERING, R., 1968—Report on coal exploration in Temporary Reserves 3518H, 3571H, and 3896H, West Kimberley District, Western Australia. *Theiss Brothers Pty Ltd, Company Report* (unpublished).

PLAYFORD, P. E., 1957—Derby town, Myalls and Broome water bores, Canning Basin, Western Australia. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

PLAYFORD, P. E., 1967—Devonian reef complexes in the northern Canning Basin, Western Australia. *In* International Symposium on the Devonian System, Volume 2. *Alberta Society of Petroleum Geologists,* 351-364.

PLAYFORD, P. E., 1976—Devonian Reef Complexes of the Canning Basin, Western Australia. *25th International Geological Congress, Excursion Guide* 38A.

PLAYFORD, P. E., 1980—Devonian 'Great Barrier Reef' of Canning Basin, Western Australia. *Bulletin of the American Association of Petroleum Geologists,* 64(6), 814-840.

PLAYFORD, P. E., & LOWRY, D. C., 1966—Devonian reef complexes of the Canning Basin, Western Australia. *Geological Survey of Western Australia, Bulletin* 118.

PLAYFORD, P. E., COPE, R. N., COCKBAIN, A. E., LOW, G. H., & LOWRY, D. C., 1975—Canning Basin. *In* The Geology of Western Australia. *Geological Survey of Western Australia, Memoir* 2, 319-368.

POWELL, T. G., & MCKIRDY, D. M., 1976—Geochemical character of crude oils from Australia and Papua New Guinea. *In* LESLIE, R. B., EVANS, H. J., & KNIGHT, C. L. (Editors)—ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA—3. PETROLEUM. *Australasian Institute of Mining and Metallurgy, Monograph* 7, 18-29.

PRICE, P. L., 1973—Permian palynostratigraphy, Denison Trough area. A to P 119P, Bowen Basin, Queensland. *Mines Administration Pty Ltd, Palynological Report* 17/3 (unpublished).

PRIDER, R. T., 1960—The leucite lamproites of the Fitzroy Basin, Western Australia. *Journal of the Geological Society of Australia,* 6(2), 71-118.

PUDOVSKIS, V., 1962—Meda No. 1 well, Western Australia, of West Australian Petroleum Pty Limited. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 7.

PUDOVSKIS, V., & CARTER, T. H., 1961—Barlee No. 1 well completion report, of West Australian Petroleum Pty Ltd. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 16.

PUDOVSKIS, V., & WILLMOTT, S. P., 1961—Thangoo No. 1 and No. 1A wells, Western Australia, of West Australian Petroleum Pty Limited. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 14.

QUILTY, J. H., 1960—Canning Basin aeromagnetic reconnaissance survey, 1954. *Bureau of Mineral Resources, Australia, Record* 1960/11 (unpublished).

QUINTON, R. G., 1974—Report on geological investigations within Temporary Reserves 5679H and 5693H, Canning Basin, Western Australia. *Conzinc Riotinto of Australia Pty Ltd, Company Report* (unpublished).

RADKE, B. M., 1976—Hierarchical classification and vector ordination in the distinction of limestones in the Fairfield Group, Canning Basin, Western Australia. *BMR Journal of Australian Geology & Geophysics,* 1(1), 63-76.

RAINE, M. J., 1970—Bibliography of the Canning Basin, Western Australia (to 31.12.69). *Bureau of Mineral Resources, Australia, Record* 1970/9 (unpublished).

RATTIGAN, J. H., 1967—Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia. *Proceedings of the Australasian Institute of Mining and Metallurgy,* 223, 17-22.

READ, J. F., 1973a—Palaeoenvironments and palaeogeography, Pillara Formation (Devonian), Western Australia. *Bulletin of Canadian Petroleum Geology,* 21(3), 344-394.

READ, J. F., 1973b—Carbonate cycles, Pillara Formation (Devonian), Canning Basin, Western Australia. *Bulletin of Canadian Petroleum Geology,* 21(1), 38-51.

REEVES, F., 1949—Geology and oil prospects of the Desert Basin, Western Australia. *Vacuum Oil Company, Company Report* (unpublished).

REEVES, F., 1951—Australian oil possibilities. *Bulletin of the American Association of Petroleum Geologists,* 35(12), 2479-2525.

REID, A. G., 1968—Willara Hill No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 68/2044 (unpublished).

ROBERTS, H. G., HALLIGAN, R., & PLAYFORD, P. E., 1968—Mount Ramsay, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/52-9.

SHANNON, P. H., & HENDERSON, S. W., 1966—St George Range No. 1 well completion report (Continental Oil Company of Australia Pty Ltd). *Bureau of Mineral Resources, Australia,* File 65/4170 (unpublished).

SHAW, R. D., & STEWART, A. J., 1975—Arunta Block regional geology. *In* KNIGHT, C. L. (Editor)—ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA—1. METALS. *Australasian Institute of Mining and Metallurgy, Monograph* 5, 437-442.

SHELL DEVELOPMENT (AUSTRALIA) PTY LTD, 1973—East Mermaid No. 1 well completion report. *Bureau of Mineral Resources, Australia,* File 73/1003 (unpublished).

SINGLETON, A. E., 1965—Sahara No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia,* File 64/4129 (unpublished).

SKWARKO, S. K., 1967—Lower Cretaceous Mollusca of the Great Artesian Basin type in the Gibson Desert, central Western Australia. *In* SKWARKO, S. K.—Mesozoic Mollusca from Australia and New Guinea. *Bureau of Mineral Resources, Australia, Bulletin* 75, 1-35.

SKWARKO, S. K., 1970—Aptian (Lower Cretaceous) *'Apiotrigonia'* from the Melligo Quartzite, Dampier Peninsula, Western Australia. *In* Palaeontological papers 1967. *Bureau of Mineral Resources, Australia, Bulletin* 108, 227-235.

SMITH, D. N., & WILLIAMS, F. B., 1955—The geology of the Edgar Ranges–Matches Springs area. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

SMITH, E. R., 1955—Progress report on a seismic survey of the Poole Ranges–Prices Creek area, Kimberley Division, W.A. *Bureau of Mineral Resources, Australia, Record* 1955/35 (unpublished).

SMITH, E. R., 1957—Seismic refraction traverse in the Christmas Creek area, Kimberley Division, W.A. *Bureau of Mineral Resources, Australia, Record* 1957/37 (unpublished).

SMITH, E. R., 1960—La Grange seismic reflection survey, W.A. 1955. *Bureau of Mineral Resources, Australia, Record* 1960/49 (unpublished).

SMITH, E. R., 1961—Broome seismic reflection survey, W.A. 1954–55. *Bureau of Mineral Resources, Australia, Record* 1961/57 (unpublished).

SMITH, E. R., 1977—Australia's onshore basins: their petroleum prospects and future exploration programmes. *APEA Journal*, 17(2), 17-23.

SMITH, J. G., 1968—Tectonics of the Fitzroy Wrench Trough, Western Australia. *American Journal of Science*, 266, 766-776.

TALBOT, H. W. B., 1920—Geology and mineral resources of the North-west, Central and Eastern Divisions. *Geological Survey of Western Australia, Bulletin* 83.

TEMPLE, P. R., 1970—Napier No. 4 well completion report (Lennard Oil NL). *Bureau of Mineral Resources, Australia*, File 70/589 (unpublished).

THOMAS, G. A., 1958—Noonkanbah—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes*, SE/51-12.

THOMAS, G. A., 1959—The Lower Carboniferous Laurel Formation of the Fitzroy Basin. *Bureau of Mineral Resources, Australia, Report* 38, 21-36.

THOMAS, B. M., & CALDWELL, R. H., 1971—Crossland 1, 2 and 3 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 71/465 (unpublished).

TOTAL EXPLORATION AUSTRALIA, 1969—Digital reflection seismograph survey, Matches Springs project, Permit 259H. *Bureau of Mineral Resources, Australia*, File 69/3028 (unpublished).

TOWNER, R. R., 1977—Crossland, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-16.

TOWNER, R. R., 1978a — Ural, Western Australia — 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-12.

TOWNER, R. R., 1978b—Wilson, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-9.

TOWNER, R. R., 1978c—Ryan, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-13.

TOWNER, R. R., 1981—Derby, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-7.

TOWNER, R. R., 1982a—Anketell, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-2.

TOWNER, R. R., 1982b—Joanna Spring, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-3.

TOWNER, R. R., 1982c—Mandora, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-13.

TOWNER, R. R., 1982d—Munro, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-14.

TOWNER, R. R., & GIBSON, D. L., 1980—Geology of Late Carboniferous and younger rocks on the onshore western Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1980/30 (unpublished).

TOWNER, R. R., CROWE, R. W. A., & YEATES, A. N., 1976—Notes on the geology of the southern part of the Canning Basin. *Bureau of Mineral Resources, Australia, Record* 1976/95 (unpublished).

TRAVES, D. M., CASEY, J. N., & WELLS, A. T., 1956—The geology of the southwestern Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Report* 29.

UNION OIL COMPANY OF CALIFORNIA, 1965—Gibson Desert aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4610 (unpublished).

VALE, K. R., & SMITH, E. R., 1956—Seismic reflection traverse west of Langey's Crossing, Kimberley Division, W.A. *Bureau of Mineral Resources, Australia, Record* 1956/112 (unpublished).

VALE, K. R., & SMITH, E. R., 1959—A seismic investigation of the Fenton Fault at Barnes Flow, Canning-Fitzroy Basins, Kimberley Division, W.A. *Bureau of Mineral Resources, Australia, Record* 1959/63 (unpublished).

VALE, K. R., & WILLIAMS, L. W., 1955—Preliminary seismic reflection investigation, Broome area, Kimberley Division, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1955/112 (unpublished).

VALE, K. R., SMITH, E. R., & GARRETT, M. J., 1953—Seismic survey of the Nerrima Dome, Kimberley Division, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1953/72 (unpublished).

VEEVERS, J. J., 1958—Lennard River—4-mile Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/51-8.

VEEVERS, J. J., & WELLS, A. T., 1961—The geology of the Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Bulletin* 60.

WADE, A., 1936—The geology of the West Kimberley district of Western Australia. *Freney Kimberley Oil Co., Company Report* (unpublished).

WADE, A., 1938—The geological succession in the West Kimberley district of Western Australia. *Australian and New Zealand Association for the Advancement of Science, Report* 23, 93-96.

WADE, A., & PRIDER, R. T., 1940—The leucite-bearing rocks of the West Kimberley area, Western Australia. *Quarterly Journal of the Geological Society of London*, 96, 39-98.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1956a—Grant Range No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1956b—Fraser River Corehole No. 1. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1956c—Fraser River No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1956d—Roebuck Bay No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1957—Wallal Core Hole No. 1 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1959—Meda No. 2 well completion report. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1962a—Blue Hills-Logue Seismic survey, Western Australia, 1959-60. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 36.

WAPET, 1962b—Dampier Fault seismograph reflection survey, final report. *Bureau of Mineral Resources, Australia*, File 62/1520 (unpublished).

WAPET, 1962c—Hawkstone Peak seismic and gravity survey. *Bureau of Mineral Resources, Australia*, File 62/1608 (unpublished).

WAPET, 1962d—Laurel Downs seismic survey. *Bureau of Mineral Resources, Australia*, File 62/1620 (unpublished).

WAPET, 1962e—Laurel Downs-Virgin Hills gravity survey. *Bureau of Mineral Resources, Australia*, File 62/1928 (unpublished).

WAPET, 1963a—Goorda-Logue seismic survey. *Bureau of Mineral Resources, Australia*, File 63/1526 (unpublished).

WAPET, 1963b—Gogo seismic survey. *Bureau of Mineral Resources, Australia*, File 63/1531 (unpublished).

WAPET, 1963c—Sahara seismic reconnaissance survey. *Bureau of Mineral Resources, Australia*, File 63/1539 (unpublished).

WAPET, 1963d—Sahara regional gravity survey, Canning Basin. *Bureau of Mineral Resources, Australia*, File 63/1910 (unpublished).

WAPET, 1963e—South Canning Basin aeromagnetic survey. *Bureau of Mineral Resources, Australia*, File 62/1728 (unpublished).

WAPET, 1964a—Balgo-Lake Betty seismograph survey. *Bureau of Mineral Resources, Australia*, File 63/1533 (unpublished).

WAPET, 1964b—Parda seismic survey. *Bureau of Mineral Resources, Australia*, File 64/4524 (unpublished).

WAPET, 1964c—Barlee Gravity Survey, Western Australia, 1959. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 38.

WAPET, 1964d—Lake Betty reconnaissance gravity survey. *Bureau of Mineral Resources, Australia*, File 63/1909 (unpublished).

WAPET, 1964e—Joanna Spring gravity survey. *Bureau of Mineral Resources, Australia*, File 63/1908 (unpublished).

WAPET, 1964f—Tandalgoo Nos. 1, 2, 3 stratigraphic wells. *West Australian Petroleum Pty Ltd, Company Report* (unpublished).

WAPET, 1965a—West Lennard digital seismic survey. *Bureau of Mineral Resources, Australia*, File 65/11016 (unpublished).

WAPET, 1965b—Southeast Kidson seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4814 (unpublished).

WAPET, 1965c—Southeast Kidson gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4814 (unpublished).

WAPET, 1965d—Mowla seismograph survey, final report. *Bureau of Mineral Resources, Australia*, File 65/11040 (unpublished).

WAPET, 1965e—Dampierland semi-detailed gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4816 (unpublished).

WAPET, 1965f—Offshore Canning aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/4614 (unpublished).

WAPET, 1966a—Willara Hill reflection seismic ('Vibroseis') survey, final report. *Bureau of Mineral Resources, Australia*, File 66/11081 (unpublished).

WAPET, 1966b—Betty detailed seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 65/11055 (unpublished).

WAPET, 1966c—Dampierland seismograph survey, final report. *Bureau of Mineral Resources, Australia*, File 66/11099 (unpublished).

WAPET, 1966d—West Meda seismograph survey, final report. *Bureau of Mineral Resources, Australia*, File 66/11100 (unpublished).

WAPET, 1966e—Roebuck seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 66/11115 (unpublished).

WAPET, 1966f—Summary of data and results: Sahara No. 1 well, Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 80.

WAPET, 1966g—King Sound aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 66/4623 (unpublished).

WAPET, 1966h—South Canning Basin aeromagnetic survey, Western Australia, 1962–3. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 72.

WAPET, 1966i—Summary of data and results: Babrongan No. 1, Langoora No. 1, Hawkstone Peak No. 1, Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 48.

WAPET, 1967—Munro Arch gravity survey, final report. *Bureau of Mineral Resources, Australia*, File 66/4829 (unpublished).

WAPET, 1968a—Lennard seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 68/3018 (unpublished).

WAPET, 1968b—Baskerville seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 68/3023 (unpublished).

WAPET, 1969a—Munro Arch seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3042 (unpublished).

WAPET, 1969b—Wallal aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3037 (unpublished).

WAPET, 1969c—Munro R-1 seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3081 (unpublished).

WAPET, 1969d—Jurgurra Terrace seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 69/3075 (unpublished).

WAPET, 1970a—King Sound marine seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/218 (unpublished).

WAPET, 1970b—Helena (267) reconnaissance seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/504 (unpublished).

WAPET, 1970c—Tabletop reconnaissance (266) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/392 (unpublished).

WAPET, 1970d—Gogo-Trig seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/718 (unpublished).

WAPET, 1970e—Lake Betty (269) detail/reconnaissance survey, final report. *Bureau of Mineral Resources, Australia*, File 70/657 (unpublished).

WAPET, 1970f—Laurel seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/763 (unpublished).

WAPET, 1970g—Oscar seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/765 (unpublished).

WAPET, 1970h—Broome-Samphire seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/857 (unpublished).

WAPET, 1970i—Pender seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/817 (unpublished).

WAPET, 1970j—Lake Auld seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/933 (unpublished).

WAPET, 1971a—Crossland (268) reconnaissance seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/687 (unpublished).

WAPET, 1971b—Anketell seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/896 (unpublished).

WAPET, 1971c—Munro detail seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 70/1000 (unpublished).

WAPET, 1971d—Crossland Platform (304) seismic project, final report. *Bureau of Mineral Resources, Australia*, File 71/150 (unpublished).

WAPET, 1971e—North Broome seismic survey. *Bureau of Mineral Resources, Australia*, File 71/252 (unpublished).

WAPET, 1971f—Poulton seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 71/326 (unpublished).

WAPET, 1971g—Munro D-2 sesimic survey, W.A., final report. *Bureau of Mineral Resources, Australia*, File 71/478 (unpublished).

WAPET, 1972a—North Broome D-2 seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/961 (unpublished).

WAPET, 1972b—East Canning seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/975 (unpublished).

WAPET, 1972c—Lennard Shelf seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/1065 (unpublished).

WAPET, 1972d—Dampier Downs (331)–Collins (336) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/2545 (unpublished).

WAPET, 1972e—Liveringa Ridge (325) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/2938 (unpublished).

WAPET, 1972f—Lennard Shelf aeromagnetic survey, final report. *Bureau of Mineral Resources, Australia*, File 72/1019 (unpublished).

WAPET, 1973a—Sahara II seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/234 (unpublished).

WAPET, 1973b—Crossland III (358) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/244 (unpublished).

WAPET, 1973c—Collins II seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/248 (unpublished).

WAPET, 1973d—Doran seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/267 (unpublished).

WAPET, 1973e—Liveringa II seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/271 (unpublished).

WAPET, 1974a—Jones Range (364)–Hall Range (370) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/255 (unpublished).

WAPET, 1974b—Barbwire II (361) seismic survey, final report. *Bureau of Mineral Resources, Australia*, File 73/263 (unpublished).

WARRIS, B. J., 1976—Canning Basin, offshore. *In* LESLIE, R. B., EVANS, H. J., & KNIGHT, C. L. (Editors)—ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA—3. PETROLEUM. *Australasian Institute of Mining and Metallurgy, Monograph* 7, 185-188.

WATERFORD, L. M., 1941—Resumé of oil drilling operations in the West Kimberley District of Western Australia by the Freney-Kimberley Oil Co. Ltd and its successor the Freney Kimberley Oil Co. (1932) N.L. *Freney Kimberley Oil Co., Company Report* (unpublished).

WATT, J. D., & NEWSTEAD, P. G., 1970—Napier No. 2 well completion report (Lennard Oil NL). *Bureau of Mineral Resources, Australia*, File 69/2031 (unpublished).

WATT, J. D., & TEMPLE, P. R., 1971—Napier No. 5 well completion report (Lennard Oil NL). *Bureau of Mineral Resources, Australia*, File 70/750 (unpublished).

WEBBY, B. D., 1978—History of the Ordovician continental platform shelf margin of Australia. *Journal of the Geological Society of Australia*, 25(1), 41-63.

WELLMAN, P., 1973—Early Miocene potassium-argon age for the Fitzroy lamproites of Western Australia. *Journal of the Geological Society of Australia*, 19(4), 471-474.

WELLS, A. T., 1959a—Yarrie—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-1.

WELLS, A. T., 1959b—Paterson Range—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-6.

WELLS, A. T., 1960a—Tabletop—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-11.

WELLS, A. T., 1960b—Mount Bannerman—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/52-13.

WELLS, A. T., 1962a—Stansmore, W.A.—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-6.

WELLS, A. T., 1962b—Billiluna, W.A.—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SE/52-14.

WELLS, A. T., 1962c—Cornish, W.A.—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-1.

WELLS, A. T., 1962d—Lucas, W.A.—4-mile geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-2.

WELLS, A. T., FORMAN, D. J., RANFORD, L. C., & COOK, P. J., 1970—Geology of the Amadeus Basin, central Australia. *Bureau of Mineral Resources, Australia, Bulletin* 100.

WESTRALIAN OIL LTD, 1968—Napier refraction survey, final report. *Bureau of Mineral Resources, Australia*, File 68/3033 (unpublished).

WHITE, M. E., & YEATES, A. N., 1976—Plant fossils from the northeastern part of the Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1976/18 (unpublished).

WHITWORTH, R., 1970—Reconnaissance gravity survey of parts of Northern Territory and Western Australia, 1967. *Bureau of Mineral Resources, Australia, Record* 1970/15 (unpublished).

WIEBENGA, W. A., & VAN DER LINDEN, J., 1953—Gravity survey in the Fitzroy Basin, Kimberley Division, Western Australia, with special reference to the Nerrima Structure. *Bureau of Mineral Resources, Australia, Record* 1953/64 (unpublished).

WILLIAMS, C. T., 1965—Parda No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 65/4137 (unpublished).

WILLIAMS, C. T., 1972—Munro No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 72/846 (unpublished).

WILLIAMS, I. R., BRAKEL, A. T., CHIN, R. J., & WILLIAMS, S. J., 1976—The stratigraphy of the Eastern Bangemall Basin and the Paterson Province. *Geological Survey Western Australia, Annual Report for 1975*, 79-83.

WILLIAMS, L. W., 1955—Seismic reflection survey over Deep Well Anticline, Myroodah, Kimberley Division, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1955/110 (unpublished).

WILLIAMS, L. W., 1956—Seismic reflection survey in the Poole Range-Christmas Creek area, Kimberley Division, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1956/66 (unpublished).

WILLMOTT, S. P., 1962—Geological report on Frome Rocks No. 2 well. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 8, 15-20.

WILLMOTT, S. P., 1966—Definitions of new formation names. *Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication* 48, 6-8.

WYBORN, L. A. I., 1977—Dummer, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-4.

YEATES, A. N., 1977—Helena, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/52-5.

YEATES, A. N., 1978—Percival, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-8.

YEATES, A. N., & CHIN, R. J., 1979—Tabletop, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-11.

YEATES, A. N., & MUHLING, P. C., 1977—Mount Bannerman, Western Australia—1:250 000 Geological Series, Second Edition. *Bureau of Mineral Resources, Explanatory Notes* SE/52-13.

YEATES, A. N., & TOWNER, R. R., 1978—Sahara, Western Australia—1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF/51-7.

YEATES, A. N., CROWE, R. W. A., TOWNER, R. R., WYBORN, L. A. I., & PASSMORE, V. L., 1975a—Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia. *Bureau of Mineral Resources, Australia, Record* 1975/77 (unpublished).

YEATES, A. N., CROWE, R. W. A., PASSMORE, V. L., TOWNER, R. R., & WYBORN, L. A. I., 1975b—New and revised stratigraphic nomenclature, northeast Canning Basin, Western Australia. *Geological Survey of Western Australia, Annual Report for 1974*, 49-51.

YEATES, A. N., CROWE, R. W. A., & TOWNER, R. R., 1976—The Veevers Crater: a possible meteoritic feature. *BMR Journal of Australian Geology & Geophysics*, 1(1), 77-78.

YOUNG, R. J. B., 1972—Barbwire No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 72/2001 (unpublished).

YOUNG, R. J. B., & O'SHAUGHNESSY, P. R., 1973a—Thangoo No. 2 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 73/218 (unpublished).

YOUNG, R. J. B., & O'SHAUGHNESSY, P. R., 1973b—Mount Hardman No. 1 well completion report (West Australian Petroleum Pty Ltd). *Bureau of Mineral Resources, Australia*, File 73/259 (unpublished).

Record 1975/77

NOTES ON THE GEOLOGY OF THE GREGORY SUB-BASIN AND ADJACENT AREAS OF THE CANNING BASIN, WESTERN AUSTRALIA

by

A.N. Yeates, R.W.A. Crowe*, R.R. Towner, Lesley A.I. Wyborn, and Virginia L. Passmore

* Geological Survey of Western Australia

CONTENTS

	Page
SUMMARY	
INTRODUCTION	1
Location	1
Aims and Methods of the Surveys	1
Previous Surface Investigations	2
Topography and Drainage	5
Geological Setting	6
Guide to Subsequent Workers	6
STRATIGRAPHY	8
Ordovician	8
Carranya Beds	8
Ordovician Undivided	10
Subsurface ?Upper Ordovician to ?Lower Devonian	11
Carribuddy Formation	11
Subsurface Lower Devonian	11
Tandalgoo Redbeds	11
Subsurface Middle Devonian	12
Mellinjerie Limestone	12
Devonian to Lower Carboniferous, Undivided	12
Upper Devonian	12
Knobby Sandstone	12
Subsurface Lower Carboniferous, Undivided	15
Upper Carboniferous to Lower Permian	15
Grant Formation	15
Permian	19
Poole Sandstone	19
?Nura Nura Member	21
Noonkanbah Formation	22
Liveringa Group	25
Lightjack Formation	26
Condren Sandstone	29
Hardman Formation	33
Kirkby Range Member	34
Hicks Range Sandstone Member	36
Cherrabun Member	37
Godfrey Beds	39

	Page
Triassic	40
Millyit Sandstone	41
Blina Shale	43
Erskine Sandstone	46
Culvida Sandstone	47
Jurassic	49
Barbwire Sandstone	49
Jarlemai Siltstone	51
Undivided	52
Cainozoic	52
Lake Gregory Beds	52
Lawford Beds	53
Calcrete and Chalcedony	55
Evaporites	57
Alluvium	58
Aeolian Sand	59
Weathering Products	60
SUBSURFACE INVESTIGATIONS	62
BMR Aeromagnetic Survey	62
BMR Gravity Surveys 1952-60	62
BMR-CGG Poole Range Seismic Survey	64
Subsidized Operations	65
WAPET South Canning Aeromagnetic Survey	65
HACKATHORN and AOC Stansmore Range Aeromagnetic Survey	66
WAPET's Preliminary Surveys in the Lake Betty Region	67
Preliminary Surveys in the Stansmore Area	68
CONTINENTAL OIL COMPANY Seismic Surveys in CROSSLAND 1964-66	70
AQUITAINE Point Moody No. 1	72
WAPET Betty Detail Seismic Project	73
AAP Geophysical Surveys 1967-71	74
BMR Systematic Gravity Survey 1968	76
WAPET's Reconnaissance Work in CROSSLAND and DUMMER	77
WAPET's Final Survey in the Lake Betty Region	78
Further work by WAPET in CROSSLAND and DUMMER	79
WAPET Drilling Program 1971	81

	Page
AAO Billiluna-Helena Aeromagnetic Survey 1971	82
AAP Aeromagnetic Survey 1972	83
WAPET's Semi-Detailed Seismic Survey 1972-3	84
WAPET Barbwire No. 1	85
WAPET detailed Surveys 1973	86
AAR Seismic Survey 1973-4	87
TECTONIC ELEMENTS AND STRUCTURAL GEOLOGY	89
Billiluna Shelf	90
Betty Terrace	91
Gregory Sub-basin	93
Jones Rise	95
Fitzroy Trough	96
Barbwire Terrace	97
Crossland Platform	98
Explanation of Surface Structures	100
GEOLOGICAL HISTORY	101
GROUNDWATER, PETROLEUM POTENTIAL AND MINERAL OCCURRENCES	104
Groundwater	104
Petroleum Potential	108
Crossland Platform	108
Gregory Sub-basin and adjacent Betty and Barbwire Terraces	109
Rocks rich in Iron, Phosphorus, and Manganese	110
Coal	111
Evaporites	111
ACKNOWLEDGEMENTS	111
REFERENCES	113
APPENDICES	

APPENDIX A. MEASURED SECTIONS

A 1. Type section of Carranya Beds

A 2. Measured section of Carranya Beds

A 3. Type section of Knobby Sandstone

A 4. Measured section of Knobby Sandstone

A 5. Measured section of part of Grant Formation

A 6. Measured section of base of Poole Sandstone and top of Grant Formation

A 7. Measured section of upper part of Poole Sandstone

A 8. Measured section of Noonkanbah Formation

A 9. Measured section from top of Poole Sandstone to base of Condren Sandstone

A10. Measured section from top of Lightjack Formation to base of Hardman Formation.

A11. Measured section of Lightjack Formation

A12. Measured section of part of Lightjack Formation and Condren Sandstone

A13. Measured section of Lightjack Formation and Condren Sandstone

A14. Measured section of Lightjack Formation

A15. Measured section of part of Lightjack Formation and Godfrey Beds

A16. Measured section of part of Condren Sandstone and Godfrey Beds

A17. Measured section of Condren Sandstone

A18. Measured section of Condren Sandstone

A19. Measured section of Condren Sandstone

A20. Type section of Kirkby Range Member

A21. Type section of Hicks Range Sandstone Member

A22. Measured section of Hicks Range Sandstone Member

A23. Type section of Cherrabun Member

A24. Measured section of Cherrabun Member

A25. Measured section of Godfrey Beds

A26. Measured section of Godfrey Beds

A27. Measured section of top of Godfrey Beds and base of Millyit Sandstone

A28. Type section of Millyit Sandstone

A29. Measured section of Millyit Sandstone and Blina Shale

A30. Measured section of Blina Shale

A31. Measured section of Erskine Sandstone

A32. Measured section of Erskine Sandstone

A33. Measured section of Erskine Sandstone

A34. Measured section of Culvida Sandstone

A35. Auger-hole sections in salt lakes

A36. Auger-hole sections in Lake Mackay

A37. Auger-hole section in salt lake

A38. Auger-hole sections in one of Gwenneth Lakes

A39. Lateritic weathering profile sections

A40. Auger-hole sections in claypans

A41. Measured section of alluvial deposits

APPENDIX B. BMR STRATIGRAPHIC HOLES

B 1. BMR Billiluna No. 3.

B 2. BMR Billiluna No. 1.

B 3. BMR Mount Bannerman No. 4.

B 4. BMR Mount Bannerman No. 3.

B 5. BMR Lucas No. 14.

B 6. BMR Crossland No. 1.

B 7. BMR Cornish No. 1

B 8. BMR Mount Bannerman No. 1.

B 9. BMR Mount Bannerman No. 2.

B10. BMR Crossland No. 2.

B11. BMR Lucas No. 13.

B12. BMR Cornish No. 2.

B13. BMR Cornish No. 3.

APPENDIX C. Palynological study of cores cut in BMR stratigraphic drillholes by R. Paten and P. Price, Mines Administration Ltd.

APPENDIX D. Palynological study of selected surface samples by R. Paten and P. Price, Mines Administration Ltd.

APPENDIX E. Registered rock samples from Crossland Sheet area.

FIGURES

Frontispiece. Scrivener Hills, CROSSLAND.

1. Location and geological setting.
2. Tectonic map and cross-section.
3. Tillite northeast of Point Moody.
4. Conical outcrops of Poole Sandstone.
5. Lightjack Formation sandstone.
6. Ironstone marker bed at base of Lightjack Formation.
7. Trace fossil in Lightjack Formation sandstone.
8. Trace fossil in Lightjack Formation sandstone.
9. Trace fossils in Lightjack Formation siltstone.
10. Trace fossil in Lightjack Formation sandstone.
11. Trace fossil in Lightjack Formation sandstone.
12. Oroganic trails in Lightjack Formation siltstone.
13. Trace fossil in Lightjack Formation siltstone.
14. Moulds of burrows in Lightjack Formation.
15. Condren Sandstone.
16. Condren Sandstone.
17. Cliff section of part of Condren Sandstone.
18. Interference ripple marks in Condren Sandstone.
19. Trace fossil in Condren Sandstone.
20. Godfrey Beds overlying Condren Sandstone.
21. Rhizocorallium burrow in Godfrey Beds.
22. Rhizocorallium burrow in Godfrey Beds.
23. Millyit Sandstone.

24. Outcrop of Blina Shale.

25. Mudcracks in Blina Shale.

26. Burrows in Blina Shale.

27. U-shaped burrows in Blina Shale.

28. Erskine Sandstone.

29. Aerial photograph of part of Lake Gregory.

30. Stromatolite-building algae in McDonaldson Spring.

31. Stromatolitic calcrete of Lawford Beds.

32. Cross-section of stromatolitic calcrete of Lawford Beds.

33. Longitudinal sand dunes with tuning-fork structure.

34. Longitudinal sand dunes showing bifurcation.

35. Massive pisolitic laterite.

36. Gravity features after Flavelle Goodspeed.

37. AQUITAINE Point Moody No. 1

38. Gravity features after Darby & Fraser.

39. WAPET Crossland No. 1.

40. WAPET Crossland No. 2.

41. WAPET Crossland No. 3.

42. WAPET Lake Betty No. 1.

43. WAPET Barbwire No. 1.

44. Aerial view of southern Stansmore Range.

TABLES

1. BMR geophysical surveys.

2. Company geophysical surveys.

3. Wells drilled.

4. Subsurface stratigraphy of exploration wells.

5. Surface occurrence of Stratigraphic units.

6. Tectonic elements covered by geophysical surveys.

7. Porosity-permeability data in Crossland Platform.

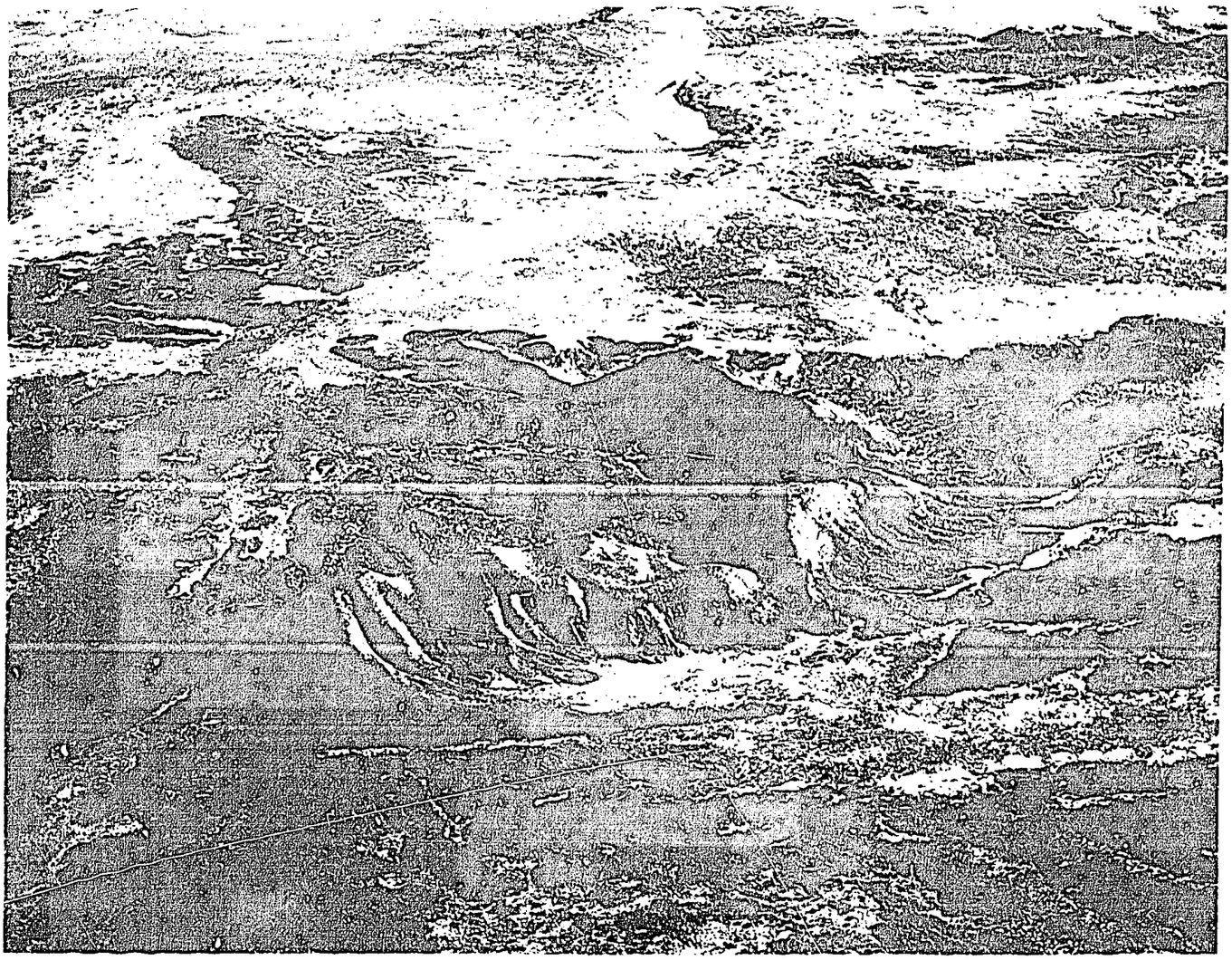
8. Porosity-permeability data in Gregory Sub-basin and adjacent Terraces.

9. Chemical analyses of iron-rich, phosphorus-rich, and manganese-rich rocks.

1:250 000 Geological Maps

BILLILUNA
LUCAS
STANSMORE
WEBB
MOUNT BANNERMAN
CORNISH
HELENA
CROSSLAND
DUMMER

FRONTISPIECE



Aerial view of Scrivener Hills, CROSSLAND 1:250 000 Sheet area, composed of Hardman Formation overlying Condren Sandstone. The Hills rise above a spinifex-covered plain with scattered low rises of Lightjack Formation. BMR Negative GB/157.

SUMMARY

During 1972 and 1973 BILLILUNA, LUCAS, STANSMORE, WEBB, MOUNT BANNERMAN, CORNISH, HELENA, CROSSLAND, and DUMMER 1:250 000 Sheet areas were geologically mapped jointly by the Bureau of Mineral Resources (BMR) and the Geological Survey of Western Australia (GSWA). The Phanerozoic sequences mainly occupy the northeastern quarter of the Canning Basin, Western Australia.

The stratigraphic sequence exposed on the surface includes some units previously unrecognized, and is described in detail. Subsurface units are described briefly. Deposition commenced in the Early Ordovician after a marine transgression. For the remainder of its history the depositional environment fluctuated between shallow marine and continental until a period of deformation in the Late Triassic or Early Jurassic. Thereafter, deposition was mainly continental; the area today is covered mainly by a sheet of red aeolian sand and lies within the Great Sandy Desert of Western Australia.

The thick accumulations of sediment that occurred at intervals after the mid-Devonian were directly a result of down-to-basin faulting along reactivated basement lineaments; their surface traces mark the boundaries between the tectonic elements recognized from an assessment of the results of subsurface geophysical surveys.

Concurrent with field mapping, shallow stratigraphic drilling and fossil collecting were carried out. Palynological examination of cores and examination of faunas and floras have helped to confirm surface identifications of Permian and Triassic stratigraphic units.

The most important resource of the area is groundwater, although the petroleum potential has not been fully tested.

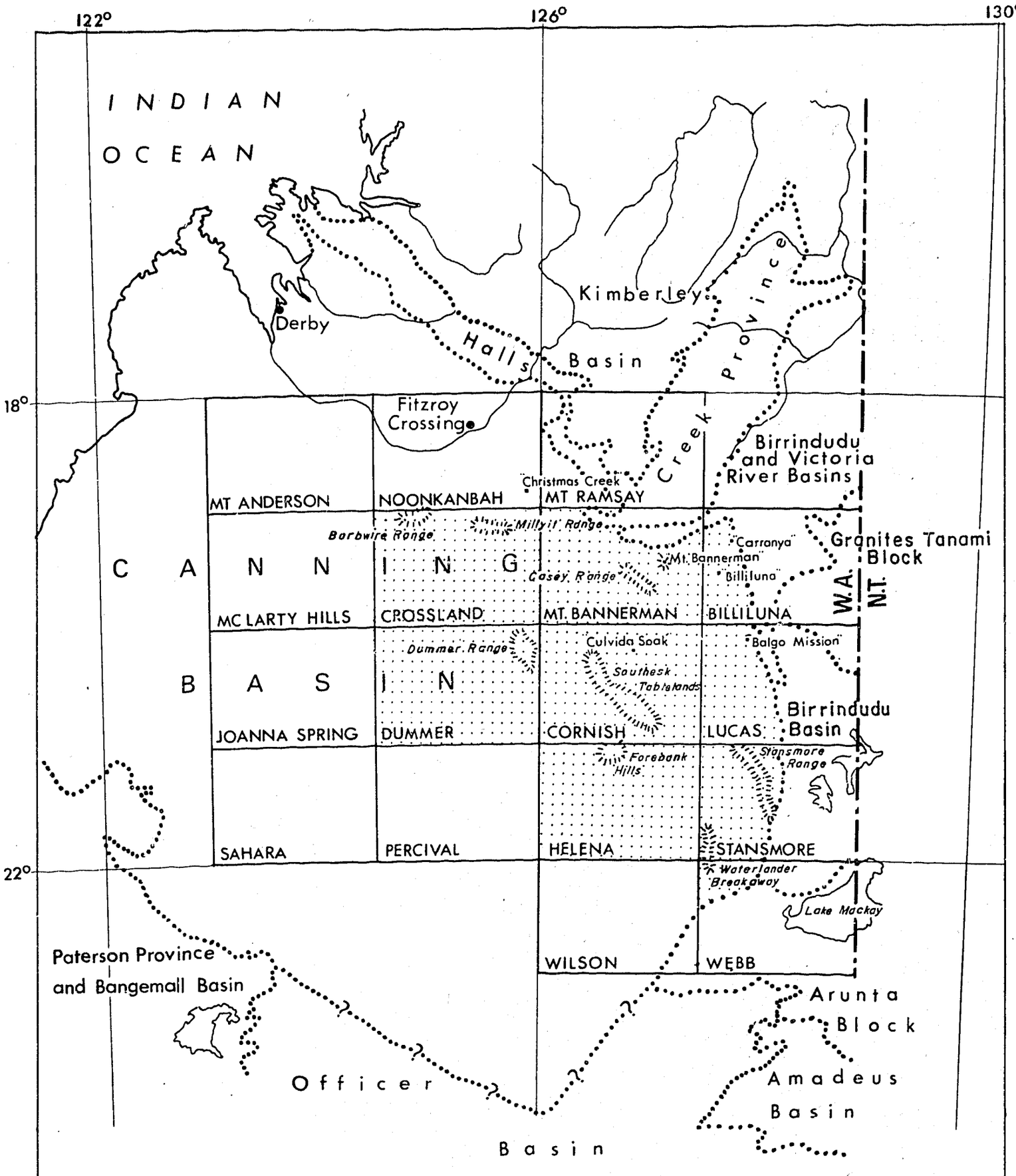


Fig.1 Location and geological setting

INTRODUCTION

1. Location

The 1972 and 1973 surveys were confined to the following 1:250 000 Sheet areas in the Canning Basin, Western Australia (designated in capital lettering throughout the text and hereinafter referred to collectively as 'the area'): BILLILUNA, LUCAS, STANSMORE, WEBB, MOUNT BANNERMAN, CORNISH, HELENA, CROSSLAND, and DUMMER (Fig. 1).

2. Aims and Methods of the Surveys

The prime objective of the surveys was to re-map part of the Canning Basin at a scale of 1:250 000, by investigating the Phanerozoic geology of BILLILUNA, LUCAS, STANSMORE, WEBB, and MOUNT BANNERMAN, by revision mapping of CORNISH and by the mapping of HELENA, CROSSLAND, and DUMMER. Access to the area was gained by four-wheel-drive vehicles and helicopter.

In 1972, mapping of the Canning Basin in BILLILUNA, LUCAS, and STANSMORE was by A.N. Yeates and Virginia L. Passmore (BMR) and R.W.A. Crowe (GSWA); A.T. Wells and J.M. Dickins (BMR) also contributed. The Precambrian parts of these Sheet areas were mapped by a joint BMR-GSWA field party led by D.H. Blake (Blake, Hodgson, & Muhling, 1973). In 1973 CORNISH, HELENA, CROSSLAND, DUMMER and the Phanerozoic of MOUNT BANNERMAN and WEBB were mapped by A.N. Yeates, R.R. Towner, Lesley A.I. Wyborn, P.A. Jell (BMR) and R.W.A. Crowe (GSWA). A.T. Wells (BMR) and P.K. Dutta (Geological Survey of India) also contributed. The Precambrian of WEBB was mapped by D.H. Blake and I.M. Hodgson in 1973 (Blake & Towner, 1974). The Precambrian of MOUNT BANNERMAN was mapped by D.H. Blake and I.M. Hodgson in 1973 and in more detail by P.C. Muhling of GSWA in 1974.

Preliminary editions of all 1:250 000 map sheets are enclosed. They were compiled by plotting geological data onto transparent overlays superimposed on the 1:80 000 scale aerial photographs of each Sheet area. The data were transferred by D. Walton to planimetric sheets reduced from 1:50 000 scale and compiled by the Division of National Mapping. The compilation sheets were photographically reduced to 1:250 000 scale and redrawn. The preliminary editions are available from the Bureau of Mineral Resources (Canberra) and the Geological Survey of Western Australia (Perth).

Phanerozoic faunas collected in 1972 were studied by Dickins & Jell (1974); faunas collected during the 1973 survey were studied by Dickins (in prep.). Floras collected during both surveys were examined by Mary E. White (White & Yeates, in prep.).

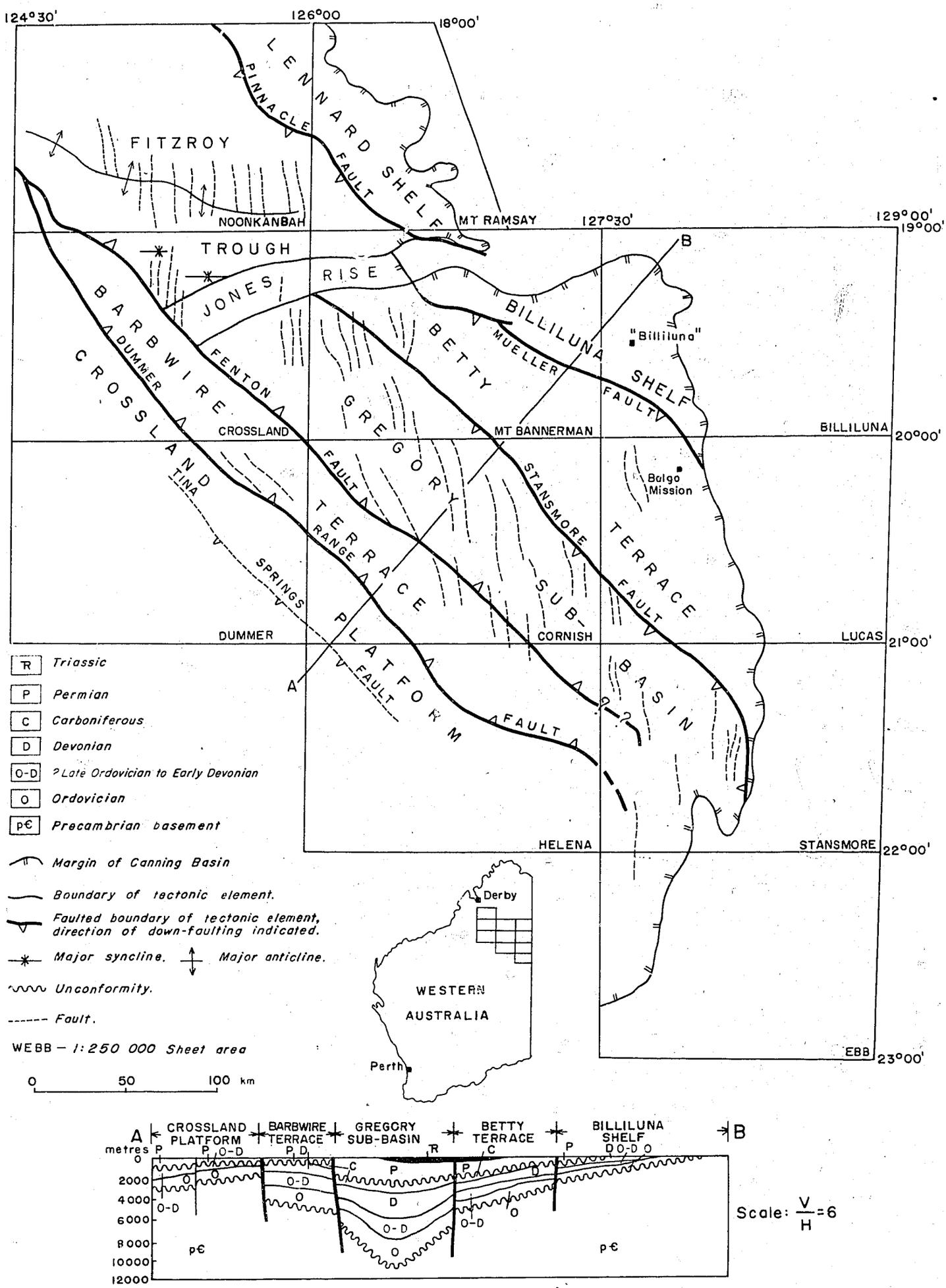


Fig. 2. Provisional tectonic map and cross-section of the northeastern part of the Canning Basin showing position and relations of main tectonic elements.

Fourteen shallow stratigraphic wells were drilled to 102 m to 262 m with a BMR Mayhew 1000 rig by drillers E. Lodwick and C. Iland. Electric and gamma-ray logs were run in some holes. The well completion reports are given in Appendix B. Core samples were examined for microfloras by R. Paten and P. Price of Mines Administration Ltd (Appendix C). The naming of holes is serial by 1:250 000 Sheet areas; for instance, BMR Mount Bannerman No. 2 refers to the second hole drilled by BMR in MOUNT BANNERMAN.

Thin sections from selected (relatively fresh) hand specimens have been examined; the findings are recorded in the stratigraphy section.

Samples of iron-rich sedimentary rocks and concretions have been analysed; others have been X-rayed. The results are given in the section on groundwater, petroleum and mineral occurrences. The presence of phosphate in the Noonkanbah and Lightjack Formations was confirmed for the first time in the area.

Several new units were recognized during the surveys and the distribution of others was considerably modified. Naming of the new units has been approved by the Western Australia Sub-committee for Stratigraphic Nomenclature and are defined separately (Yeates, Crowe, Towner, Wyborn, & Passmore, in press).

During the surveys, we have combined the results of our mapping with the subsurface results of numerous unpublished geophysical and drilling operations in the area. As a result, a provisional tectonic subdivision of the area has been made. It is presented in map form (Fig. 2) and each element is defined in the section on tectonic elements and structural geology. The results of all previous subsidized geophysical surveys are summarized.

We also discuss the geological history of the area and demonstrate the effects of the various tectonic elements on sedimentation; the economic geology of the area is also discussed.

3. Previous Surface Investigations

In this section, brief mention is made to the surface investigations by explorers and geoscientists in the area. The extensive subsurface information is documented in the section entitled 'subsurface investigations'.

Aborigines occupied the area until very recently, and made use of a number of geological features. For instance, they sheltered in caves in laterite and sandstone

cliffs; they used chalcedony for implements; they recognized the relatively impervious nature of weathered Permian micaceous sandstone and excavated, by hand, rockholes for water storage, and also they used blocks of this rock type as grinding stones.

In their book 'The Discovery and Exploration of Australia', Feeken, Feeken, & Spate (1970) described: A.C. Gregory's expedition down Sturt Creek to Lake Gregory, both of which he named (Gregory, 1857; 1898); Colonel P.E. Warburton's journey from Alice Springs to the Oakover River which crossed the area (Warburton, 1875) and D.W. Carnegie's expedition from the WA Goldfields to Halls Creek and return (Carnegie, 1898). Carnegie named the Stansmore Range on the return journey.

A.W. Canning, a surveyor, discovered a route for travelling stock between Wiluna and Halls Creek in 1906-7, which became known as the Canning Stock Route. Water wells were sunk along the Route mainly by deepening native wells during Canning's well-sinking trip begun in 1908. A geologist, H.W.B. Talbot, who accompanied Canning for much of the latter journey, published an account of his geological observations and made an excellent assessment of the groundwater resources along the Route (Talbot, 1910). Drovers began moving cattle along the Stock Route in 1911. Kidson (1921) recorded magnetic observations made along the Stock Route in 1914.

L.J. Jones investigated the geology and water resources of the northeastern part of the Canning Basin. He made the first assessment of the petroleum potential of the area and discovered fossils (Jones, 1922).

Exploration of the area continued with the prospecting trips of M. Terry in 1925 and 1932. Terry described his first trip from Halls Creek to Godfreys Tank (Terry, 1925; 1927) and his visit to the extreme east of the area (Terry 1934; 1937). During these expeditions he named some important topographic features. He later summarized the exploration history of the Canning Basin up to the time of the first BMR surveys in the area, and described the topography and drainage of this region (Terry, 1957).

A. Wade described the geology of the Fitzroy Trough, and noted Permian units around Christmas Creek in the extreme north of the area (Wade, 1924; 1936).

W.G. Woolnough made an aerial survey from Louisa Downs (north of the area) to Lake Gregory (Woolnough, 1933). D.F. McKay also took aerial photographs of part of the

Canning Basin (McKay, 1934). Several flights were made in the area. C. St. J. Bremmer made aerial reconnaissances over the desert areas to assess amount of outcrop and vehicular access. He noted dipping strata near Godfreys Tank and low lateritized ridges in western DUMMER (Bremmer, 1940; 1942).

Kraus (1941) described Permian sedimentary rocks in the Christmas Creek area. Maddox (1941) described results of reconnaissance mapping in the northeastern part of the Canning Basin. During this survey, part of the basin margin was delineated and Permian units were mapped.

An account of the geology south and southwest of old Balgo Mission, known then as Pallotine Mission, was given by Evans (1948).

After aerial and ground surveys and from reference to previous work, F. Reeves described the geology and petroleum potential of the Canning Basin (Reeves, 1949).

BMR commenced geological mapping of the Canning Basin in 1948, and in 1955 J.N. Casey and A.T. Wells made a regional geological investigation of BILLILUNA, LUCAS, STANSMORE, MOUNT BANNERMAN, and CORNISH, culminating in the printing of geological maps at a scale of four miles to the inch (Wells 1962a, 1962b, 1962c, 1960 and 1962d respectively), and the publication of a report on the geology of these Sheet areas (Casey & Wells, 1964). The operational problems of this survey are referred to in Casey & Wells (1956). During their survey, Permian and Triassic units were subdivided and Ordovician and Devonian-Carboniferous strata were recognized for the first time. New geographic names allocated were documented by Casey & Nelligan (1956). In 1957, J.J. Veevers of BMR, during a regional helicopter survey in the central part of the Canning Basin, made geological observations and took gravity readings in CROSSLAND, DUMMER, MOUNT BANNERMAN, HELENA, and WEBB (Veevers, 1957). From the results of this and other BMR surveys such as those of Guppy et al. (1952; 1956), Traves et al. (1956), and Stinear & Wells outside the area, and from the work of Casey and Wells, Veevers & Wells (1961) published an account of the geology of the entire Canning Basin with an accompanying geological map at a scale of 1 inch to 20 miles. This is still the foremost account of the geology of the Canning Basin.

Brunnschweiler & Dickins (1954) described possible Devonian plants from an obscurely defined locality of Reeves (1949) in the Lake Gregory area. This locality seems doubtful as we have found only Permian rocks in this area. However plant-bearing Devonian sandstone does occur at Falconer Hills (BILLILUNA) to the north.

White (1957) identified plant fossils and suggested ages from specimens collected by Casey and Wells; these workers also collected dune sand samples which were described by Brown (1959).

Other reports which refer to the area, McWhae et al. (1958) and Playford et al. (in press) are based on previous work from other sources.

Tomlinson (1968) referred to a Bothriolepis locality near Billiluna. Veevers et al. (1967) described Leptophloem occurrences at Knobby Hills and suggested that the Knobby Sandstone (unnamed then) was either Upper Devonian or Lower Carboniferous.

Balme (1969) referred to the area in his review of the Triassic of Western Australia.

Unpublished reports on the geology of a large part of the area relate to fieldwork carried out by geologists of Mines Administration Ltd on behalf of Associated Australian Resources NL (Paten et al., 1972a, b; Evans & Brown, 1974).

Dickins & Jell (1974) identified faunas collected during our 1972 survey and White in White & Yeates, in prep. identified floras from both the 1972 and 1973 surveys. G.C. Young (in press) described fish plates collected from the Knobby Sandstone (BILLILUNA) during the 1972 survey. J.M. Dickins is preparing a report on the fossils collected during the 1973 survey (Dickins, in prep.).

4. Topography and Drainage

The area is largely part of the extensive sand plain named the Great Sandy Desert by Warburton (1875) and the Canning Plain by Veevers & Wells (1961). This sand plain within the area is a gently undulating surface with altitude varying from about 500 m in the Stansmore Range (STANSMORE) to about 300 m in broad depressions in HELENA and DUMMER and about 250 m in the Lake Gregory area.

East-west trending longitudinal sand dunes cross the sand plain; the regular parallel arrangement of the dunes is interrupted where isolated ranges, mesas, and plateaux rise above the sand plain and where drainage depressions with associated claypans and salt lakes meet the aeolian sand sheet.

Because of the prevailing arid climate, there is little run-off from the low ranges and hills. Most drainage is subsurface and terminal. There are no permanent watercourses.

The largest expanse of surface water is in Lake Gregory (LUCAS and CORNISH), which has been known to dry up. Semi-permanent water can also be found in waterholes in Shiddi Creek (MOUNT BANNERMAN), in Sturt Creek (BILLILUNA) and in a few rockholes such as Godfreys Tank, Breaden's Pool (CORNISH), a large rockhole in the headwaters of Warri Creek (STANSMORE), and in a few aboriginal rockholes.

5. Geological Setting

The Canning Basin is a Phanerozoic sedimentary basin with an onshore area of about 430 000 km^2. Its western boundary (offshore) has not been fully delineated (Forman et al., 1973).

The onshore boundaries of the Basin lie within Western Australia and coincide with mainly Precambrian provinces (Fig. 1).

The Canning Basin lies south of the Halls Creek Province (Plumb & Derrick, 1973), a belt of metamorphic and igneous rocks. To the east and northeast lies the Granites-Tanami region, comprising low-grade metamorphics, volcanics, and granites of Lower Proterozoic or Archaean age and Carpentarian and Adelaidean sedimentary rocks. The Archaean or Lower Proterozoic rocks are continuous southward into the Arunta Block (Blake, Hodgson, & Muhling, 1973) which also adjoins the Canning Basin to the east. The northwestern edge of the Amadeus Basin also coincides with the basin margin in the east (Blake & Towner, 1974) and in the southeast.

A gravity high, thought to coincide with an area of elevated basement, separates the Canning Basin in the south from a sequence of mainly flat-lying sedimentary rocks referred to by the loosely defined term Officer Basin (Kreig, Jackson, & Van de Graaff, in press). To the southwest lie Precambrian metamorphic and igneous rocks of the Bangemall Basin and Paterson Province (Playford et al., in press).

6. Guide to Subsequent Workers

The extensive sand plain with its longitudinal dunes covers most of the Permian and Triassic sequence. It also hinders vehicular access. Where formations crop out, complete sections are rare. Subaerial denudation, especially of soft-weathering units, has facilitated burial of rock sequences by unconsolidated Cainozoic deposits. Outcrops usually occur as scattered, scree-flanked mesas up to 30 m high, and as rubble-covered flats. The best exposures

occur in the ranges of CROSSLAND and along major fault line scarps. Incomplete sections, commonly only 10 m thick, make it difficult, at first, to assign formation names; the respective type sections are much thicker.

In most places, pre-Permian units are covered by the Permo-Triassic sequence.

Surface weathering and its products (laterite, ferricrete, silcrete, and some calcrete) have also hindered identification of formations, particularly in southern HELENA where in many localities, less than 1 m of sedimentary rock is exposed beneath laterite cappings. Further, weathered profiles which are usually almost flat-lying give the impression that the underlying formations are also flat-lying. However some laterite surfaces with dips up to 8° were recorded. In most areas, Permian and Triassic units dip at 1° to 3°, so that different sections are exposed in different mesas, though the mesas appear similar. This makes photo-interpretation difficult without a reasonable amount of ground checking.

Throughout the Permo-Triassic sequence there are repetitions of lithologic units, each with its own stratigraphic name. In fact this sequence is largely an alternation of sandstone and siltstone units. Care must be used when assigning formation names and knowledge of one's stratigraphic position with respect to marker units is important. The best marker units are the Noonkanbah Formation and the Blina Shale, both soft-weathering units and conspicuous by their poor outcrop usually on rubble-covered alluvial flats.

Fossils collected, and microfossils obtained from cores cut during shallow stratigraphic drilling have helped to confirm the identification of formations made from surface observations.

No elaborate schemes of sandstone classification have been used. 'Sandstone' is used in the sense of Pettijohn (1957) and is qualified quartzose, feldspathic, lithic, micaceous etc., according to the dominant constituent of the framework. Most descriptions are hand specimen identifications. Goudie's (1972) definition of calcrete is used. Scale of cross-bedding units is that of Allen (1963). The nomenclature for unconformities is that of Dunbar and Rogers (1963).

STRATIGRAPHY

Ordovician

Carranya Beds

The name Carranya Beds has recently been proposed for a sequence of fine and medium-grained sandstone containing thin interbeds of well rounded pebble and cobble conglomerate (McTavish, in Playford et al., in press). Casey & Wells (1964) described this sequence but did not formally name it. The Beds are Early Ordovician and are the oldest known Paleozoic rock unit in the area. They rest with angular unconformity on Proterozoic rocks, and are thought to be overlain unconformably by possible Upper Ordovician to Lower Devonian rocks in the subsurface and by the Upper Devonian Knobby Sandstone and Upper Carboniferous to Lower Permian Grant Formation. The name is derived from Carranya homestead, Latitude 19°33'S, Longitude 127°41'E (BILLILUNA).

Geographic distribution and type locality The Carranya Beds crop out along the basin margin in MOUNT BANNERMAN and BILLILUNA in a series of low rises flanked by pebbles and scree. The exposures, which are isolated and widely separated, extend over an area of about 500 km^2 and are restricted to the Billiluna Shelf. Younger formations and superficial sand obscure the unit to the south and southwest away from the basin margin. The subsurface extent of the Carranya Beds is unknown.

The type section of the Carranya Beds is 14 km west of the Wolf Creek Meteorite Crater along the Halls Creek road, Latitude 19°11'S, Longitude 127°40'E, BILLILUNA, where it is 107 m thick (A1); 15 km to the west another section 135 m thick was measured (A2). At both localities the top and the base of the unit are obscured.

Lithology The Carranya Beds are composed predominantly of fine to medium-grained sandstone with subordinate thin beds of rounded pebble and cobble conglomerate and intraformational claystone conglomerate. The unit is thin to medium-bedded, with some low-angle small-scale cross-bedding, and contains a few beds ferruginized and silicified by weathering. The sandstone is white, yellow, brown, and orange, thinly bedded to laminated, mainly fine-grained, and well sorted; the sequence at the type section becomes more poorly sorted and coarser-grained higher in the sequence. A bioturbated sandstone with macrofossils and abundant worm trails occurs at the base of a measured section (Fig. A1). Beds of pebble and cobble conglomerate in a quartzose sand matrix are interbedded with fine and medium-grained sandstone above the basal bioturbated sandstone. The clasts

consist of well rounded quartz, quartzite, and silicified pebble conglomerate probably derived from nearby Proterozoic outcrops. The abundant pebble and cobble scree between ridges of sandstone may be the residue from weathered conglomerate beds.

Dips in the unit vary from 5° to 40°.

Thickness The total thickness of the Carranya Beds is unknown, but it is probably about 500 m as the measured sections represent only part of the unit. The increasing thickness of outcrop westward suggests the formation thickens to the west; alternately it may reflect greater erosion towards the eastern margin of the basin.

Rock Stratigraphic Position The Carranya Beds lie with angular unconformity on Proterozoic rocks. The lower contact is generally obscured and where exposed occurs on a scree-covered slope. Regional relations suggest that the formation is unconformably overlain by Upper Devonian Knobby Sandstone which crops out south and west of the Carranya Beds in BILLILUNA. At its only outcrop in MOUNT BANNERMAN, it is unconformably overlain by the Upper Carboniferous to Lower Permian Grant Formation. South of the Billiluna Shelf and in the subsurface, Upper Ordovician to Lower Devonian rocks may disconformably overlie the Carranya Beds.

Fossils and Time Stratigraphic Position Fossils have been found in the Carranya Beds only at the type section. Fragments of the trilobite Dikelokephalina (Casey & Wells, 1964) and the gastropod Ophileta sp. (J.G. Tomlinson, 1971 pers. comm.) collected low in the section date the Beds as Early Ordovician (early Arenigian). Abundant worm casts from the same part of the section and fossil fragments of uncertain identity are undiagnostic (J.G. Tomlinson, 1971 pers. comm.), as also are pelecypods from a bed higher in the formation. No microfossils have been found.

Environment of deposition The macrofossils, trace fossils, and bioturbated sandstone indicate that the Carranya Beds were deposited in a shallow-marine environment. The textural maturity of the sandstone, good sorting, lamination, and absence of siltstone and shale suggest high-energy conditions allowing reworking and winnowing of sediments. The abundance of terrigenous derived clastic marine sediment, including conglomerate, suggest that the Carranya Beds may be shoreline deposits. The Redbank Yard Conglomerate and the Peterson Beds, both Proterozoic units nearest to exposures of the Carranya Beds, contain medium to fine-grained sandstone and conglomerate with rounded pebbles of quartz, quartzite, and chert. The similarity in lithology of these

units to that of the Carranya Beds suggest they may have been the clastic source area for the Carranya Beds. If so, the shoreline would have been very close to the present northeast margin of the basin.

Field description The unit is faulted at an outcrop where the Alice Springs road leaves the Halls Creek/Balgo road, BILLILUNA, and within the fault zone silicification and quartz veining is common. Farther east at the contact with the underlying Proterozoic rocks, the Carranya Beds are cut by minor faults. The slickensided planes are filled with vein quartz. Elsewhere the unit crops out as rises less than 5 m high.

Ordovician Undivided

Seismic evidence suggests that about 1000 m of Ordovician sedimentary rocks lie with angular unconformity on Precambrian rocks in the subsurface of a large part of the area. These rocks have not been subdivided because of lack of information; they are best known south of the area where they have been intersected in AQUITAINE Wilson Cliffs No. 1 and AQUITAINE Contention Heights No. 1 drilled by AUSTRALIAN AQUITAINE PETROLEUM Pty Ltd (AAP) (AAP, 1969c; 1974). They have also been intersected in WAPET Barbwire No. 1 drilled by WEST AUSTRALIAN PETROLEUM Pty Ltd (CROSSLAND) on the Barbwire Terrace (WAPET, 1972b). Their presence has been inferred in the remainder of the area from seismic interpretation.

In the Crossland Platform, Lower Ordovician rocks may include equivalents of the Nambeet Formation (Koop, 1966b) and the Willara Formation (Playford et al., in press) recognized outside the area and which have an unknown relation to the sandstone-siltstone 'Lower Formation' and the carbonate-bearing 'Middle Formation' encountered in AQUITAINE Wilson Cliffs No. 1 (AAP, 1969c) to the south of the area. These latter units are overlain by the Middle Ordovician Goldwyer Formation (defined by Elliot, 1961) which consists of sandstone, siltstone, shale, and limestone.

In the subsurface sequences of the Gregory Subbasin, the adjacent Barbwire and Betty Terraces, and the Billiluna Shelf, an interval traceable on seismic sections has been referred to the Ordovician. This interval may include equivalents of the carbonate-bearing Lower Ordovician Prices Creek Group (Veevers & Wells, 1961) that crops out north of the area or of the sandstone and minor conglomerate sequence of the Lower Ordovician Carranya Beds. The interval may also include the Middle to Early Upper Ordovic-

ian Nita Formation (Playford et al., in press) present in WAPET Barbwire No. 1 (Fig. 43) (WAPET, 1972b) in the northwest of the area.

Subsurface ?Upper Ordovician to ?Lower Devonian

Carribuddy Formation

No exposures of the Carribuddy Formation are known within the area. South of the area, it is a sequence of shale with minor dolomite, and a thick basal bedded evaporite unit all thought to have been deposited in a restricted shallow-marine and evaporitic environment.

The type section is in WAPET Sahara No. 1 west of the area, between 1726.7 and total depth of 2120.7 m (Koop, 1966a). Its lower contact is disconformable on Middle to Upper Ordovician units (Playford et al., in press); it is conformably overlain by an other subsurface unit, the Lower Devonian Tandalgoo Redbeds and unconformably by the Upper Carboniferous to Lower Permian Grant Formation. No fossils are known from the Carribuddy Formation.

The evaporite unit which contains halite and anhydrite is a widespread seismic reflector south of the area. The Carribuddy Formation was intersected in WAPET Crossland No. 2 (Fig. 40) (WAPET, 1971c). This section contains sandstone, siltstone, limestone, and dolomite, but lacks evaporites.

Subsurface Lower Devonian

Tandalgoo Redbeds

The Tandalgoo Redbeds, a sequence of red and brown sandstone with minor brown siltstone and shale with traces of limestone and evaporite, was defined from WAPET Sahara No. 1, SAHARA (Koop, 1966a). The type section is between 1127.8 and 1726.7 m in the well where it is conformable with the overlying Middle Devonian Mellinjerie Limestone and with the underlying Carribuddy Formation. Where the Mellinjerie Limestone lenses out along other parts of the Crossland Platform, the Tandalgoo Redbeds are unconformably overlain by the Grant Formation. In the Barbwire Terrace and Gregory Sub-basin they may be overlain both with disconformity and conformity by other Devonian units. However, distribution of the Tandalgoo Redbeds in these latter areas can only be traced tentatively from seismic interpretation.

An Early Devonian age based on fish remains found in AQUITAINE Wilson Cliffs No. 1 to the south has been assigned to the Tandalgoo Redbeds (Gross, 1971).

Subsurface Middle Devonian

Mellinjerie Limestone

Between 931.2 and 1127.8 m in WAPET Sahara No. 1 the sequence of limestone and dolomite with minor interbedded shale was named the Mellinjerie Limestone (Koop, 1966a). The unit is conformable on the Tandalgoo Redbeds but is overlain by the Upper Carboniferous to Lower Permian Grant Formation with low-angle regional unconformity. Spores date this shallow marine unit as Middle Devonian.

On seismic evidence, its distribution is restricted entirely to the subsurface of parts of the Crossland Platform and to the Kidson Sub-basin outside the area.

Devonian to Lower Carboniferous, Undivided

Part of an unnamed sequence of late Middle Devonian to Lower Carboniferous bedded limestone and dolomite occurs in the subsurface northeast of the Dummer Range Fault System. These rocks were intersected from 477.3 to total depth of 915.3 m in WAPET Crossland No. 3 (DUMMER) (Fig. 41) on the Barbwire Terrace where they consisted of bedded and massive limestone which is increasingly dolomitic with depth and which has minor shale bands near the top.

The base of the unit is a well defined seismic reflecting horizon in this area and the carbonates are assumed to conformably overlie the Tandalgoo Redbeds as in WAPET Barbwire No. 1 (Fig. 43) (WAPET, 1972b). Between the basal carbonate reflector and the base of the Grant Formation in this area is some 4000 m of sedimentary rock; the carbonate unit may only constitute the lower half of this; the other half may consist of clastics.

In the Gregory Sub-basin, the known Devonian rocks are the clastics encountered in WAPET Lake Betty No. 1 (Fig. 42): a Lower to Middle Devonian sandstone sequence referred to the Poulton Formation and an Upper Devonian sandstone and siltstone sequence referred to the Luluigui Formation (WAPET, 1972a). Their relations to the unnamed carbonate sequence is not known.

Upper Devonian

Knobby Sandstone

The Knobby Sandstone (Yeates et al., in press) is predominantly medium to coarse-grained sandstone, reddish brown, cross-bedded, and with abundant intraformational claystone clasts and fragments of wood and fish plates.

Interbeds of siltstone, and granule and pebble conglomerate are common but vary locally in thickness and abundance. The formation is Late Devonian on fossil evidence and lies unconformably on Proterozoic sedimentary rocks and possibly the Lower Ordovician Carranya Beds; it is probably overlain unconformably by the Upper Carboniferous to Lower Permian Grant Formation. Casey & Wells (1964) described exposures in the Knobby Hills area which Veevers et al. (1967) informally named the 'Knobby Sandstone'. The name has now been formalized (Yeates et al., in press).

Geographic distribution and type locality The Knobby Sandstone crops out in hills and rises along the northeastern margin of the Canning Basin in the western half of BILLILUNA and the northern edge of LUCAS. Outcrops are restricted to the Billiluna Shelf and are mostly within a 40-km radius of Knobby Hills.

In the subsurface the Knobby Sandstone is probably restricted to the Billiluna Shelf as rocks of an equivalent age are of different lithologies in WAPET Lake Betty No. 1 (WAPET, 1972a) 170 km west of Knobby Hills on the Betty Terrace, and WAPET Crossland Nos 1 and 3 (WAPET, 1971c) about 250 km southwest on the Crossland Platform.

The type section of the Knobby Sandstone (A3) is in the Knobby Hills, from which the formation is named, at Longitude 127°45'44"E and Latitude 19°24'24"S, about 2 km east of Sturt Creek and 7 km north of Skeen Hill. Only a partial section is present as the base is obscured and the top eroded.

Lithology The Knobby Sandstone is reddish brown, coarse to medium-grained quartz sandstone interbedded with fine-grained sandstone, thin beds of multi-coloured siltstone and shale, and quartz pebble and granule conglomerate. Intraformational claystone clasts are abundant throughout the sequence; fragments of fish plates and fossil wood are common and widespread. Rare occurrences of the plant Leptophloem are present. The sandstone is generally poorly sorted, medium to thickly bedded, with clay clasts up to 20 mm across. Medium and large-scale (up to 5 m) high-angle (up to 22°) cross-bedding is prevalent and characteristic of the formation. Siltstone and shale beds are rarely seen in outcrop, but where they are present are generally a few cm thick and locally up to 1 m.

Close to the outcropping hills of Precambrian rock, the sandstone contains rounded to subrounded boulders of white quartz, quartzite, and silicified conglomerate up to 1 m in diameter.

Some beds are silicified and a few ferruginized. A few silicified sandstone beds have quartz-filled cavities. Silicification and ferruginization are surface weathering features.

The Knobby Sandstone in outcrop has dips of up to 15°, and rarely up to 35°. Dip directions vary and may reflect gentle folding. Local faulting occurs associated with a steepening of dip. Within these fault zones the sandstone is silicified and in places is cut by quartz veins.

Thickness The total thickness is unknown but is estimated to exceed 200 m. BMR Billiluna No. 3 (B1), a shallow stratigraphic hole, penetrated 162 m. The thickest measured outcrop of Knobby Sandstone is a section 14.4 m thick at Falconer Hills (A4). Lateral equivalents of the Knobby Sandstone are appreciably thicker; marine clastics at WAPET Lake Betty No. 1 are greater than 300 m thick (WAPET, 1972a).

Rock Stratigraphic Position Regional geology and structure suggest that the Knobby Sandstone unconformably overlies the Carranya Beds and is overlain unconformably by the Upper Carboniferous to Lower Permian Grant Formation. The contact with underlying and overlying units is not exposed and has not been intersected in drilling. Where it overlaps the Carranya Beds, the Knobby Sandstone rests with angular unconformity on Proterozoic sedimentary rocks. Near the eastern margin of the basin in BILLILUNA the Knobby Sandstone is close to steeply dipping Proterozoic Peterson Beds, suggesting an angular unconformity between them in this area. The Knobby Sandstone may be overlain by the Lower Carboniferous Laurel Formation in the Betty Terrace and Gregory Sub-basin.

Fossils and Time Stratigraphic Position The lycopod Leptophloeum australe (McCoy, 1874) collected by Casey & Wells (1964) previously indicated a Late Devonian to Early Carboniferous age. Abundant other fossil wood is undiagnostic in terms of age determination. The fish plates are fragments of placoderm fishes, including undetermined arthrodires (Tomlinson, 1968), Bothriolepis sp., Asterolepis sp., and crossopterygian remains (Young, in press). They indicate a Late Devonian age.

Environment of deposition The abundance of wood and plant remains, extensive medium and large-scale high-angle cross-bedding, and the absence of marine invertebrate fossils suggest a non-marine environment of deposition. Although Bothriolepis sp. is recognized as both a freshwater and

marine fish, most occurrences are freshwater. The predominance of coarse clastics indicate a fluvial rather than lacustrine environment.

Subsurface Lower Carboniferous, Undivided

In the Gregory Sub-basin and probably in parts of the Barbwire Terrace and the Betty Terrace, the Lower Carboniferous sandstone, siltstone, and limestone of the Laurel Formation (WAPET, 1972a) overlie Devonian rocks. In turn, it is probably overlain in the axial region of the Gregory Sub-basin by sandstone, siltstone, and shale of the Anderson Formation, the unit in which AQUITAINE Point Moody No. reached total depth (AAP, 1966). No rocks of proven Lower Carboniferous age are known to crop out in the area. In all places, they are overlapped by younger units.

Upper Carboniferous to Lower Permian

Grant Formation

Outcrops of the Grant Formation consist largely of cross-bedded quartzose sandstone and subordinate siltstone and shale. The unit averages about 1000 m in thickness. It is Late Carboniferous-Early Permian in age, and was deposited in both fluvial and marine environments, with at least minor glacial influence.

Distribution and Type Locality The Grant Formation, named from the type section outside the area in the Grant Range (Long. 124°05'E, Lat. 18°02'S) MOUNT ANDERSON, was first defined by Guppy et al. (1952). Throughout the Fitzroy Trough the formation is characterized by sandstone up to 3000 m thick, with minor siltstone, conglomerate, tillite, and varves. It unconformably overlies Lower Carboniferous, Devonian to Ordovician, and Precambrian rocks.

In the area the Grant Formation crops out as low rugged hills and dissected plateaux around Mt Mueller, BILLILUNA, and Mt Bannerman, MOUNT BANNERMAN; small isolated outcrops of tillite occur 22 km northeast of AQUITAINE Point Moody No. 1 well adjacent to the Stansmore Fault; conglomerate in the headwaters of Christmas Creek near Kai Ki Yard, MOUNT BANNERMAN is possibly part of the Grant Formation.

On the Crossland Platform and Barbwire Terrace, exposures of the Grant Formation occur along fault line scarps up to 35 m high, around French Hills and Fisher Bluff, CORNISH: at the western extremity of an outcrop 17 km west southwest of Pt Massie (CORNISH), 20 m of sedi-

ments is exposed. In all these areas the Grant Formation forms steep cliffs. Rocks mapped as possible Grant Formation are well exposed at Forebank Hills (HELENA).

The Grant Formation has been intersected in the following petroleum exploration wells: WAPET Lake Betty No. 1 (Fig. 42), AQUITAINE Point Moody No. 1 (Fig. 37), WAPET Crossland Nos 1, 2, 3 (Figs 39, 40, 41), WAPET Barbwire No. 1 (Fig. 43), and in BMR stratigraphic holes Billiluna No. 1 (B2), and Mount Bannerman Nos 3 and 4 (B3, B4).

Lithology The main rock type is a fine to coarse-grained cross-bedded quartzose sandstone. Minor rock types include quartz granule and pebble conglomerate, thin siltstone and shale beds, and polymictic conglomerate interpreted as tillite (Fig. 3).

The sandstone in the Mount Mueller and Mount Bannerman area is fine to medium and locally coarse-grained, quartzose, moderately sorted and contains intraformational clay clasts; wood impressions are common. The beds are prominently cross-bedded (A5) the dips of the foreset beds are as much as 22° and the cross-sets up to 2 m thick. Numerous conglomerate beds consisting of pebbles and granules of quartzite and vein quartz in a matrix of silt and sand are common, particularly at Mount Bannerman.

Locally, conglomerate sequences in the Grant Formation occur at outcrops in the headwaters of Christmas Creek, north of Cummins Range, and in an east-trending ridge 40 km east-southeast of Bulka Swamp. Clasts up to 1 m long are of quartz, quartzite, schist, and acid volcanic rocks.

In the French Hills and Fisher Bluff areas, the sandstone appears massive and is strongly resistant to weathering but in the unweathered exposures it is friable and cross-bedded. At both these localities and 17 km west-southwest of Point Massie (CORNISH) and at Forebank Hills (HELENA) the Grant Formation consists of thick beds of medium to coarse-grained quartzose sandstone interbedded with subordinate laminated shale and fine micaceous thin-bedded siltstone. The sandstone is composed of subrounded grains, is moderately sorted, and contains numerous lenses of intraformational clay-pellet conglomerates with rare quartz pebbles. It is extensively bioturbated, and worm tubes and trails are common.

Symmetrical and interference ripple marks are present on some bedding surfaces. Large scale cross-bedding with sets of cross strata 5 m thick and maximum dip of foreset beds of 25° is prominent.

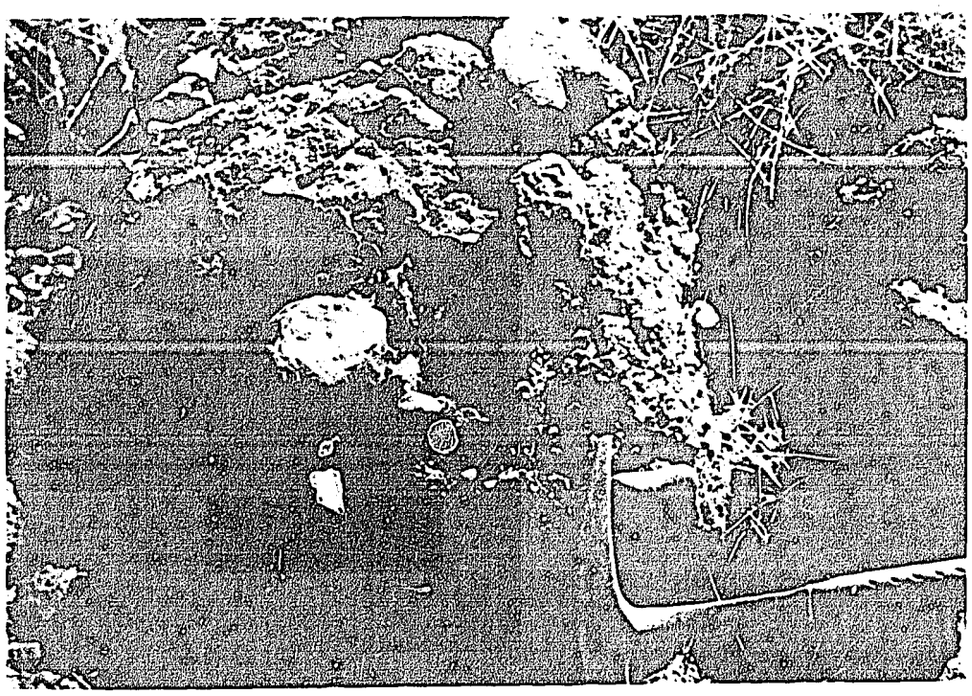


Fig. 3 Tillite consisting of unsorted pebbles and cobbles of quartz, quartzite, schist, granitic rocks, acid volcanics, and limestone set in an unsorted finer-grained matrix lacking bedding, 22 km northeast of Point Moody, STANSMORE. GSWA Negative

Tillite (Fig. 3) occurs at the eastern edge of the Stansmore Range 22 km northeast of Point Moody, STANSMORE. It consists of completely unsorted subangular to subrounded clasts of granite, schist, gneiss, quartzite, vein quartz, and limestone (derived from Precambrian source areas) in a slightly calcareous sandy matrix which locally makes up 60% of the rock.

In the subsurface, the Grant Formation consists predominantly of white, fine to coarse-grained quartzose sandstone, minor conglomerate and tillite, with interbedded fine to very fine-grained sandstone, grey argillaceous siltstone, and dark grey shale (WAPET, 1972a; 1972b). Thin carbonaceous seams and tillites were recorded in the Grant Formation from AQUITAINE Point Moody No. 1 (AAP, 1966). Calcareous beds occur at the base of the Grant Formation in WAPET Lake Betty No. 1 well (WAPET, 1972a).

Thickness The thickness in outcrop is not known as no complete sections were measured. In well sections, the following thicknesses are present: AQUITAINE Point Moody No. 1, 1240 m; WAPET Crossland No. 1, 950 m; WAPET Crossland No. 2, 1500 m; WAPET Lake Betty No. 1, 900 m; BMR Billiluna No. 1, at least 45 m; BMR Mount Bannerman No. 3, at least 30 m; BMR Mt Bannerman No. 4, at least 100 m.

The Grant Formation is known to be 2900 m thick in the Fitzroy Trough (Playford et al., in press).

Rock Stratigraphic Position The base of the Grant Formation is a widespread low-angle regional unconformity readily recognizable on seismic reflection records.

The Grant Formation overlies Precambrian rocks and the Ordovician Carranya Formation with angular unconformity and probably unconformably overlies the Upper Devonian Knoby Sandstone in BILLILUNA and LUCAS. In petroleum exploration wells, the Grant Formation unconformably overlies Carboniferous Anderson Formation in the Gregory Sub-basin (AAP, 1966) and the Devonian Mellinjerie Limestone, Tandalgoo Redbeds, and the Carribuddy Formation on the Crossland Platform (AAP, 1969c; 1974).

The Grant Formation is overlain everywhere with apparent slight disconformity by the Lower Permian Poole Sandstone; at Mount Mueller, BILLILUNA, the Noonkanbah Formation overlaps the Poole Sandstone in places and lies on the Grant Formation.

Fossils and Time-Stratigraphic Position Wood fragments, leaves, stem impressions, and trace fossils are present but of no use in age determination. The only marine macro-

fossils found are rare Pectinids (Etheripecten sp.). Microfloral assemblages of Permian age were obtained from Core 3 in BMR Billiluna No. 1 (Crowe, 1973). Palynological data from the subsurface of the Canning Basin indicates a Late Carboniferous to Early Permian (Sakmarian) age (WAPET, 1971c; 1972a; 1972b; AAP, 1966). Core samples in BMR Mount Bannerman Nos 3 and 4 give an Early Permian age (Appendix C).

Environment of Deposition In the Mount Muellier area, BILLILUNA, at outcrops in MOUNT BANNERMAN and 17 km west-southwest of Point Massie, CORNISH the fine to coarse grainsize, poor sorting, conglomerate pebbles, and high-angle large-scale cross-bedding all suggest high-energy river channel deposition; in the Fisher Bluff/French Hills area, CORNISH and Forebank Hills, HELENA symmetrical ripple marks, bioturbation including Rhizocorallium-type burrows suggest that the environment of deposition was shallow marine or at least brackish in these latter areas; this is also supported by the abundance of bedding-surface trace fossils in these areas, suggesting that the siltstone and shale may be tidal flat deposits.

In AQUITAINE Point Moody No. 1, a fining-upward sequence of sediments in interpreted from the SP log, which with lack of marine fossils in this section suggest deposition in a fluviatile environment for the Grant Formation. AAP (1966) have described the formation in this well as a sequence of brackish-water and fluvioglacial deposits. The tillite outcrop 22 km northeast of Point Moody supports a glacial origin for part of the formation.

In petroleum exploration wells, particularly WAPET Crossland No. 3, rare acritarchs occur near the top of the Grant Formation, suggesting a weak marine influence in that area.

Within the Gregory Sub-basin and the adjacent platform areas, the environment of deposition appears to have been of a moderate to high-energy fluvial regime during sand deposition, anaerobic during silt/clay deposition indicated by the preservation of carbonaceous material in WAPET Point Moody No. 1, and shallow marine.

The tillite in the Stansmore Range has a calcareous matrix, is laterally discontinuous, and was probably formed by debris released from floating ice as it melted in the sea.

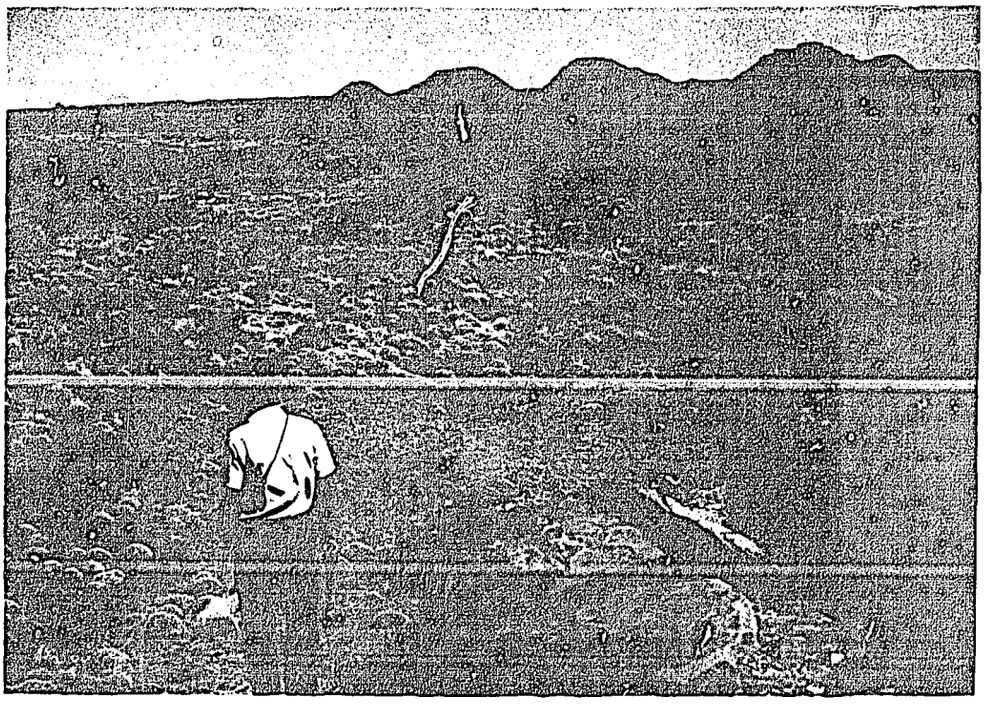


Fig. 4 Conical outcrops of Poole Sandstone at major joint intersections, Southesk Tablelands, CORNISH. BMR Negative GB/186

Permian

Poole Sandstone

The Poole Sandstone is a fine thin-bedded quartzose sandstone unit of Early Permian age.

Distribution and Type Locality The Poole Sandstone (Guppy et al., 1952) in the Fitzroy Trough consists of white and brown, well-bedded, fine-grained, micaceous quartzose sandstone and minor shale. The type area is in the Poole Range (Long. 125°45'E, Lat, 18°50"S) where the name was first used by Talbot (1927).

In the northeast Canning Basin, the unit was mistaken for the Upper Permian Condren Sandstone and was not identified in outcrop nor photo-pattern by Casey & Wells (1964); its 'absence' they thought was due to overlap by the Noonkanbah Formation (Veevers & Wells, 1961). Such overlap is known to occur locally near Mount Mueller, BILLILUNA, but more detailed mapping during the 1972 and 1973 field seasons resulted in recognition of the Poole Sandstone throughout a large part of the area.

The Poole Sandstone is exposed at several localities: it crops out discontinuously in anticlinal cores and as strike ridges in the Stansmore Range; in a fault-bounded block in the breakaway near Namalook Rockhole (LUCAS): at Mount Bannerman; in places south of and around Mount Mueller, BILLILUNA; in the Southeast Tablelands and east of French Hills (CORNISH), and near Thornton Flat (HELENA). In the Southesk Tablelands, conical-shaped outcrops occur at major joint intersections (Fig. 4) where there has been preferential surface silicification.

In the subsurface, sections in the various petroleum wells - WAPET Lake Betty No. 1 (Fig. 42), AQUITAINE Point Moody No. 1 (Fig. 37), WAPET Crossland Nos 1, 2, and 3 (Figs 39, 40, 41) - a quartzose sandstone unit overlying the Grant Formation has been identified as the Poole Sandstone. BMR Billiluna No. 1, and BMR Mount Bannerman Nos 3 and 4 also intersected Poole Sandstone (B3, B4).

Lithology The main rock type is quartzose sandstone; siltstone is minor. The sandstone is white to light grey, fine-grained, thin-bedded to laminated, clean, and well sorted, and the individual grains are subangular to subrounded. The beds are commonly planar but some low-angle cross-bedding in sets up to 0.5 m thick with maximum dips on foresets usually less than 5° are present. Flakes of detrital mica are generally present on the bedding surfaces. Parting lineations are present. Thin interbeds of laminated siltstone and shale are common.

The uniformly fine-grained, thin-bedded nature of the sandstone differentiates this from other Permian sandstone units. Well preserved symmetrical and asymmetrical wave-formed ripple marks are a characteristic feature of the unit. Organic trails are abundant in some places e.g. in the Thornton Flat area.

Where weathered, the unit is dark-brown, ferruginized and/or slightly silicified, and in places its scree has a blocky appearance. East-west joints are characteristic in the Poole Sandstone in southern CORNISH and northern HELENA. South of Dummer Range Fault, the Poole Sandstone may be coarse-grained, as in AQUITAINE Wilson Cliffs No. 1 and AQUITAINE Contention Heights No. 1 (AAP, 1969d; 1974).

Thickness Incomplete sections of up to 100 m of sandstone were measured in the Stansmore Range (A6, A7). No other sections were measured but the formation is about 180 m thick in the French Hills (Evans & Brown, 1974).

In the subsurface, the following thicknesses have been penetrated:- WAPET Lake Betty No. 1, 114 m; AAP Point Moody No. 1, 312 m; WAPET Crossland Nos 2 and 3, 63 m and 73 m respectively; BMR Billiluna No. 1, 34 m; BMR Mt Bannerman Nos 3 and 4, at least 40 m and 26 m respectively. These sections show that the Poole Sandstone thickens towards the axial region of the Gregory Sub-basin.

Rock-Stratigraphic Position In the Stansmore Range about 17 km west-southwest of Point Massie (CORNISH) the Poole Sandstone rests disconformably on the Grant Formation. At Mount Bannerman, the boundary appears conformable. In AQUITAINE Point Moody No. 1 well, the two units grade into each other (AAP, 1966).

Few contacts with the overlying Noonkanbah Formation were observed in the field but from these observations, subsurface data, and regional structure, it is considered to be conformable and gradational as in BMR Billiluna No. 1 (Crowe, 1973).

Fossils and Time Stratigraphic Position The Poole Sandstone is mainly unfossiliferous in the Gregory Sub-basin. Marine macrofossils in quartzose sandstone considered to be at the top of the Poole Sandstone or in a sandstone unit near the base of the Noonkanbah Formation near Namalook Rockhole indicate an early Artinskian age (Dickins & Jell, 1974). Core 2 from BMR Billiluna No. 1 (Crowe, 1973) contains a rich spore assemblage which indicates a time range from early to late Artinskian (R. Paten, pers. comm.). Plant fossils at Mount Bannerman indicate an Early Permian age (White and Yeates, in prep.).

Environment of Deposition The occurrence of laterally continuous, thin-bedded, well sorted quartzose sandstone with subordinate siltstone beds and abundant wave-formed ripple marks indicate uniform conditions of sedimentation in very shallow water. The uniform, fine, well sorted, laminated characteristics of the Poole Sandstone over a large area, and the nature of cross-bedding suggest a marine (largely inter-tidal) environment. The carbonaceous units encountered in BMR Billiluna No. 1 and BMR Mount Bannerman Nos 3 and 4 and the plant-bearing unit at Mt Bannerman could be lagoonal, estuarine or marsh facies of a coastal plain near the shoreline at time of deposition.

We consider that the Poole Sandstone was deposited during a shallow-marine transgression north of Dummer Range Fault during a period of gentle subsidence; the sandstone may largely be derived from marine reworking of underlying deposits of the Grant Formation. South of Dummer Range Fault, the Poole Sandstone may have been deposited by rivers, as descriptions of lithology in AQUITAINE Wilson Cliffs No. 1 and AQUITAINE Contention Heights No. 1 differ from those north of the fault. The characteristics described (AAP, 1969d; 1974) agree more with river deposits than shallow-marine.

?Nura Nura Member

The Nura Nura Member (Guppy et al., 1952) is the basal part of the Poole Sandstone at Nura Nura Ridge (Long. 124°28'E, Lat. 18°02'S) in the Fitzroy Basin. The only rocks assigned to the Member in the Gregory Sub-basin area crop out at one locality in an anticlinal core adjacent to the Stansmore Fault (STANSMORE).

The upper contact with the Poole Sandstone is transitional; its lower contact with the Grant Formation is also transitional.

In its type area, the Nura Nura Member is very fossiliferous (Guppy et al., 1958; Veevers & Wells, 1961) and an upper Sakmarian age is indicated by the macrofauna and palynological data.

The sequence of the Nura Nura Member represents a marine incursion during the late Sakmarian.

We tentatively assigned the Nura Nura Member to the outcrops in the Stansmore Range in 1972 on the basis of the calcareous sandstone lithology. No fossils were found at this locality. However, because the Grant Formation contains calcareous rocks, this unit could be part of the Grant Formation.

Noonkanbah Formation

The Noonkanbah Formation is a soft-weathering unit, conspicuous by its poor outcrops of shale, siltstone, calcareous siltstone, minor sandstone, and limestone.

Distribution and Type Locality The name Noonkanbah Formation (Guppy et al., 1958) was derived from Noonkanbah homestead (Long. 124°48'E, Lat. 18°30'S) near the type locality in the Fitzroy Trough. It crops out commonly as rubble adjacent to deflation flats, claypans, and plains or sandy soil areas in which sinuous lines of vegetation, readily recognizable on aerial photographs, mark the strike of the outcropping more resistant calcareous beds.

In the eastern Canning Basin, the Noonkanbah Formation crops out over a considerable area. In BILLILUNA, outcrops are restricted to isolated subhorizontally bedded rocks south of Mount Mueller. Around Balgo Mission in LUCAS, many exposures originally photo-interpreted as the Lightjack Formation of the Liveringa Group by earlier workers (Casey & Wells, 1964) are now considered part of the Noonkanbah Formation.

Low rises of the formation occur around Bull Flat, Christmas Creek, and Salt Creek (MOUNT BANNERMAN). Rubbly outcrops of fontainbleu siltstone crop out on the flat plains across the northern part of CROSSLAND, just south of the Shore Range and near Dean Hill. Relatively fresh exposures of interbedded limestone and sandstone occur in the small fault blocks in the Hall Range, CROSSLAND.

Rocks exposed in northeast DUMBAR and southern CROSSLAND are deeply weathered and ferruginized. They have been mapped as Noonkanbah Formation on general outcrop appearance, the presence of sinuous vegetation lines common to this unit, and fossils.

In CORNISH, the best exposures of the formation are at Point Massie; a distinctive vegetation pattern in aerial photographs and fossils have confirmed Noonkanbah Formation west of Mt Stewart and on the flat deflation plains west of Fisher Bluff and French Hills. Low rubbly outcrops of fountainbleu sandy limestone rising from Thornton Flat, HELENA are also mapped as Noonkanbah Formation. In STANSMORE, the Noonkanbah Formation is exposed in the Stansmore Range and in an anticline around Point Moody.

The Noonkanbah Formation has been intersected in petroleum exploration wells WAPET Lake Betty No. 1, AQUITAINE Point Moody No. 1, WAPET Crossland Nos 2 and 3; and in stratigraphic holes BMR Billiluna No. 1, and BMR Mount Bannerman No. 4.

Lithology The Noonkanbah Formation consists of siltstone, shale, calcareous siltstone, fontainbleu limestone, minor coquinite beds rare phosphatic beds, and sandstone lenses. It is laminated throughout. Both calcareous and ochreous concretions occur in places. Chemical analyses of these rocks are summarized in Table 9.

The siltstone and shale units are grey to green, highly micaceous, laminated to thinly bedded and are characterized by very low-angle small-scale cross-bedding and by ripple marks preserved on some of the bedding surfaces. The interbedded fontainbleu limestone and calcareous siltstone are light grey, fine-grained, thin-bedded and form prominent lines of float on lowland plains. Coquinite beds cropping out around Balgo Mission and south of Mount Mueller form locally persistent marker beds consisting of numerous whole or fragmentary shells replaced by calcite set in a calcite and siltstone matrix. Some calcareous beds are highly ferruginous due to weathering, and the shells are preserved as casts.

At Point Massie, CORNISH, coarse-grained sandstone lenses are prominent in the Noonkanbah Formation. The sandstone there is buff to grey, quartzose, poorly sorted, and contains both angular and spherical grains. It is pebbly in places.

A local marker bed of grey, fine to medium-grained quartzose micaceous sandstone occurs about 100 m above a richly fossiliferous limestone at Tula yard and in the Salt Creek area, northwest MOUNT BANNERMAN.

In the sub-surface, the formation consists of dark grey, thinly bedded, commonly pyritic, carbonaceous, slightly calcareous, micaceous shale and siltstone with a few interbeds of grey, very fine-grained silty sandstone.

Petrography The fontainbleu siltstone has a fairly even grainsize (0.125 mm) and most of the grains are angular. The main minerals present are quartz, and minor amounts of iron oxide, muscovite, clay minerals, and rare feldspar, set in a calcareous cement.

The cement is calcite which has grown as large crystals enclosing grains. The iron minerals appear as opaque grains associated with mica and form very fine layers in thin section.

Thickness A section measured in the Stansmore Range totalled 52 m (A9).

In the well sections, thicknesses are at least 330 m in AQUITAINE Point Moody No. 1 (AAP, 1966); 300 m in WAPET Lake Betty No. 1 (WAPET, 1972a); 130 m in WAPET Crossland No. 2; 90 m in WAPET Crossland No. 3 (WAPET, 1971c); and at least 43 m in BMR Billiluna No. 1.

Rock-Stratigraphic Position The contact between the Noonkanbah Formation and the underlying Poole Sandstone in the Stansmore Range is conformable and gradational. This relation also exists in BMR Billiluna No. 1. The Noonkanbah Formation is conformably overlain by the Lightjack Formation except in the Balgo Hills area where an erosional break is marked by an intraformational clay pellet conglomerate at the base of the latter unit.

Fossils and Time-Stratigraphic Position Marine invertebrate fossils including brachiopods, pelecypods, and gastropods are abundant in the Noonkanbah Formation (Dickins & Jell, 1974). This formation contains the richest Permian faunal assemblage known from the Canning Basin. A few phosphatized fish and shark teeth and bones are present in coquinas near Balgo Mission.

There appear to be at least three biostratigraphic subdivisions within the formation. The fossils occur as coquinite beds or within intraformational clay pellet conglomerate at the top of the formation. In the clay pellet conglomerate which is commonly ferruginized and concretionary, the pelecypod Atomodesma mytiloides which is characteristic of the Noonkanbah Formation is the most common species present.

Numerous brachiopods (Thomas, 1958), bryzoans (Crockford, 1957), and pelecypods (Dickins, 1958) have been identified from the formation elsewhere in the Canning Basin (Veevers & Wells, 1961); the age is Artinskian.

Other fossil remains include trace fossils, organic trails, foraminifera (R. Nicholls, pers. comm.); no conodonts were found in the limestones.

Well preserved microfloral assemblages from cuttings and cores in BMR Billiluna No. 1, BMR Mt Bannerman No. 4, (Appendix C) and from AQUITAINE Point Moody No. 1 indicate an Early Permian age (R. Paten, pers. comm: APP, 1966).

Environment of Deposition In the Balgo Hills area, the fine-grained thin-bedded arenaceous and calcareous fossiliferous sediments and coquinite interbeds of the Noonkanbah Formation indicate accumulation in a shallow-water marine environment under low-energy conditions. Local concentra-

tions of limonite and detrital limonite probably also indicate a near-shore environment for part of the sequence. The presence of both chemically and biochemically deposited limestone and ochreous phosphorite and of small-scale sedimentary structures indicates quiet sedimentation for the formation, with periods of non-detrital deposition.

The abundance of sands in the formation e.g. at Point Massie (CORNISH), Hall Range (CROSSLAND), and in DUMMER may be due to near-shore wave deposition of clastics.

In general, the Noonkanbah Formation represents a continuation of sedimentation in the shallow sea in which much of the Poole Sandstone was deposited.

Liveringa Group

The name Liveringa Group (Yeates et al., 1974) is used for the sequence of interbedded siltstone, sandstone, shale, and minor conglomerate which lies disconformably and unconformably beneath the Blina Shale, Millyit Sandstone, and Barbwire Sandstone and conformably overlies the Noonkanbah Formation. The type section is on Liveringa Ridge near the southern flank of the Grant Range (Lat. 18°08'S, Long, 124°E., MOUNT ANDERSON) outside the area.

The sequence was first named Liveringa Formation by Guppy et al. (1958) who recognized three lithological units; the Lightjack Member, the middle unit, and the Hardman Member. The middle unit was named the Condren Sandstone Member (Casey & Wells, 1964) in the northeast Canning Basin. Since these members have now been widely recognized, and since the Hardman Member can be separated into three distinct units, the members have been upgraded to formation status and the Liveringa Formation to group status (Yeates et al., in press). The group now consists of the following formations:-

Top	Hardman Formation	marine and deltaic
	Condren Sandstone	fluvial deltaic
Base	Lightjack Formation	marine and paralic

In the northeast Canning Basin, Casey & Wells (1964) recognized a Balgo Member (named from Balgo Mission LUCAS; Lat. 20°08'S, Long. 127°48'E). Mapping in 1973 showed that this member was lithologically, stratigraphically, and palaeontologically equivalent to the Lightjack Member and the former name has been dropped in favour of the term Lightjack following Playford et al. (in press) as continuity of the unit throughout the area has now been established.

The sequence mapped as Godfrey Beds is now regarded as an equivalent of the Hardman Formation of the Liveringa Group. On the basis of Rhizocorallium burrows, Casey & Wells (1964) considered the Beds to be Lower Cretaceous. However, they contain remains of a Permo-Triassic plant and their stratigraphic relations with adjacent units indicate that they may be a lithologic equivalent of the Hardman Formation. Rhizocorallium-type burrows have been found in the Lightjack Formation and Grant Formation, proving that this fossil is not restricted to the Cretaceous as once thought (see Veevers, 1962).

At its type section, the Liveringa 'Formation' is 564 m thick but it is not complete. Between Mt Ibis and Mt Hardman (NOONKANBAH) the thickness is 915 m (Guppy et al., 1958).

Fossils have been collected from all the formations of the Group. They include brachiopods, pelecypods, gastropods, scaphopods, trace fossils, and plants. The age of the fossils range from late Artinskian in the Lightjack Formation to late Tatarian in the Hardman Formation (Guppy et al., 1958).

Lightjack Formation

The Lightjack Formation is the basal unit of the Liveringa Group. It has a regional marker bed of fossiliferous concretionary siltstone at its base, and comprises thin-bedded sandstone, siltstone, minor conglomerate, and shale.

Distribution and Type Locality The Lightjack Formation crops out over a wide area of the northeastern and eastern parts of the Canning Basin. The sandstone units are relatively resistant and form small mesas; the siltstone weathers easily, is ferruginous, and crops out at the base of the hill slopes or occurs as ferruginized rubble flanking mesas. The name is derived from Lightjack Hill (Lat. 18° 59'S, Long. 125°50'E) NOONKANBAH, the type section (Guppy et al., 1958).

In BILLILUNA the formation is restricted to outcrops in the extreme southwest. Exposures occur in the breakaways and mesas east of Gunnawarrawarra Rockhole, around Micha Bore, and near Thomas Peak in LUCAS. Farther south in STANSMORE, the Lightjack Formation crops out extensively along the scarps of the Stansmore Range, and also to the southwest along the prominent Waterlander Breakaway. It has also been mapped east of the Stansmore Range on the northern edge of STANSMORE.

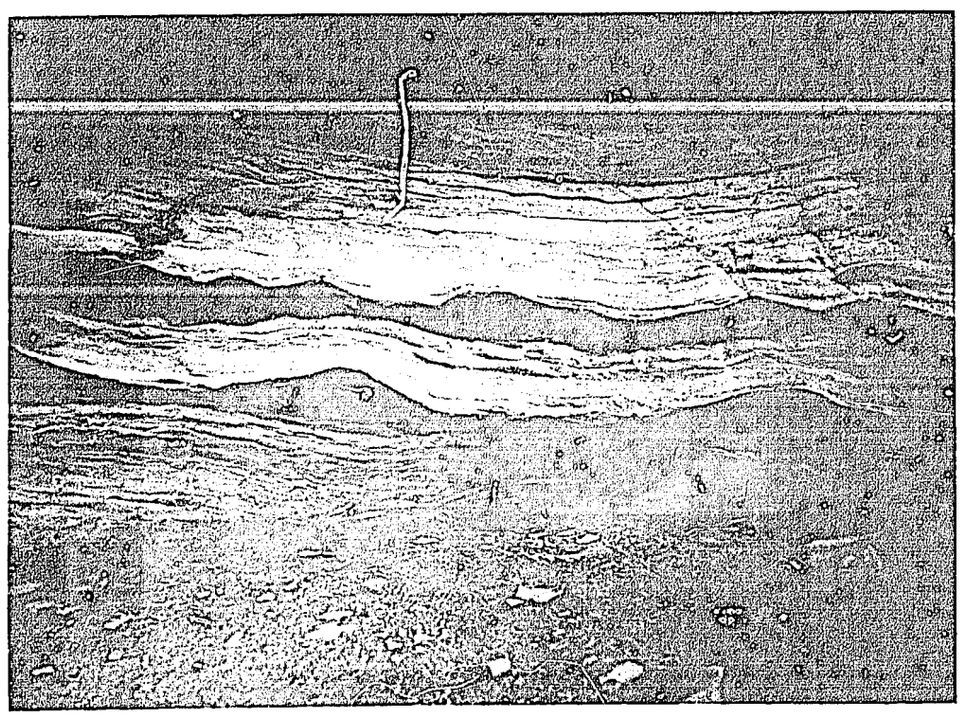


Fig. 5 Megarippled lenticular coarse sandstone interbedded with laminated to thinly bedded fine-grained micaceous sandstone. Lightjack Formation, southern side of Millyit Range, CROSSLAND. BMR Negative GB/190

In WEBB, along the continuation of the Waterlander Breakaway, and at isolated nearby low hills, the rocks were also mapped as Lightjack Formation.

In CORNISH, in the Southesk Tablelands, the formation is best exposed along a line joining Mt Romilly through Mt Stewart to Mt Fothringham. This line is a conspicuous feature on the aerial photographs with its characteristic darker tone than the surrounding country. Farther southeast, the rocks of the formation constitute part of the Roberts Range.

At several localities in HELENA, poor outcrops of the formation are exposed in low strike-ridges and rubble-covered hills in the eastern part of Thornton Flat, and in the southeastern corner.

The Lightjack Formation has been intersected in WAPET Lake Betty No. 1; BMR stratigraphic holes Lucas No. 14 (B5), Crossland Nos 1 and 2 (B6, B10) and Mt Bannerman No. 2 (B9).

Lithology The Lightjack Formation consists of lower and upper units of micaceous siltstone, shale, and silty sandstone with thin lenses of coarse to very coarse-grained sandstone and a middle unit of medium-grained quartzose sandstone in CROSSLAND, MOUNT BANNERMAN, and CORNISH. The middle unit is readily distinguishable on aerial photographs by its lighter tone relative to the upper and lower units, and on electric logs (e.g. BMR Mt Bannerman No. 2). Minor rock types include thin beds of ochreous limonite, intraformational breccia, and concretionary layers. Lithologies are shown diagrammatically in A9, A10, A11, A12, A13, A14, and A15.

The upper and lower units are laminated to thinly bedded, and characterized by low-angle small-scale cross-bedding, ripple cross-lamination, and abundant ripple marks (Fig. 5). The silty sandstone is labile, micaceous, fine-grained, poorly sorted, and ferruginous at the surface. Intraformational clay-pellet conglomerates are common throughout the lower unit. At the base of the sequence, the clay pellet conglomerate with abundant fossils forms a distinctive basal marker bed throughout the area (Fig. 6). The clay pellets commonly form the nucleus for ferruginous concretions 2 to 20 cm across (e.g. near Balgo Mission, LUCAS and Arundel Bore, CROSSLAND). The presence of these concretions associated with fossils on the scree plains indicates proximity of the boundary between the Lightjack Formation and the Noonkanbah Formation. The concretions are manganese rich (Table 9). Concretionary beds of ochreous limonite are in places abundant at the Lightjack Formation/Condren Sandstone contact.

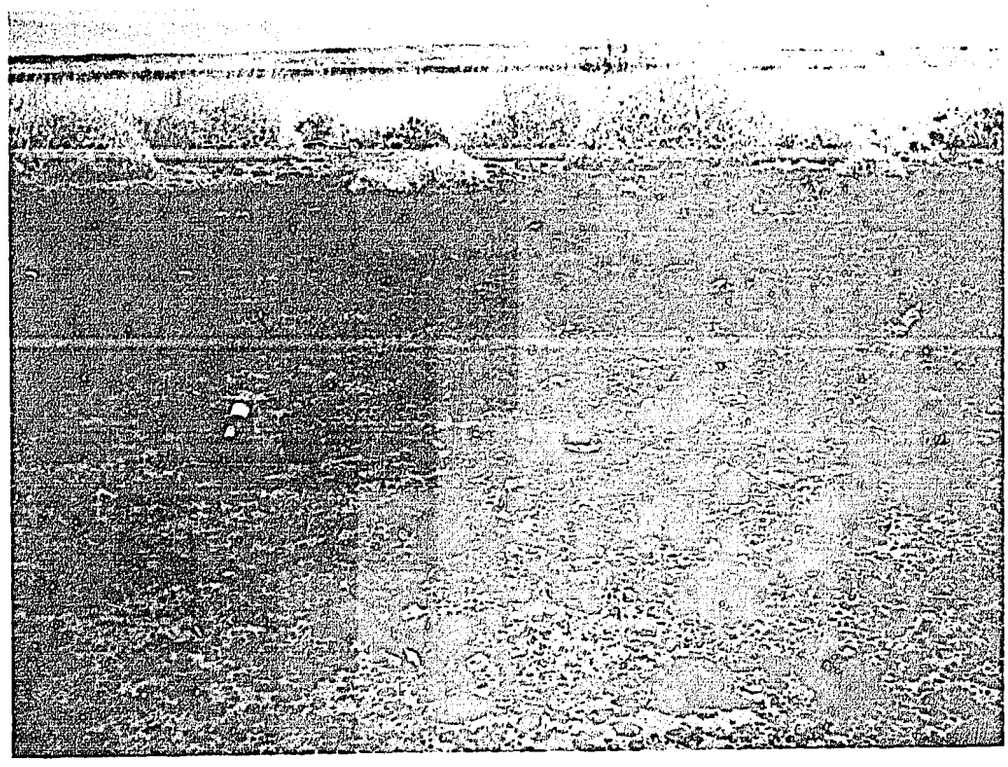


Fig. 6 Outcrop of fossiliferous concretionary ironstone, the marker bed at the base of the Lightjack Formation, at Arundel Bore, CROSSLAND. Most of the concretions have been weathered out of their soft siltstone matrix. BMR Negative GB/169

Bioturbated zones, burrows (Fig. 14) and numerous trace fossils (Figs 7-13) are common in the siltstone sequence. Ochreous ironstones composed of goethite with small amounts of quartz, feldspar, mica, and kaolinite are interbedded with the bioturbated siltstones and intraformational breccia. The ironstones are primary, chemically deposited, or possibly biochemically deposited sedimentary rocks, some of which have sand-filled burrows. They contain up to 55% Fe_2O_3 (Table 9).

The lenses of sandstone up to 1 m thick are pale to dark brown, hard, porous, coarse to very coarse-grained, moderate to poorly sorted, and consist mainly of subangular grains set in a very fine-grained sandstone matrix.

The distinctive middle sandstone unit succeeds the basal unit e.g. in the Barbwire Range, CROSSLAND, and at Mt Fothingham, CORNISH, but not in LUCAS and STANSMORE. This sandstone unit consists predominantly of clean friable white quartz sandstone mainly in beds up to 3 cm thick or in cross-bedded units up to 30 cm thick. It is fine to medium-grained, well sorted, and laminated in places; the individual grains are rounded to subrounded. Mica is common on bedding surfaces, and ripple marks and clay pellets are present.

In the subsurface, the Lightjack Formation consists of grey to black siltstone with carbonaceous laminae, interbedded grey fine-grained micaceous labile sandstone, and quartzose sandstone.

Thickness During the 1972 and 1973 field seasons, the following sections were measured: 152 m, 221 m (A9) and 255 m (A12) in the Stansmore Range; 87.5 m near Mt Stewart (CORNISH); 50 m in the Stretch Range (A13) 18 m at Gumbo Point (LUCAS) (A14), 85 m and 79 m at Rowley Rock and in the Halls Range (CROSSLAND) (M. Galloway, pers. comm.). Most of the sections are incomplete owing to erosion.

In the following BMR stratigraphic holes, the minimum thicknesses of sediments intersected were 90 m in Lucas No. 14, 100 m in Crossland No. 1, and 55 m in Mt Bannerman No. 2 (see Appendix B).

Rock Relations In most areas, the contact between the Lightjack Formation and the overlying Condren Sandstone is conformable and gradational, the boundary being placed just below the first bed of quartzose sandstone. In the Barbwire Range, CROSSLAND an angular unconformity exists between the Lightjack Formation and the overlying Jurassic Barbwire Sandstone. In part of LUCAS, the Lightjack Formation is disconformably overlain by the Godfrey Beds.

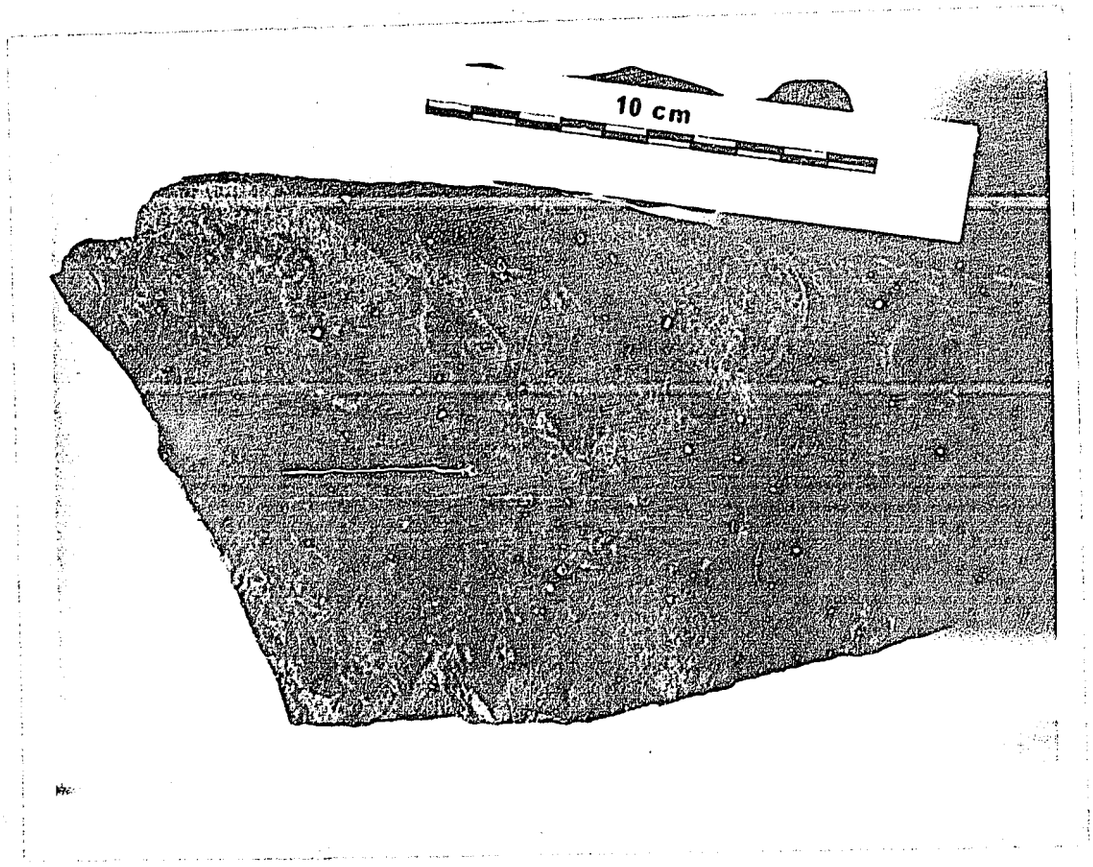


Fig. 7 Trace fossil in ferruginized micaceous sandstone of Lightjack Formation near Gunnawarrawarra Rockhole, LUCAS 1:250 000 Sheet area. BMR Negative M1919.

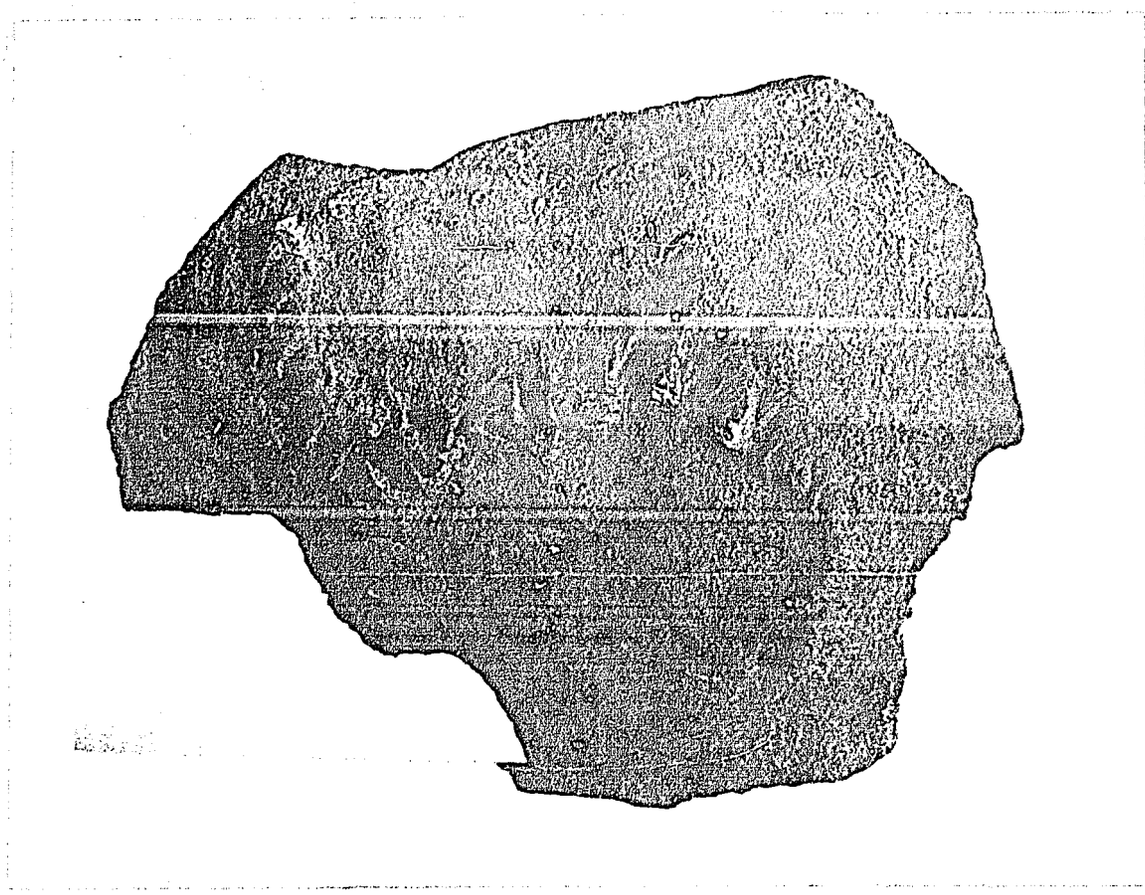


Fig. 8 Trace fossil in micaceous sandstone of Lightjack Formation, 6 km southwest of Dooma Dora yard, LUCAS. XI. BMR Negative M/1919

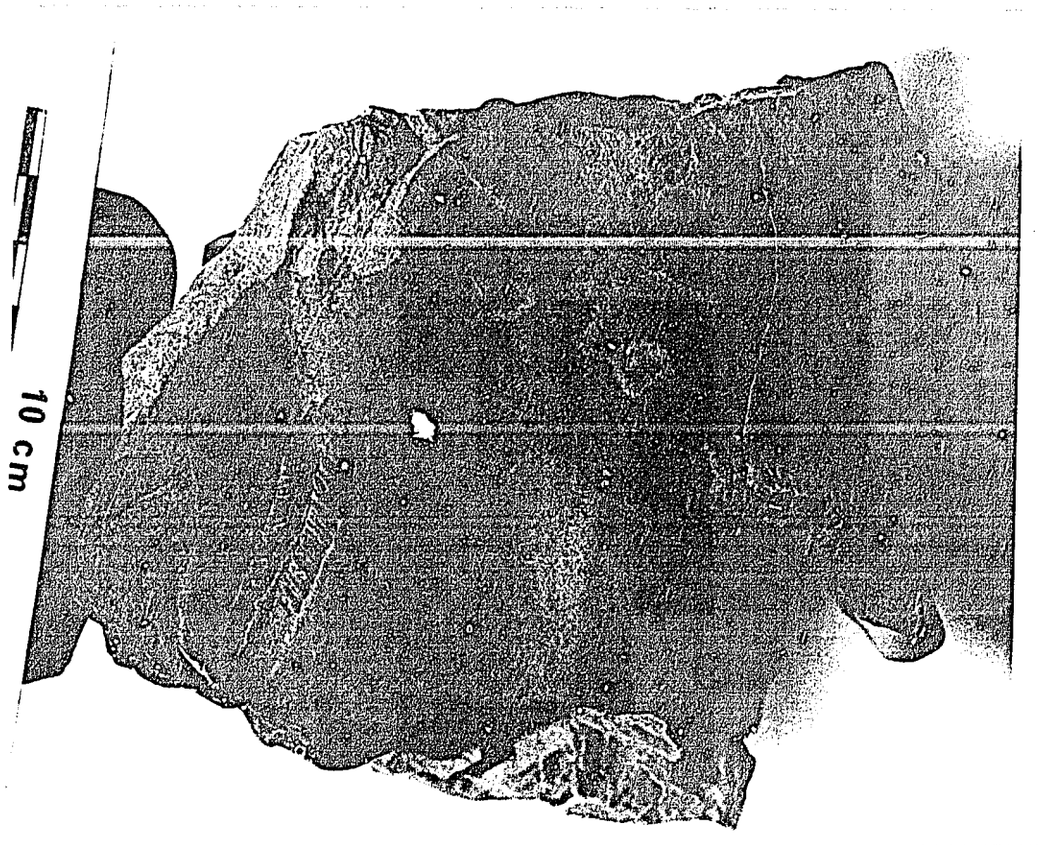


Fig. 9 Trace fossils in ferruginous siltstone of Lightjack Formation, Hall Range, CROSSLAND. BMR Negative M/1919.

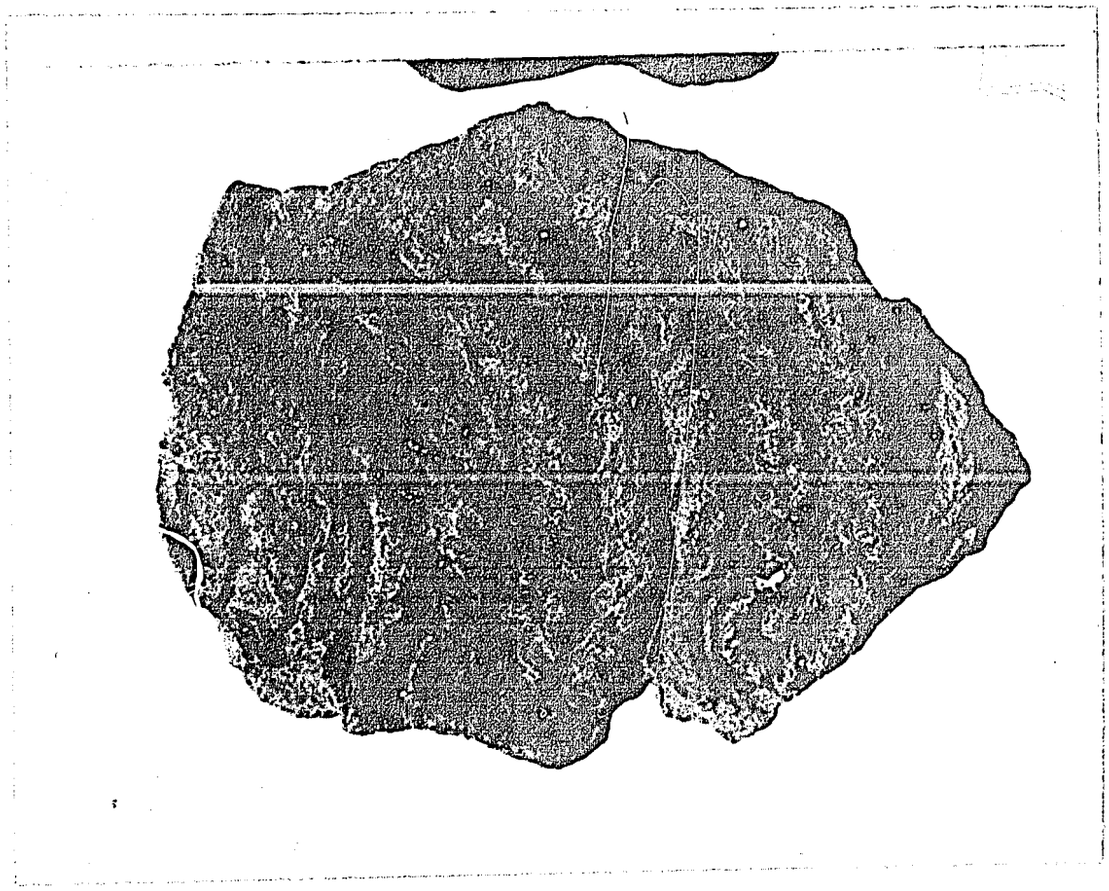


Fig. 10 Trace fossil in ferruginous sandstone of Lightjack Formation, southern Stansmore Range, STANSMORE. BMR Negative M/1919.

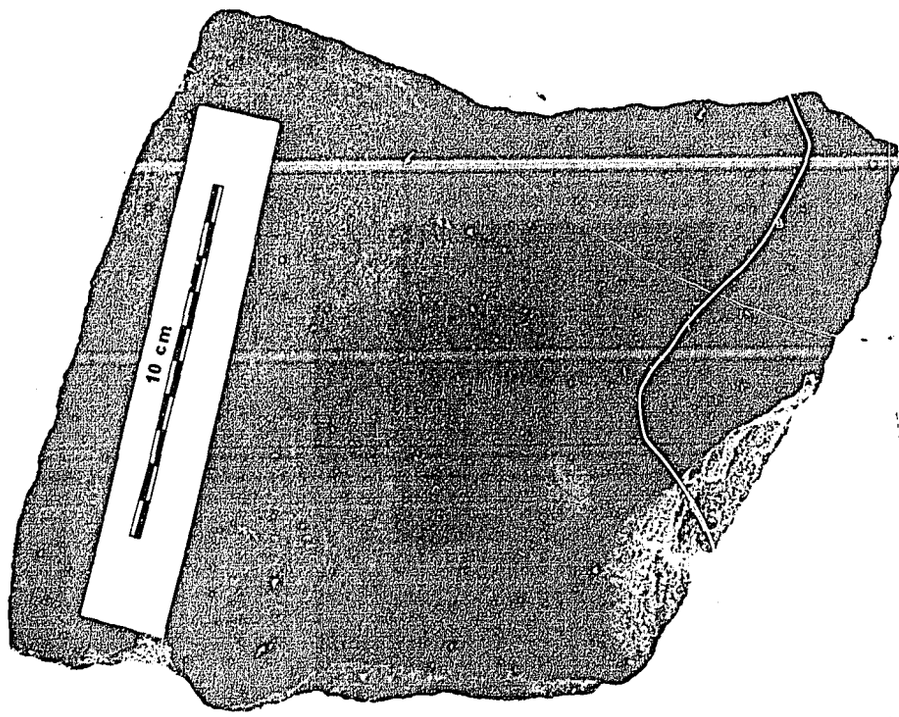


Fig. 11 Trace fossil on lower surface of a quartzose sandstone bed in Lightjack Formation, 11 km west of Warri Peak, STANSMORE. BMR Negative M/1919.

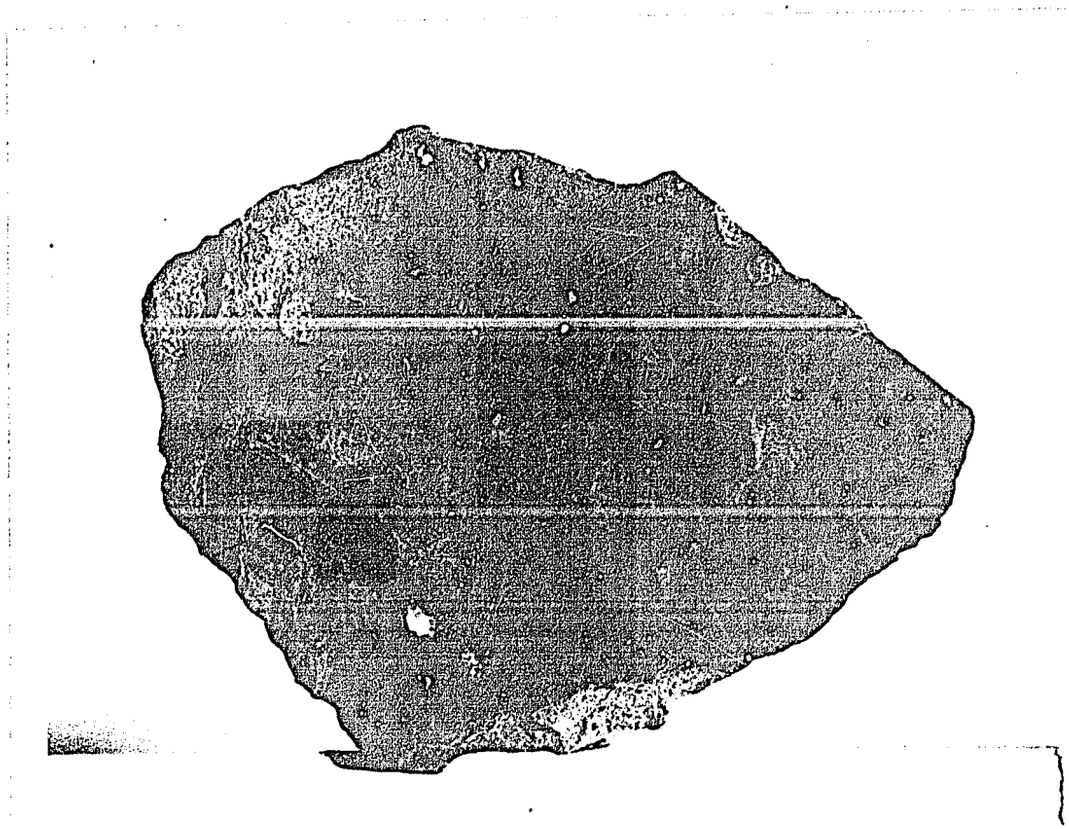


Fig. 12 Ferruginized organic trails in micaceous siltstone of Lightjack Formation, near Old Balgo Mission, LUCAS. BMR Negative M/1919.

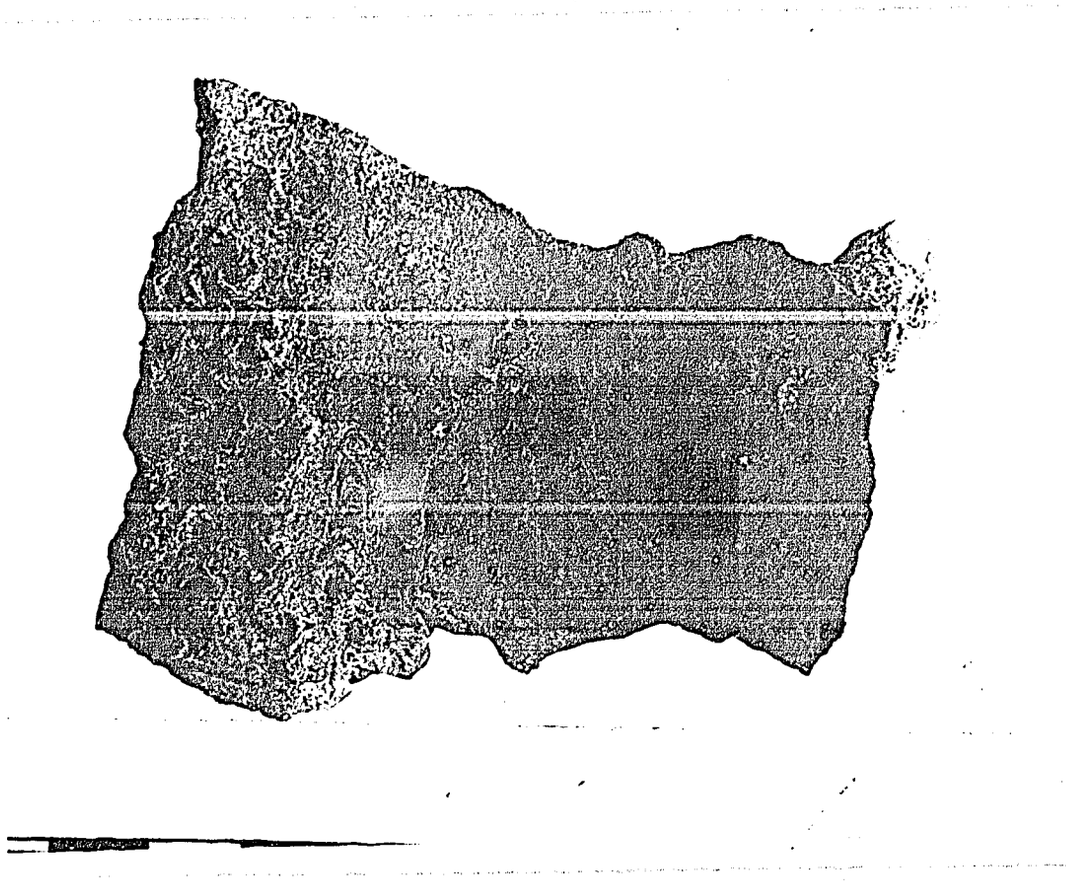


Fig. 13 Trace fossil in ferruginized micaceous siltstone of Lightjack Formation, near Old Balgo Mission, LUCAS. BMR Negative M/1919.

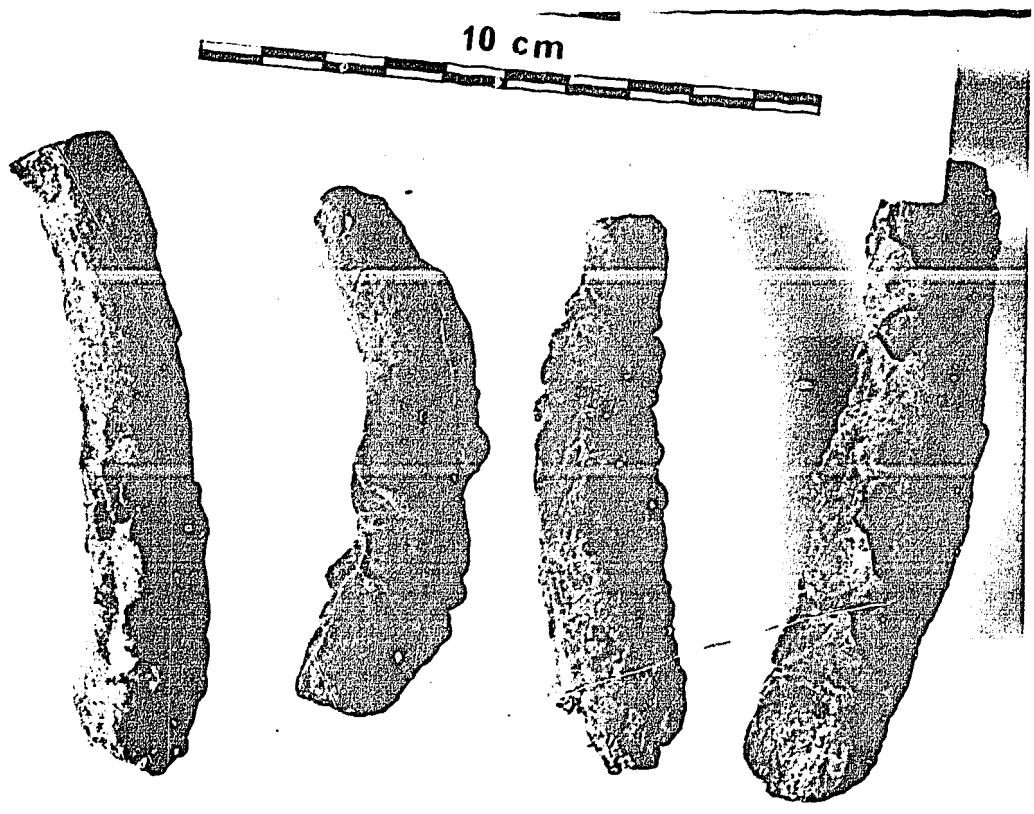


Fig. 14 Ferruginized sandstone moulds of burrows from which the surrounding soft-weathering shale has been removed. Lightjack Formation northwest MOUNT BANNERRAN. BMR Negative M/1919

The contact between the Lightjack Formation and the underlying Noonkanbah Formation is gradational and conformable except in the Balgo Hills (LUCAS) where the units are slightly disconformable.

Fossils and Age Fossils in the Lightjack Formation include pelecypods including large Pectinids, gastropods, schaphopods, a few brachiopods, trace fossils (Figs 7-13) coprolites, burrows (Fig. 4), and rare plant fragments. The pelecypods Atomodesma exerata and Stutchburia muderongenses are characteristic. The fossils indicate a late Artinskian to early Kungurian age (Dickins, in prep.).

Environment of Deposition The broad similarity of the lithologies of the Noonkanbah Formation and the Lightjack Formation suggests a continuation of sediment deposition under fairly low-energy conditions in an extensive shallow sea. The thick body of quartz sandstone in the middle of the Formation in some areas may be an intertidal deposit.

The dark carbonaceous clayey siltstone, shale, and silty sandstone comprising much of the Lightjack Formation in the Gregory Sub-basin may reflect continuing deposition in a shallow sea with restricted circulation, and low topography landward. The intraformational clay pellet conglomerates may have been formed by either the reworking of the cracked mud on emergent marginal flats and the subsequent deposition of the pellets by later tides. The ironstones may have precipitated close to the saltwater/freshwater interface following Borchert (1960) and Stanton (1972), which would fit a tidal flat setting. The conglomeratic beds in the Roberts Range (CORNISH) include clasts of soft-weathering Precambrian schist probably derived from reworking of the Grant Formation. This suggests that some of the Crossland Platform was emergent in this area during deposition of the Lightjack Formation, a fact further supported by the absence of the Lightjack Formation in much of the Platform. The underlying Noonkanbah Formation, however, is present in the Crossland Platform. This therefore suggests that the sea became confined mainly to the Gregory Sub-basin and its adjacent Terraces during Lightjack Formation time, or that it also covered other areas and deposited a negligible amount of sediment, or that other areas were not subsiding, thus not allowing accumulation of sediment.

Condren Sandstone

Distribution and Type Locality The Condren Sandstone is the middle formation of the Liveringa Group; it was previously termed the 'middle member' in the Fitzroy Trough (Guppy et al., 1958). The name is derived from Condren Pinnacles

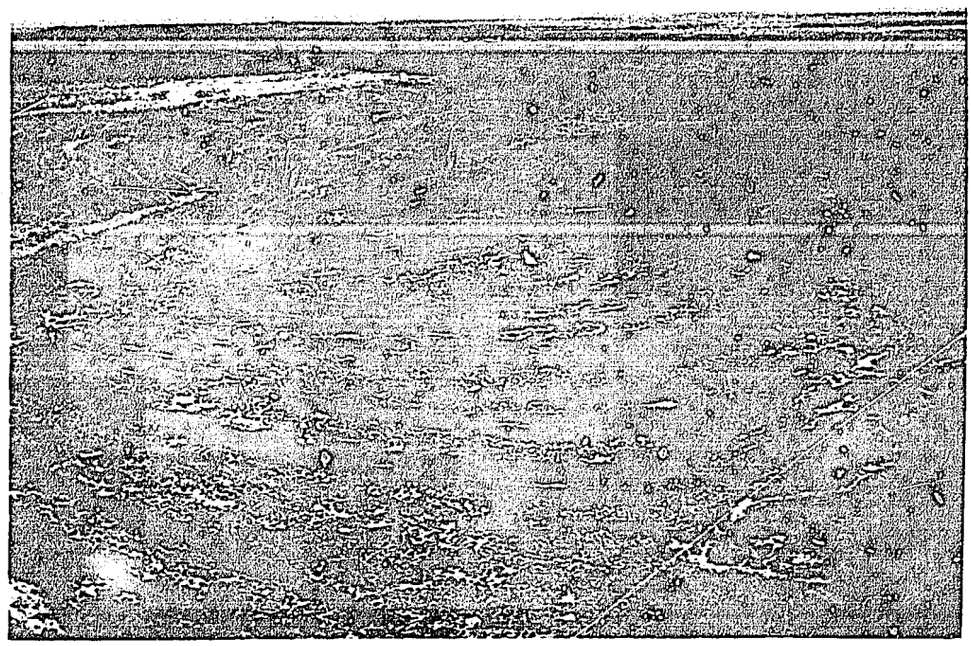


Fig. 15 Condren Sandstone. Relatively resistant beds of quartzose sandstone define strike ridges and basin-and-dome type folding in parts of the Stansmore Range, STANSMORE. Between each resistant bed is soft weathering kaolinitic quartzose sandstone and kaolinitic siltstone. This example of cyclic sedimentation was formed by meandering rivers. BMR Negative GB/206

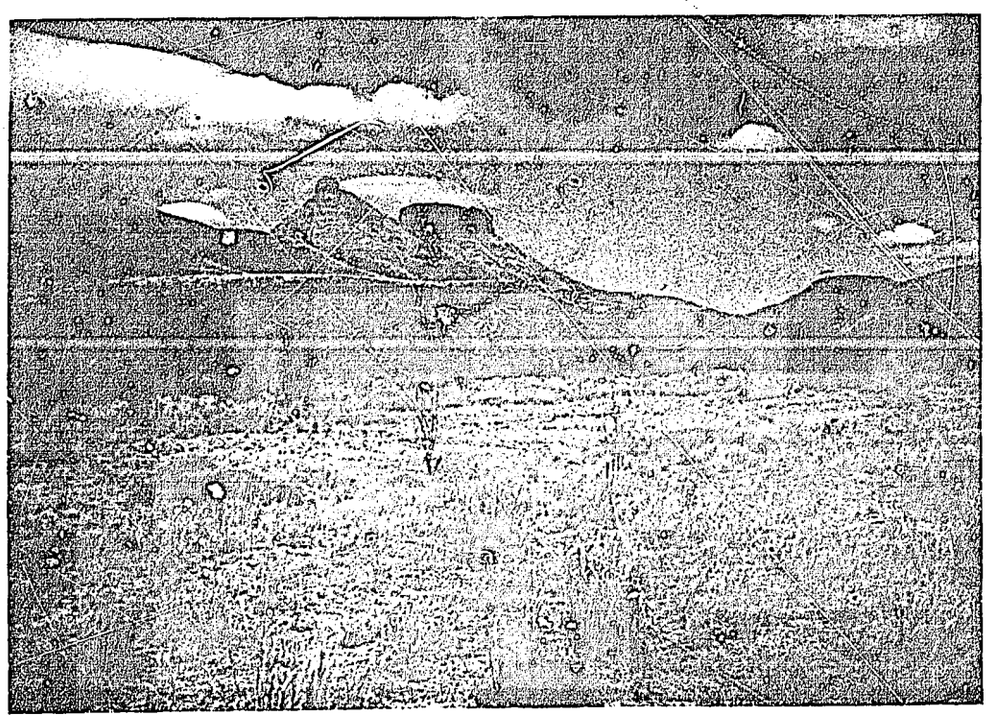


Fig. 16 The Condren Sandstone at Scrivener Hills, CROSSLAND. The prominent bench above the base of the outcrop is a ferruginous plant-bearing fine-grained quartzose sandstone, which is interbedded with kaolinitic siltstone and thin-bedded sandstone units. The pinnacles in the centre are capped by the Kirby Range Member of the Hardman Formation.
BMR Negative GB/174

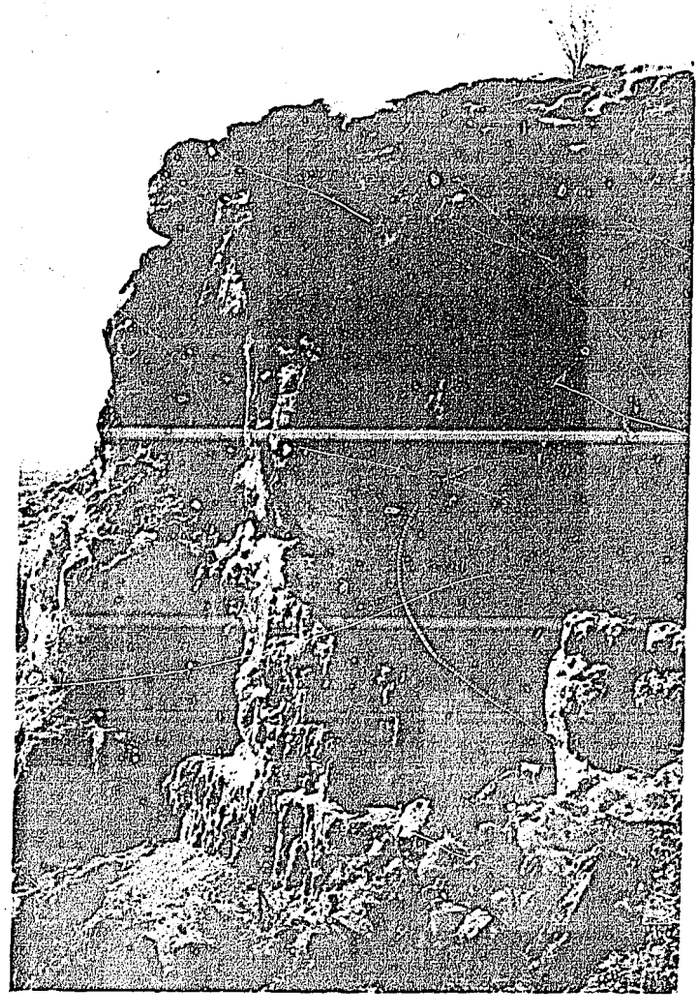


Fig. 17 Cliff section of part of the Condren Sandstone near BMR Mount Bannerman No. 2 in northwest MOUNT BANNERMAN. The section is composed mainly of thin-bedded fine-grained quartzose sandstone with a kaolinitic matrix. The top half of this section is lithologically identical to the bottom half but has been slightly ferruginized and hardened by surface weathering. In contrast, the lower half of the section has a crumbly texture. BMR Negative GB/202.

(Lat. 20°06'S, Long. 127°8'E), 19 km west-northwest of Balgo Mission, LUCAS and it was defined with member status by Casey & Wells (1964). At this locality, however, the top 9 m of section is here mapped as Godfrey Beds (A16).

Outcrops of the Condren Sandstone occur in the southwest corner of BILLILUNA around the ruins of Old Billiluna homestead; and in the breakaways 3 km west of Micha Bore, at Condren Pinnacles, and north of Thomas Peak in LUCAS. The sandstone parts of the formation are relatively resistant and form prominent strike ridges in the Stansmore Range (Fig. 15) and low outcrops cap part of the Waterlander Breakaway in southwest STANSMORE. The Condren Sandstone also crops out in the cliff faces of Millyit Range, in Scrivener Hills (Fig. 16), and on the southern side of the Kirkby Range, CROSSLAND; in the Casey Range, at Mt Erskine, and in the mesas and buttes around Christmas Creek in MOUNT BANNERMAN (Fig. 17). In CORNISH, the formation is well exposed in low hills of the Southesk Tablelands, particularly northwest and southeast of Mt Elliot. Here and in parts of the Stansmore Range, the Condren Sandstone is cut by two intersecting joint sets. Preferential silicification along the joint intersections and accompanying relative resistance to weathering compared with the surrounding less silicified rock has resulted in series of conical hills after subaerial denudation. It also forms the lower unit exposed around the Godfrey's Tank/Catspaw Hills area, and in the southeast low ridges and mesas of the formation crop out in the Roberts Range.

The only outcrops of Condren Sandstone in HELENA have been photo-interpreted and are in the southeastern part of Thornton Flat. The Condren Sandstone is not present in WEBB or DUMMER.

In the subsurface, the Condren Sandstone has been intersected in BMR Mt Bannerman Nos 1 and 2, BMR Cornish No. 1, and BMR Crossland Nos 1 and 2 (Appendix B).

Lithology The Condren Sandstone consists of sandstone and siltstone with minor quartz-granule and rare quartz-pebble conglomerate.

Near the edge of the Canning Basin, in LUCAS and STANSMORE, the formation consists of rhythmic alternations of sandstone and siltstone (Fig. 15, A17, A18). Here the buff to white sandstone is friable, fine to medium-grained, in places coarse, and thin to medium-bedded, moderately sorted, with little clay or silt matrix. Detrital muscovite is a common constituent. High-angle cross-bedding with a maximum dip of the foreset beds of 22° is common in the



Fig. 18 Assymmetrical interference ripple marks on bedding surface of fine-grained quartzose sandstone. Condren Sandstone, Stansmore Range, STANSMORE. BMR Negative GB/179.

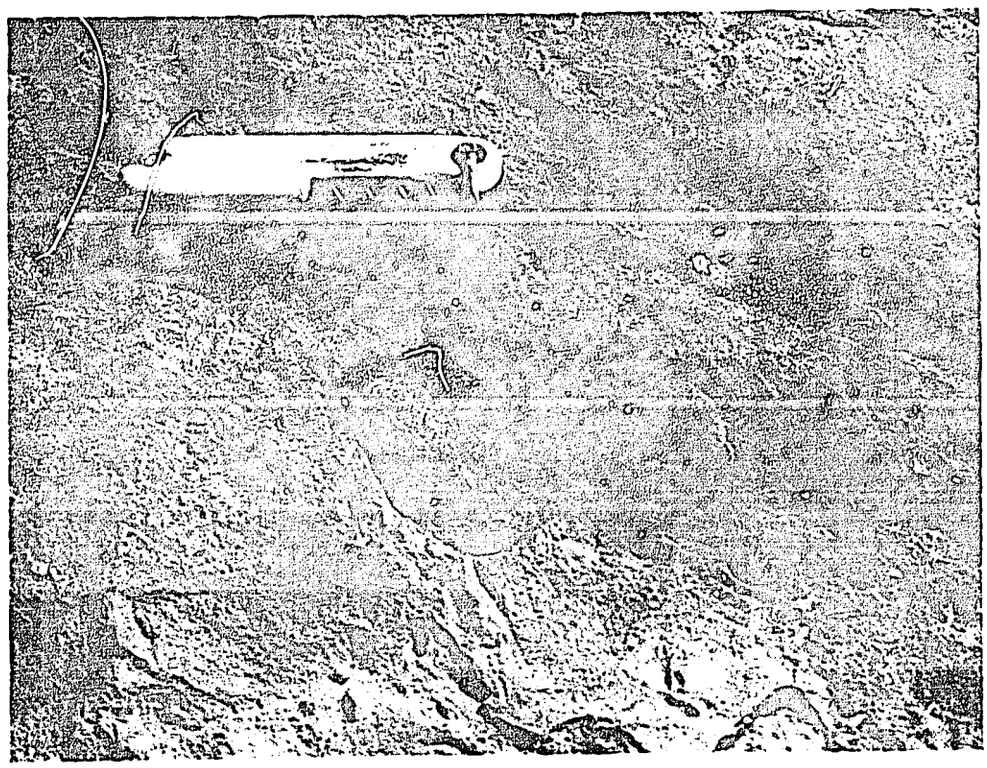


Fig. 19 Trace fossil preserved in fine-grained quartzose sandstone, Condren Sandstone near BMR Mount Bannerman No. 2 stratigraphic hole, northwest MOUNT BANNERMAN.

basal sand units grading to small-scale low-angle cross-bedding higher in each sandstone unit. The sandstone becomes finer upwards, grading into ripple-marked (Fig. 18) and ripple cross-laminated fine-grained sandstone and parallel laminated siltstone. Thin conglomerate beds containing pebbles of quartz and quartzite are scattered throughout the formation. Intraformational claystone clasts formed by the erosion of underlying siltstone units occur in the basal parts of the sandstone units.

A lithologically similar sequence to that in STANSMORE occurs in the Roberts Range (southeast CORNISH) where the sandstone is fine to coarse-grained, cross-bedded, poorly sorted, and the bedding is medium to thick.

Exposures of the Condren Sandstone in CROSSLAND, CORNISH, and MOUNT BANNERMAN are of predominantly quartzose sandstone, generally fine to very fine-grained and with a clay or silt matrix (A19). It is light-coloured, well sorted, poorly cemented, and friable. The sandstone is thinly bedded with low-angle cross-stratification; the cross-stratification is generally planar but some trough cross-stratification is present, particularly in CORNISH. Thin beds of siltstone and shale are common. Current directions measured in CORNISH from cross-bedding show a bimodal distribution. Minor slump-structures are present in places along the Southesk Tablelands.

A characteristic feature of the formation in CROSSLAND, CORNISH and MOUNT BANNERMAN is the numerous well developed ripple marks, groove casts load casts, and bio-turbated beds with trace fossils (Fig. 19).

In the subsurface, the Condren Sandstone consists of white to grey micaceous siltstone, grey carbonaceous shale interbedded with grey fine-grained micaceous well sorted quartz sandstone. Thin beds of coal were recorded in BMR Mt Bannerman No. 2 in northwest MOUNT BANNERMAN (B9).

Thickness The only complete section measured was 66 m thick on the south side of Millyit Range, CROSSLAND (A10). All other sections measured are incomplete. 130 m in the Stansmore Range (A17); 43 m at Mt Erskine, MOUNT BANNERMAN (Casey & Wells, 1964); 85 m in BMR Crossland No. 1; 80 m in BMR Mt Bannerman No. 1; and 83 m in BMR Mt Bannerman No. 2 (Appendix B). In the Kirkby Range area, CROSSLAND, the Condren Sandstone becomes very thin and may lens out. It is not present in NOONKANBAH Sheet area to the north (Crowe & Towner, pers. comm.).

Rock-Relations The Condren Sandstone rests on the Lightjack Formation with apparent conformity. In MOUNT BANNERMAN and

CROSSLAND the contact is gradational over a distance of about 10 m and the boundary is placed immediately below the first appearance of light-coloured quartzose sandstone.

The Condren Sandstone is unconformably overlain by the Godfrey Beds in LUCAS, conformably overlain by the Godfrey Beds in CORNISH, and conformably overlain by the Hardman Formation in CROSSLAND. In part of MOUNT BANNERMAN the Condren Sandstone is disconformably overlain by the Lower Triassic Blina Shale and the Lower Triassic Millyit Sandstone. In the northwest of the Sheet area, it is conformably overlain by the Hardman Formation.

Fossils and Time-Stratigraphic Position Plant remains and wood fragments are abundant throughout the Condren Sandstone and comprise a typically early Gondwana flora of Glossopteris, Gangamopteris, and Vertebraria of Permian age (White and Yeates, in prep.). Trace fossils and burrowing is well developed in the unit in MOUNT BANNERMAN and CROSSLAND.

The underlying Lightjack Formation is dated as Early Permian (Artinskian to Kungurian) in age and the overlying Hardman Formation is Late Permian (Tatarian) (Thomas & Dickins, 1954). Therefore, on stratigraphic position, a Late Permian age is ascribed to the Condren Sandstone (possibly Kazanian).

Environment of Deposition In some places in LUCAS and STANSMORE, the cyclic grading upwards of the sediments from coarse sandstone to fine sandstone and siltstone, together with corresponding change in the size and nature of the cross-stratification and bedding thickness in each cycle indicates that sedimentation occurred under a meandering river regime. In STANSMORE, the cyclic sequence is overlain by laminated fine quartzose sandstone with wave ripples, representing possibly a return to marginal marine or lagoonal conditions.

In the Southesk Tablelands, CORNISH, the laterally continuous thin-bedded nature of the unit together with abundant wave-formed ripple marks, trace fossils, and a bimodal current direction strongly suggests a shallow-water, probably marine, environment. However, outcrops in the Roberts Range in southeast CORNISH lack these features, and have variable grainsize and exhibit high-angle cross-bedding. Here, the Condren Sandstone is fluvial.

In other places in CROSSLAND and MOUNT BANNERMAN, the predominance of fine grainsize, thin bedding, and low-angle cross-bedding and the abundant carbonaceous and plant material suggests that the Condren Sandstone was deposited

under low-energy conditions. Plant remains, thin coal seams, sedimentary structures, and the absence of any spinose acritarchs attest to a low-energy fluvial or deltaic environment for the Condren Sandstone in these areas. The coal may indicate swampy conditions.

Hardman Formation

Guppy et al. (1958) defined the Hardman Member (now Formation) of the Liveringa Formation (now Group) as a sequence consisting of '. . . dominantly thin-bedded, friable fine to medium-grained micaceous silty-sandstone, commonly ripple-marked and interbedded with massive current-bedded, medium to coarse-grained, well-sorted quartzose sandstone. A rich assemblage of marine fossils is found at the base of the type section within red-brown and olive-brown micaceous sandstone, very similar in lithology to the Lightjack Member'; it was thought to conformably overlie the 'middle member' near Mt Hardman (NOONKANBAH). The Hardman Formation is confined to outcrops in CROSSLAND and northwest MOUNT BANNERMAN. It may be a lateral equivalent of the Godfrey Beds on LUCAS and CORNISH.

Fieldwork in 1973 showed that the formation contains at least three distinct mappable members in CROSSLAND: the Kirkby Range Member at the base, the Hicks Range Sandstone Member in the middle, and the Cherrabun Member at the top (Yeates et al., in press). In northwest MOUNT BANNERMAN, around Boundary Hill, the Hardman Formation cannot be subdivided into constituent members. The rocks exposed are bioturbated, mottled white, red-brown, and dark grey medium-grained micaceous flaggy sandstone and siltstone, extensively ferruginized by weathering.

In CROSSLAND, the Kirkby Range Member is the most widespread member; the Hicks Range Sandstone Member is confined to a narrow belt trending southeast across the northern part of the Sheet area and the Cherrabun Member crops out in the axial region of the Millyit Syncline.

The type section for the Hardman Formation was described by Guppy et al. (1958) at Mt Hardman (Lat. 18° 19'S, Long. 124° 49'E, NOONKANBAH) when given member status. The individual members of the formation have now been assigned their own type sections though the section at Mount Hardman remains the type section for the Formation (Yeates et al., in press) in accordance with the Australian Code of Stratigraphic Nomenclature (1973, p. 110). The exposed thickness of the Hardman Formation at Mt Hardman is 36 m and there is about 100 m in the Millyit Range area.

Kirkby Range Member

Distribution and Type Locality The name Kirkby Range Member is derived from the Kirkby Range, an arcuate ridge 40 km southwest of Cherrabun homestead (Lat. 19°07'S, Long. 125° 13'E, CROSSLAND).

Outcrops are present in Kirkby Range (Fig. 50) and Millyit Range in CROSSLAND. In the subsurface, the Kirkby Range Member was intersected in BMR Crossland No. 1.

The type section for the member is in the north side of Millyit Range, west of Spring Creek, CROSSLAND at Lat. 19°09'39"S, Long. 125°34'24"E.

Lithology The Kirkby Range Member consists of interbedded argillaceous siltstone with minor shale and calcareous sandstone.

The lowermost part of the type section consists of varicoloured but mainly grey micaceous shale, strongly ferruginized by surface weathering. Outcrop is poor.

Argillaceous sandstone is the most abundant rock type. It is white to pale brown, fine-grained, very micaceous, poorly sorted, and contains much silt and clay. It is commonly laminated to thinly bedded, with cross-bedding in the lower parts of the sequence. Here, dips on foresets range from 10° to 15°. The sandstone weathers to dark brown and is massive, forming cliff faces in the Millyit Range and benches in the Kirkby Range.

Siltstone is a subordinate constituent and is white, brown, or grey. It is laminated, though laminations are poorly defined in highly weathered outcrops.

Cross-bedding and ripple cross-laminations are common and small slump structures and ripple marks are present.

A very fossiliferous calcareous silty sandstone forms a distinctive marker bed in the middle of the member. The sandstone has been ferruginized as a result of weathering and the calcareous material has been partly or completely replaced by iron compounds. The fossils are weathered out as both ferruginous casts and as whole specimens. Immediately above this fossiliferous bed is a silty sandstone unit up to 10 m thick (e.g. in northwest Millyit Range). The sandstone is mottled and extensively bioturbated; the worm tubes are strongly ferruginized in places. Bedding has been mainly destroyed.

In the subsurface in BMR Crossland No. 1 the unit consists of dark carbonaceous shale overlying laminated silty sandstone and calcareous siltstone.

Petrography The principal constituents present in the argillaceous sandstone are quartz (40%), argillaceous material (45%), muscovite (10%), feldspar (2%), and iron oxides.

Most of the quartz grains are angular, less than 0.1 mm across, and have non-undulatory extinction; composite grains are rare. Thin layers of brown iron oxide have developed around some grains possibly as the result of weathering. The feldspar grains are mostly microcline, a few are plagioclase; some are partly kaolinized and sericitized. Flakes of muscovite are abundant and most are oriented parallel to the bedding but many lie in random directions. Much of the mica has been altered to clay. Argillaceous material, very fine quartz grains, and iron oxide form the matrix.

The constituents of the worm tubes within the argillaceous sandstone consist dominantly of quartz and minor feldspar and muscovite. The grainsize is slightly larger than the host sediment's grains. Argillaceous material within the tubes is much less abundant, and the pore spaces in the tubes accounts for 15% of the rock. The margins of the tubes are stained black by opaque oxides.

Thickness

In the Millyit Range, at the type section, the member is at least 50 m thick (A20), and on the south side of the Range at least 22 m thick. Both sections are incomplete. In the Kirkby Range, a section measured by WAPET geologists in 1956 comprised about 75 m of sediments now identified as Kirkby Range Member. In BMR Crossland No. 1, 70 m of Kirkby Range Member was intersected.

Rock-Relations The contact of the Kirkby Range Member with the Condren Sandstone is gradational, and the boundary between the two units is difficult to pick. Both units are essentially sandstone, but the Condren Sandstone is light-coloured, plant-bearing, consistently more friable, and dominantly quartzose while the Kirkby Range Member is darker and harder with a clayey matrix, and lacks plant fossils. In Kirkby Range, the Condren Sandstone possibly lenses out so that the Kirkby Range Member may also lie on the Lightjack Formation, disconformably.

The contact with the overlying Hicks Range Sandstone Member was not observed in the field, but from aerial photographs the units appear conformable; in places the contact is faulted (e.g. the Millyit Range).

Fossils and Age Abundant marine fossils are present in the Kirkby Range Member in all the outcrops visited in CROSSLAND. The fossils include brachiopods and pelecypods and are of Late Permian (Tatarian) age (J.M. Dickins, pers. comm.).

The well preserved microfloral assemblage collected from the cores 1, 2, and 3 from BMR Crossland No. 1 give a Late Permian age (R. Paten pers. comm. Appendix B).

Environment of Deposition The abundance of interbedded and interlaminated fine silty sandstone and siltstone, the small-scale cross-stratification, the marine fossils, bioturbated beds, and wave ripple marks indicate that the Kirkby Range Member was deposited in a low-energy shallow-marine environment. The carbonaceous shale and laminated, carbonaceous, and calcareous siltstone in the well section suggests a marginal marine (lagoonal) environment of deposition.

Hicks Range Sandstone Member

Distribution and Type Locality The Hicks Range Sandstone Member, the middle member of the Hardman Formation, consists predominantly of medium-grained quartzose sandstone which crops out in a narrow belt stretching from the Hicks Range in the east to the Barbwire Range in the west, in northern CROSSLAND. It has a characteristic joint pattern easily recognized on aerial photographs. The name is taken from the Hicks Range, a low series of mesas around Lat. 19°14' 06"S, Long. 125°54'12"E. The type section is a scarp located in the centre of the Hicks Range at Lat. 19°13'48"S, Long. 125°53'42"E.

Lithology The Hicks Range Sandstone Member is composed predominantly of friable to medium-hard, very micaceous quartzose sandstone. The sandstone is light-coloured, mainly medium-grained, thin to massively bedded, prominently cross-bedded, and well sorted. Minor thin, coarse-grained and fine-grained beds of sandstone are present throughout. Thin beds of granule conglomerate occur in the lower part of the sequence. The granules are generally well rounded.

The dip of foreset beds in cross-strata varies from 15° near the base to 26° near the top of the sequence. Individual cross-sets are up to 1 m thick.

Petrography The sandstone consists of quartz (70-80%), feldspar (2-3%), muscovite (2%), argillaceous material (2-10%), and minor apatite, zircon, and iron oxide. The rock is generally medium-grained and most grains are sub-angular.

Most of the quartz has non-undulatory extinction; a few grains are composite. Inclusions and cracks in the quartz grains are abundant.

The feldspar grains appear to be orthoclase or microcline, and rare plagioclase. They have been partly kaolinized by surface weathering. The argillaceous material forming the matrix is composed of fine aggregates of quartz, iron oxides, and clay minerals. The muscovite flakes are randomly orientated.

Thickness The thickness varies from 14.8 m at Spring Creek in the Millyit Range (A22) to 27.9 m at the type section in Hicks Range (A21). About 10 m is exposed in the Kirkby Range.

Rock Stratigraphic Position In the Millyit Syncline, the Hicks Range Sandstone Member appears to rest conformably on the Kirkby Range Member and is everywhere conformably overlain by the Cherrabun Member of the Hardman Formation.

Time Stratigraphic Position No fossils have been found in this member. The fauna in the underlying Kirkby Range Member and the overlying Cherrabun Member indicates that this member is Late Permian, possibly lowermost Tatarian.

Environment of Deposition The absence of marine fossils, the medium grainsize, and the high-angle cross-bedding indicate a fluvial environment. Increase in dips of cross-strata towards the top shows increasingly stronger currents. The orientation of the cross-strata measured in a reference section suggests that current direction was from the north-west.

Cherrabun Member

Distribution and Type Locality The Cherrabun Member is exposed in the Millyit, Jones, and Hicks Ranges, CROSSLAND. The name is derived from Cherrabun homestead (Long. 125° 31'24"E, Lat, 18°54'42"S), NOONKANBAH. The type locality is at the head of a tributary of Spring Creek at Lat. 19°11' 00"S, Long. 125°33'06"E, CROSSLAND.

Lithology The Cherrabun Member consists of brown fine-grained micaceous argillaceous fossiliferous sandstone interbedded with micaceous laminated siltstone and shale

ferruginized by weathering. The sandstone is poorly sorted, thin to medium-bedded, cross-bedded, and friable. It is calcareous in part, especially towards the base. A few thin pebble conglomerate beds and lenses occur towards the top of the sequence as well as numerous beds containing intraformational clay pellets. Organic tracks and burrows are present in the lower section of the member in the Hicks Range area.

Petrography The minerals present in the sandstone include quartz (45%), skeletal calcite fragments (35%), argillaceous matrix (5%), feldspar (2%), mica (2%), black iron oxides, zircon, and glauconite. Pore spaces account for 8%.

The grainsize of the quartz varies, averaging about 0.25 mm and the grains are subangular, non-undulatory with a few inclusions. The feldspar comprises ?orthoclase and rare plagioclase; it has been partly kaolinized by weathering. The iron minerals are dark red and black possibly earthy hematite and goethite. The mica flakes have no preferred orientation.

The skeletal fragments consist of abraded brachiopod and pelecypod shells. The fragments have thin oolite-like coatings replaced by limonite. They also are partly replaced internally along cracks by iron minerals, a feature probably due to extensive deep weathering.

The matrix is yellow-brown, argillaceous, and small grains of glauconite fill some spaces between the grains.

Thickness In the type section in Millyit Range, the member is at least 22 m thick (A23) and to the southeast in the Hicks Range at least 24 m (A24).

Rock Stratigraphic Position A very slight angular unconformity separates the Cherrabun Member from the overlying Millyit Sandstone in the Millyit Range. In most areas, the contact of the Cherrabun Member with the underlying Permian sediments is apparently conformable as at Hicks Range where it rests conformably on the Hicks Range Sandstone.

Fossils and Time Stratigraphic Position A very rich marine fauna occurs in the Cherrabun Member in CROSSLAND. In some outcrops, the original shell material is preserved, including the delicate spines of brachiopods. The fauna from this sequence indicates a Late Permian age, Tatarian (Thomas, 1954). A sample from near the top of the Cherrabun Member examined palynologically confirmed a Late Permian age (P. Price and R. Paten, pers. comm.).

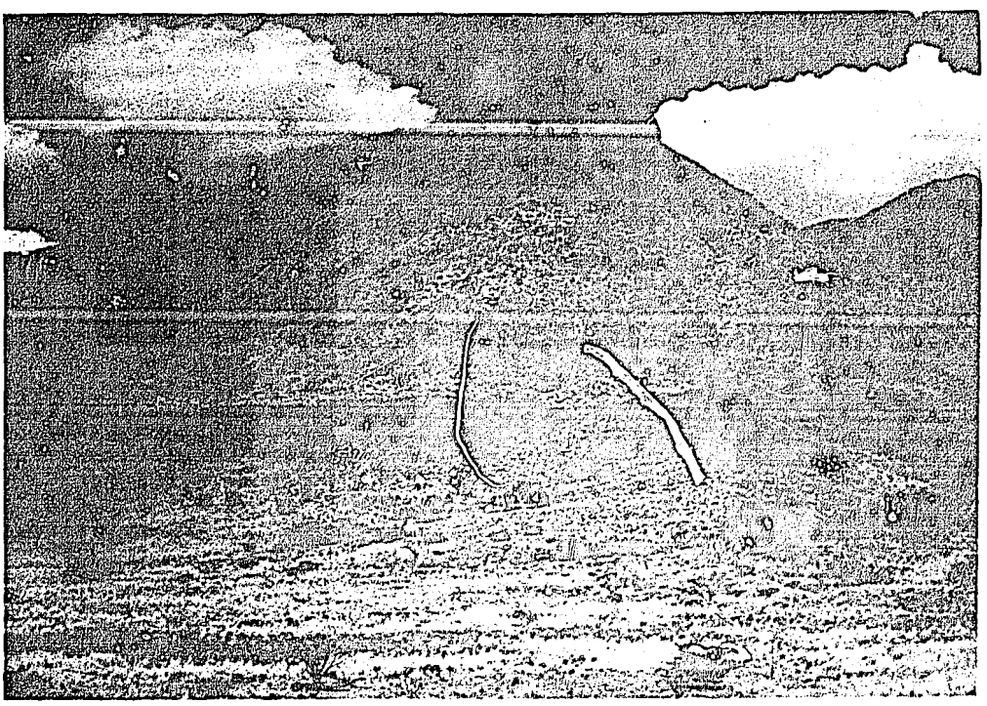


Fig. 20 Godfrey Beds at Twin Heads, CORNISH. The prominent bench near the base of the hill marks the top of the Condren Sandstone. Above this, the Godfrey Beds are composed of fine-grained, well sorted, laminated quartzose sandstone with a few thin beds of siltstone. The prominent bluffs at the top of the section are of the same lithology but have been hardened by slight silicification and ferruginization which has accompanied surface weathering. BMR Negative GB/205.

Environment of Deposition The abundant shell fossils, the fine-grained sandstone, and siltstone units with very low-angle cross-bedding indicate that the Cherrabun Member is marine. The rich fossil beds in which the delicate spines are still preserved suggests deposition at intervals under low-energy conditions. However, other beds containing a large proportion of skeletal fragments indicate an environment where wave and current agitation was prevalent, possibly on tidal flats. The presence of glauconite accords with a marine environment.

Godfrey Beds

The Godfrey Beds is a sequence of fine-grained quartzose sandstone containing the trace fossil Rhizocorallium. The Beds are equivalent in stratigraphic position to the Hardman Formation of the Liveringa Group.

Distribution and Type locality The Godfrey Beds (Elliott, Casey, & Wells, 1958) were named from Godfreys Tank, a rockhole (Lat. 20°12'S, Long. 126°33'E, CORNISH) in which they crop out as prominent breakaways, ranges, and isolated peaks (Fig. 20).

In northwestern LUCAS, the Godfrey Beds crop out as low rises, mainly west of Micha Bore and in places in the Stretch Range farther south. Other areas where the Beds were previously photo-interpreted by earlier workers (Casey & Wells, 1964) are now assigned to the Condren Sandstone e.g. at Mt Cornish and Mt Ernest (CORNISH).

Lithology Outcrops of the Godfrey Beds consist predominantly of fine-grained quartzose sandstone, and minor shale, siltstone, and conglomerate.

The basal part of the Beds consists of a medium to coarse-grained quartz sandstone. It is white to pale brown, poorly sorted; the grains vary from angular to rounded. In places, a granule to pebble conglomerate occurs.

The basal sequence is succeeded by laminated to thinly bedded sandstone and siltstone with small-scale cross-stratification and bi-directional ripple marks. Intraformational clay pellets and thin pebble lenses occur in places. The brown to grey sandstone is fine-grained, argillaceous, and friable, consisting essentially of quartz grains in clay matrix. It is slightly micaceous. Numerous Rhizocorallium burrows are widespread in this section (Figs 21, 22).

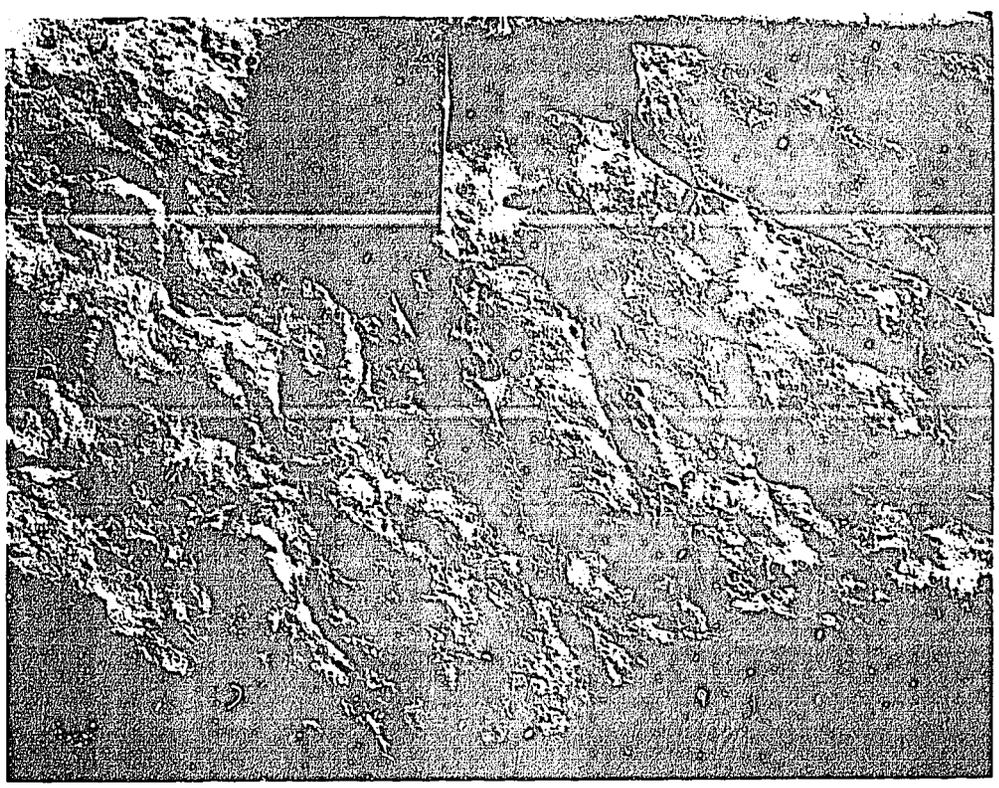


Fig. 21 Rhizocorallium burrow in fine-grained quartzose sandstone of Godfrey Beds, southeast of Well 49, CORNISH. GSWA Negative.



Fig. 22 Rhizocorallium burrow in sandstone of the Godfrey Beds near Bababaru Rockhole, LUCAS BMR Negative GB/1166.

At the top of the breakaway at Crown Head, the sandstone contains intraformational clay pellets and is cross-bedded. Current directions measured in the Godfreys Tank area give two directions, 310° and 155°.

Thickness Owing to erosion, the Godfrey Beds are nowhere fully exposed. 85 m of sediments is exposed in a breakaway due south of Crown Head (A25); at least 61 m nearby (A26). In sections measured by Casey & Wells (1964), the sequence at Breadens Pool is 45 m; at Crown Head, 90 m.

Rock Stratigraphic Position Near Godfreys Tank and in LUCAS, a slight disconformity may exist between the Godfrey Beds and the underlying Condren Sandstone. The contact of the Godfrey Beds with overlying Millyit Sandstone is disconformable in LUCAS (A27) but appears from regional relations to be conformable elsewhere.

Fossil-Age Relations The burrow Rhizocorallium (Figs 21, 22) is widespread in the upper part of the Godfrey Beds. It was originally considered to indicate a Cretaceous age, but the current mapping (1973) showed that it was present in most of the Permian units. Earlier workers also collected a pelecypod from the Catspaw Hills, CORNISH which was tentatively identified as ? Etea sp. thought also to be Cretaceous. However, on the basis of the field mapping the Godfrey Beds are now thought to be Late Permian. They contain the Permo-Triassic plant identified as Lycopodiopsis pedroanus (White and Yeates, in prep.). No pelecypods were found at this locality in 1973.

Environment of Deposition The unit was probably laid down in a shallow water, perhaps tidal-flat environment as suggested by the lithology, intraformational clasts, and bi-directional currents. The presence of Rhizocorallium, other trace fossils, and wood fragments accords with a shallow-water marine environment.

Triassic

Triassic rocks are more widespread in the northeast Canning Basin than previously thought. Four units are recognized and their total maximum thickness may reach 500 m.

Veevers & Wells (1961) described three Triassic units in the Canning Basin; the Erskine Sandstone, the Blina Shale, and the Culvida Sandstone, though Casey & Wells (1964) only recognized the latter two units in the northeastern part of the basin.

At Erskine Range (17°51'S, 124°21'E, DERBY) in the Fitzroy Trough, the Blina Shale is conformably overlain by the Erskine Sandstone. The relations of the Culvida Sandstone to the Blina Shale had, however, been in doubt in the northeast Canning Basin. Veevers & Wells (1961, p. 112) show the Blina Shale overlying the Culvida Sandstone though Casey & Wells (1964, p. 28) stated that the reverse is the case and consequently confusion had arisen about the relations of the units (Balme, 1969).

BMR Cornish No. 2 stratigraphic borehole was sited in the Minnie Range in an effort to resolve this problem. Study of the age-diagnostic microflora from the units intersected showed the Culvida Sandstone to be younger than the Blina Shale. Plant fossils further indicate that the Culvida Sandstone is younger than the Erskine Sandstone, which overlies the Blina Shale (White and Yeates, in prep.). The present mapping has shown that the sandstone unit beneath the Blina Shale at Chilpada Chara (CORNISH) and elsewhere can be lithologically correlated with the Millyit Sandstone of Early Triassic age. Previous workers (Elliott, in McWhae et al., 1958; and Veevers & Wells, 1961) considered the Millyit Sandstone to be Jurassic. It is however of very similar lithology to the Culvida Sandstone.

Millyit Sandstone

The Millyit Sandstone is mainly a cross-bedded sandstone unit which crops out in CROSSLAND, MOUNT BANNERMAN, CORNISH, and LUCAS. It was laid down in a fluvial environment.

Distribution and Type Locality The name Millyit Sandstone was proposed by Elliott (in McWhae et al., 1958) who designated the type section at the head of Spring Creek (19°12' 00"S, 125°33'30"E), CROSSLAND.

In CROSSLAND the unit crops out only in the Millyit Range but is exposed over larger parts of MOUNT BANNERMAN and CORNISH between Lake Jones and the Minnie Range. It is also present in Stretch Range and in northwest LUCAS. The type section (A28) only includes the lower part of the sequence so a reference section (A29) covering the upper part is proposed at Chilpada Chara (20°07'30"S, 126°53' 55"E), CORNISH.

Lithology The Millyit Sandstone in the Minnie Range (A29) consists of medium and fine-grained sandstone with minor clay matrix. It is commonly poorly or thinly bedded and is characteristically cross-bedded with scour-and-fill structures containing intraformational clay-pellet conglomerates.

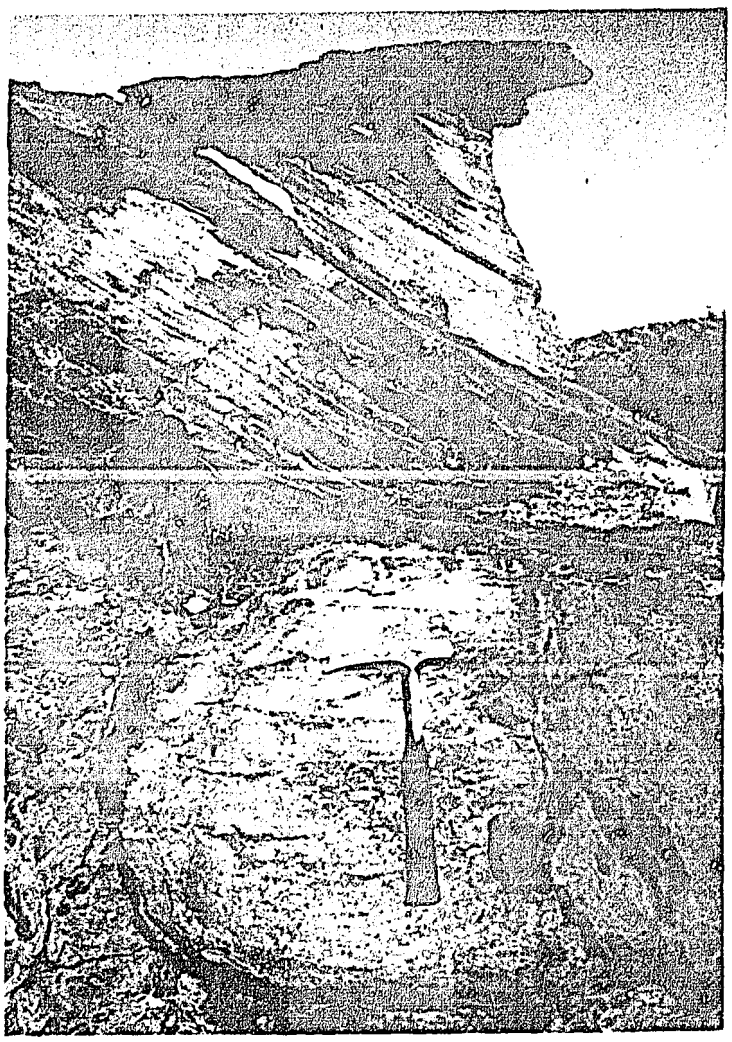


Fig. 23 Cross-bedded, medium and coarse-grained quartzose sandstone overlying thin-bedded units of intra-formational claystone conglomerate and clayey sandstone which have small-scale cross-bedding. Millyit Sandstone 60 km east of Bishops Dell, LUCAS. BMR Negative GB/178.

In some places there are quartz pebble conglomerates which become more common towards the base of the unit. In LUCAS the unit is generally coarser than in CORNISH and shows a cyclic sedimentation pattern with fining-upwards sequences of cross-bedded quartz and quartzite-pebble conglomerate which passes into coarse and medium-grained cross-bedded sandstone and then into fine-grained sandstone and siltstone. Each cyclic sequence is about 5 m thick. The most common cross-bedding is the trough type, with foreset dips up to 25° (Fig. 23). Burrows are present locally in central-west LUCAS.

In BMR Lucas No. 13 (B11) the unit becomes finer towards the top. The upper part of the section in the bore is correlated with the sequence in the Minnie Range, whereas the lower part is correlated with exposures identified around 20°17'S, 127°40'E and with exposures in southeastern MOUNT BANNERMAN, eastern CORNISH, and in the Millyit Range, CROSSLAND.

Thickness In BMR Lucas No. 13 the Millyit Sandstone is 90 m thick in the only complete section encountered.

Rock Stratigraphic Position The correlation of the Millyit Sandstone in CROSSLAND with exposures on the other Sheet areas is made on the basis of similar plant fossils and lithology and the same stratigraphic position.

In CROSSLAND the Millyit Sandstone rests with a slight angular unconformity of 1-2° on the Cherrabun Member of the Hardman Formation. In Cornish the unit overlies the Godfrey Beds though the contact was not seen. To the east, in LUCAS, the unit rests conformably or disconformably on the Godfrey Beds whereas in southeastern MOUNT BANNERMAN it overlaps the Godfrey Beds and rests disconformably on the Condren Sandstone. In western MOUNT BANNERMAN and in CORNISH the Blina Shale disconformably overlies the Millyit Sandstone.

Fossils and Time-Stratigraphic Position Plant fossils from two localities in CROSSLAND indicate a Permian or Early Triassic age for the Millyit Sandstone (White and Yeates, in prep.) though earlier workers (Veevers & Wells, 1961) had considered the unit Jurassic in age based on lithology.

At 20°16'30"S, 127°39'00"E plant fossils include Vertebraria and fragments of equisetalean stems. In the Minnie Range species found during the previous mapping were Equisetites woodsi, Dicroidium odontopteroides, Yabiella, and Equisetites sp. (White, in Veevers & Wells, 1961). During this study further collections were made and White

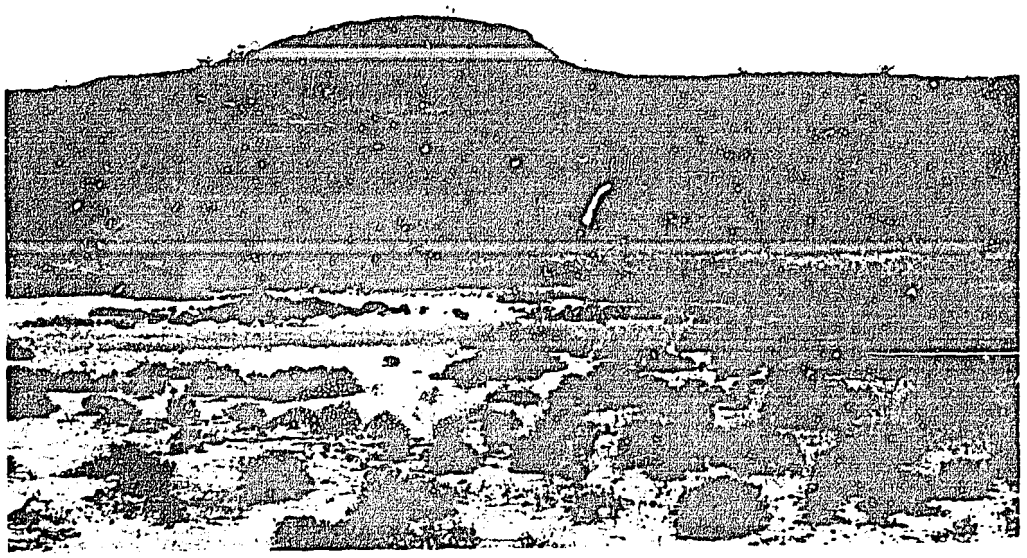


Fig. 24 Outcrop of Blina Shale adjacent to a small claypan south of Lake Betty, MOUNT BANNERMAN showing thinly bedded and laminated sedimentary rocks. GSWA Negative.

and Yeates have assigned a Permian-Triassic age to the unit. Palynology from BMR Lucas No. 13 indicates an Early Triassic age (Appendix C).

Environment of deposition The presence of trough-type cross-bedding throughout the Millyit Sandstone is indicative of a fluvial environment of deposition. The pebble conglomerates near the base of the unit represent high-energy conditions whereas the thin laminae of claystone in the upper part show low-energy conditions. The cyclical fining-upwards sequences near the base of the unit in LUCAS are interpreted as point bar deposits of meandering-rivers.

Blina Shale

The Lower Triassic Blina Shale (Brunnschweiler, 1954) comprises shale, siltstone, and fine-grained sandstone laid down under paralic conditions.

Geographic Distribution and Type Locality The Blina Shale crops out in a belt between Lake Jones in the northwest (MOUNT BANNERMAN) to Stretch Range in the southeast (LUCAS). It is exposed over large areas in MOUNT BANNERMAN, particularly the Lake Betty area (Fig. 24) the Bishops Range, CORNISH and Bababaru Rockhole area in LUCAS. Casey & Wells (1964) photo-interpreted many of these exposures as Permian. Similarly, around Pt Alphonse (LUCAS) they mapped the area as mainly Permian, whereas it has not been demonstrated that the rocks in this area are Triassic.

In the subsurface, the Blina Shale is thought to have covered a larger area than Veevers & Wells (1961, p. 108) showed and it may have extended throughout the Fitzroy Trough and the Gregory Sub-basin.

Playford et al. (in press) suggest that the type section be taken at 17°51'25"S, 124°21'40"E in the Erskine Range (DERBY). Typical exposures in the northeast Canning Basin occur in breakaways south of Lake Betty (MOUNT BANNERMAN), the lowermost part of the section at Pt Alphonse (LUCAS), and numerous sections in the Bishops Range (CORNISH).

Lithology The Blina Shale is a micaceous, medium-bedded to laminated sequence of fissile shale, siltstone, and thin units of fine-grained sandstone (A30). The whole sequence becomes sandy towards the top. The bedding is mainly continuous but pinch-and-swell structures are common. Slump and flowage structures are present in places, and there is some planar low-angle small-scale cross-bedding in the sandstone beds.

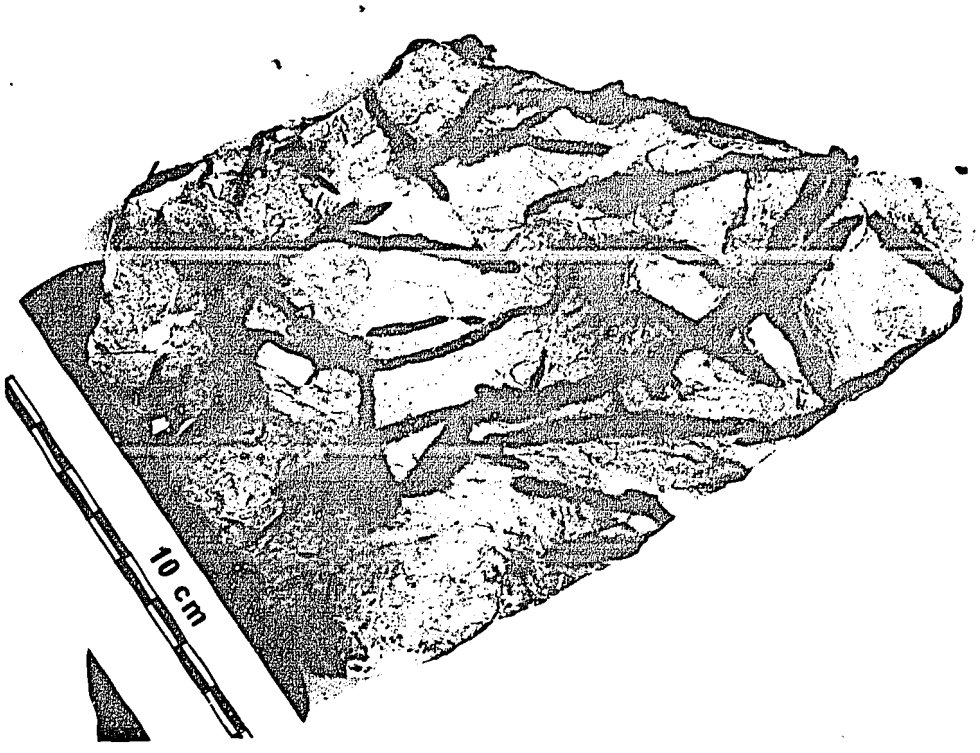


Fig. 25 Ferruginized sand-fillings of mudcracks (dark-coloured) in laminated kaolinitic siltstone of the Blina Shale, near Lake McLernon, MOUNT BANNERMAN. BMR Negative F 5948.

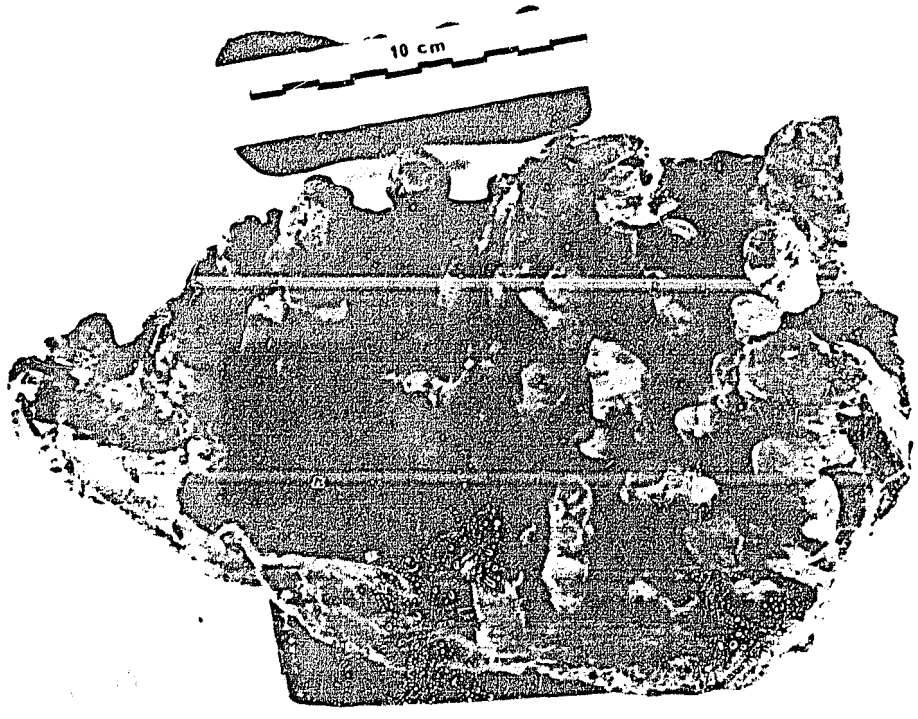


Fig. 26 Ferruginized sand moulds of ferruginized vertical burrows on lower surface of a sandstone bed from which the underlying shale has been removed by erosion. Blina Shale, Bishop Range, CORNISH. BMR Negative 5951/B.

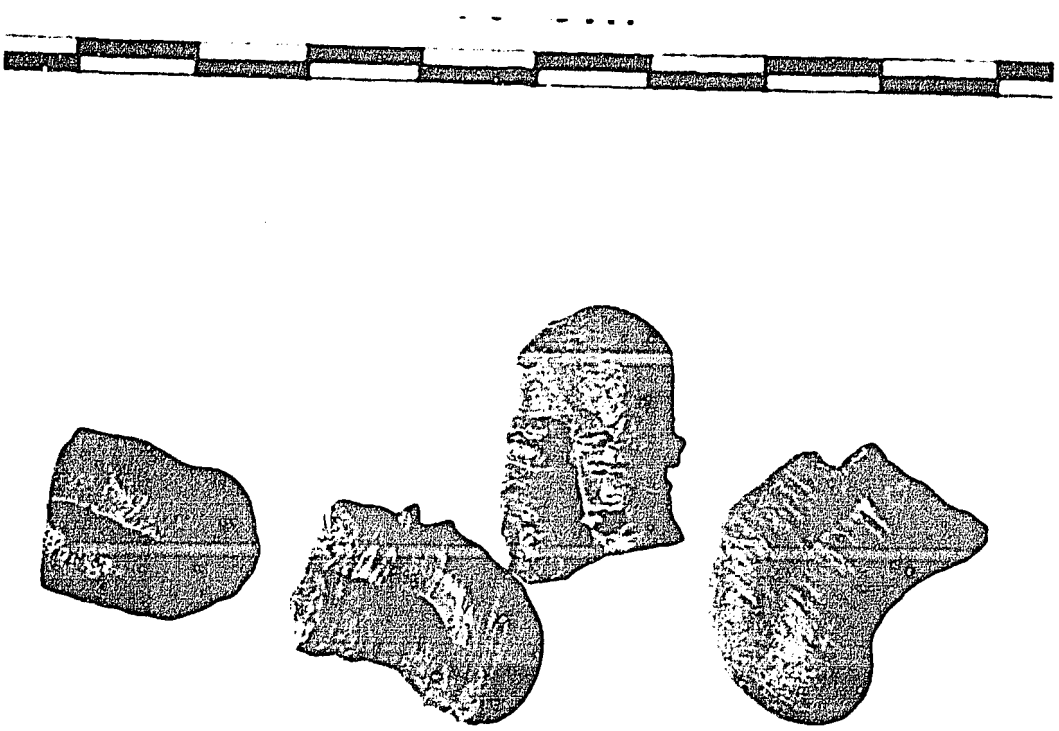


Fig. 27 Ferruginized U-shaped burrows from which the surrounding soft-weathering shale has been removed. Blina Shale, Lake Doman, MOUNT BANNERMAN. BMR Negative M/1919.

Ripple marks occur widely, and at three localities (Lake Jones, Minnie Range, and Pt Alphonse) were measured and the ripple mark indices of Tanner (1967) were used to identify them. All three sets of ripple marks were identified as being wave types. Other sedimentary structures include mudcracks (Fig. 25) mud curls, and rain prints. Intraformational claystone clasts are also present.

The most characteristic feature of the Blina Shale are the widespread burrows. The most common types consist of closely spaced vertical burrows (Fig. 26), U-shaped (Diplocraterian-type) burrows (Fig. 27), and other less definitive structures. Richly fossiliferous beds of conchostrachans are present in silty sandstone beds often associated with burrowed units. Other fossils found in the Blina Shale include plants, vertebrate bones, trace fossils, and poorly preserved indeterminate shells from near the top of the unit in MOUNT BANNERMAN. The bones occur in an intraformational conglomerate with goethite concretions. A chemical analysis of this rock is given in Table 9.

Near Lady Edith Lagoon (CORNISH) some calcareous sandstone beds are present, though normally surface exposures are non-calcareous.

The colour of the rocks is due to weathering and varies from brown to red, purple, and yellow. In the subsurface the unit is mainly dark grey, black, and carbonaceous. The Blina Shale has been particularly susceptible to deep weathering and subaerial denudation so that it crops out poorly except where it is preserved beneath resistant laterite caps (e.g. south of Lake Betty, MOUNT BANNERMAN). Its photo-pattern is distinctive but is one that is easily confused with the terrain patterns of the Permian Noonkanbah Formation.

Thickness In the Stretch Range (at 20°56'00"S, 127°42'00"E) 129 m of Blina Shale was measured, but at Pt Alphonse (LUCAS) the unit is about 90 m thick. The sequence from there thickens towards the northwest, and also to the south of Lake Betty (MOUNT BANNERMAN) where photo-interpretation suggests it may be as thick as 200 m.

Rock-Stratigraphic Position At Chilpada Chara, CORNISH and in LUCAS the Blina Shale rests disconformably on the Millyit Sandstone (A29). The boundary is a sharp lithologic change. In the Mt Erskine area, MOUNT BANNERMAN, the Blina Shale overlaps the Millyit Sandstone and rests disconformably on the Condren Sandstone.

The Blina Shale is conformably overlain by the Erskine Sandstone in most areas. This contact is well exposed at Pt Alphonse (LUCAS) and to the south of Lake Betty (MOUNT BANNERMAN). At Pt Alphonse the boundary is mostly conformable though, in places, it is marked by a thin quartz-pebble conglomerate suggesting slight erosional break. In MOUNT BANNERMAN the boundary is sharp and locally disconformable.

Brunnschweiler (1954, p. 43) believed that: 'The folding in the Fitzroy Trough ..... took place towards the end of the Permian and during early Triassic time. The angular unconformity between Liveringa Group (folded) and Blina Shale (unfolded),..... proves that the surface of the Fitzroy Sub-basin has emerged from the sea during the tectonic activity'.

In the Gregory Sub-basin, no evidence has been found to suggest there is an angular unconformity between Permian and Triassic rocks. In many places the Blina Shale is folded (around Lake Betty, Minnie Range, Bishop Range, etc.) and where it crops out adjacent to the Permian rocks the trends of both are parallel. Therefore there does not appear to have been a major period of folding between deposition of the Permian and the Blina Shale in the northeastern Canning Basin. The Gregory Sub-basin is separated from the Fitzroy Trough by the Jones Rise, which may have been emergent during the Early Triassic marine transgression into the Gregory Sub-basin. The Rise, an area of elevated basement, may have absorbed the early Triassic movement referred to by Brunnschweiler (1954) thus accounting for apparent conformity between the Permian and Triassic in the northeast Canning Basin.

Fossils and Time-Stratigraphic Position Vertebrate bones, a conchostrachan, and abundant plant remains are present in the Blina Shale. The microflora indicates a Scythian to Anisian age (R. Paten, pers. comm.).

Environment of Deposition The fine-grained nature of the unit shows that it was laid down under low-energy conditions, and the presence of wave ripple marks implies deposition in fairly extensive shallow bodies of water.

Various lines of evidence suggest a brackish-water mudflat environment of deposition, with both continental and marine influence, though no clear distinctions can be made between the marine and continental phases. For instance reptilian bones, mudcracks, and plant fossils are indicative of continental influence; the conchostrachan Isaura may be

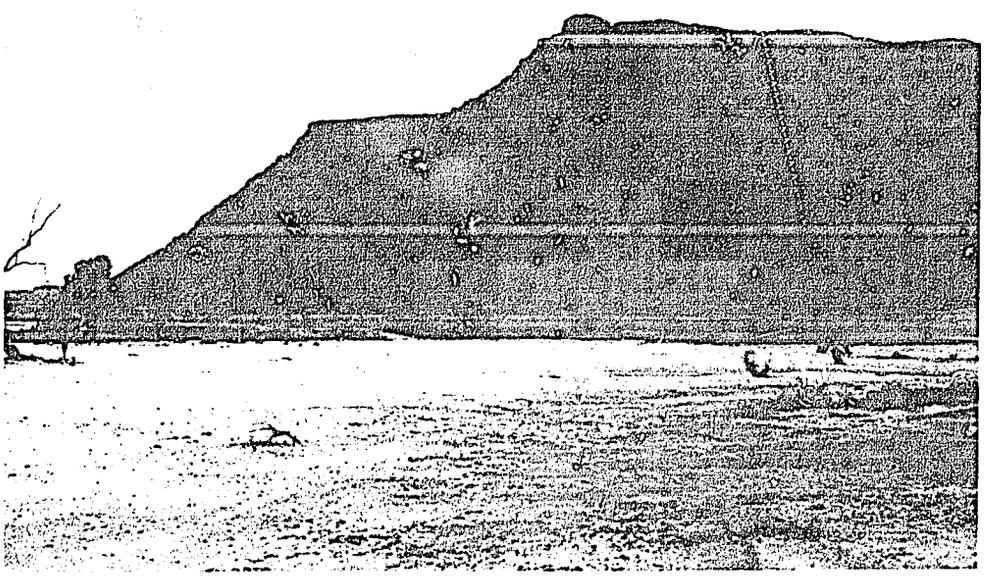


Fig. 28 Erskine Sandstone exposed at Point Alphonse, LUCAS. GSWA Negative.

indicative of brackish-water lagoonal conditions (J.M. Dickins, pers. comm.), and spinose acritarchs identified in BMR Lucas No. 13 (R. Paten, pers. comm.) are thought to be indicative of marine conditions. The plant, Lycopodiopsis pedroanus is known to have grown in swampy environments (White and Yeates, in prep.).

The topography of the time must have been extremely low, and the sediment supply relatively uniform during deposition. These conditions existed over a large area for a prolonged period. Correlatives of the Blina Shale in other Western Australian Basins are also very similar, so that this environment (i.e. extensive brackish-water mudflat) was not confined only to the Canning Basin.

Erskine Sandstone

The Erskine Sandstone is a thin-bedded, cross-bedded, plant-bearing sandstone and siltstone unit which overlies the Blina Shale. It was previously photo-interpreted by Casey & Wells (1964) as Condren Sandstone and Blina Shale.

Geographic Distribution and Type Locality The type section is in the Erskine Range (DERBY) at 17°50'S, 124°22'E (McWhae et al., 1958, p. 83). It was first named by Brunnschweiler (1954). The section at Point Alphonse (LUCAS) from 2 m above the base to the top of the hill is a good reference section (Fig. 67).

The Erskine Sandstone is confined to the southern edge of the Betty Terrace and to the axial region of the Gregory Sub-basin in MOUNT BANNERMAN, CORNISH, and LUCAS. It is well exposed in the Point Alphonse area (Fig. 28).

Lithology At Point Alphonse (LUCAS) and at Bishops Range (CORNISH) the Erskine Sandstone consists mainly of cross-bedded and parallel-bedded medium and fine-grained sandstone; minor siltstone beds become increasingly common higher in the sequence. The cross-bedding, which is very well developed at Point Alphonse is moderate to high-angled (up to 18°) and of trough-type; cut-and-fill structures with a fill of intraformational clay pellets are common. Some clay pellet clasts are slightly curled, suggesting their origin by dessication of mud and subsequent fragmentation. Fore-set dip directions at Point Alphonse suggest that the currents flowed northwestwards in this area. In the Bishops Range (CORNISH) and in MOUNT BANNERMAN, parallel-bedded (thin-bedded to laminated) units are more prevalent than cross-bedded units, which are of smaller scale than those at Point Alphonse.

A characteristic feature of the Erskine Sandstone is a high percentage of silt and clay matrix in the sandstone units. Only a few sandstone beds, mainly near the base of the unit in MOUNT BANNERMAN, contain silica cements. Thin lenses of quartz pebble conglomerate are also present in these areas, especially near Lake Betty (MOUNT BANNERMAN) at the contact with the underlying Blina Shale. In this region, outcrops have been locally altered to both ferricrete and silcrete.

Plant fossils, trace fossils, and flute casts are locally present in the Erskine Sandstone.

Thickness In most parts of the area the top of the formation is eroded. The thickest measured section is 40 m at Point Alphonse (LUCAS) (A31). Other measured sections are illustrated in A32 and A33.

Rock Stratigraphic Position The Erskine Sandstone lies both conformably and locally disconformably on the Blina Shale. The upper boundary is usually eroded and covered by Cainozoic units. Near Culvida Soak, it is conformably overlain by the Culvida Sandstone.

Fossils and Time Stratigraphic Position A flora of equisetaleans and lycopods (White and Yeates, in prep.) was recovered from the Erskine Sandstone. A few trace fossils and burrows are also present. The plants are much the same as those in the Blina Shale, but they differ from those in the late Early to early Middle Triassic, and younger Culvida Sandstone (White and Yeates, in prep.). The Erskine Sandstone is Early Triassic (White and Yeates, in prep.).

Environment of Deposition The absence of marine fossils and the presence of a fossil flora is consistent with non-marine deposition. The high-angle trough type cross-bedding at Point Alphonse (LUCAS) and lithology suggest a fluvial environment. The fine grainsize and thin bedding of sandstones, their silty to clay matrix, and abundance of interbedded siltstone suggest fairly low-energy conditions. The plant Lycopodiopsis pedroanus requires an abundance of water and is thought to have colonized swampy environments (White and Yeates, in prep.).

After Blina Shale deposition on an extensive mudflat, the Erskine Sandstone probably represents progradation of sand and silt of alluvial deposits across the flat.

Culvida Sandstone

The Culvida Sandstone, the youngest known Triassic unit in the area, is mainly sandstone with beds of plant-bearing siltstone and a sequence containing redbeds at the

base. This unit was named by Casey & Wells (Wells, 1962; Casey & Wells, 1964) who also included the Millyit Sandstone (a lithologically similar sandstone unit beneath the Blina Shale) in the Culvida Sandstone. This explains why they considered that the Culvida Sandstone appeared to both overlie and underlie the Blina Shale (Casey & Wells, 1964). The redbeds found only in BMR Cornish No. 2 are the first recorded redbeds in the Triassic of the Canning Basin.

Distribution and Type Locality The type section is 1 km south of Culvida Soak and the type area is at Culvida Soak, 20°13'S, 126°55'E CORNISH (Casey & Wells, 1964). The Culvida Sandstone is restricted to within 20 km of the type area and occurs only in CORNISH. BMR Cornish No. 2 provides the best reference section (Fig. B12).

Lithology The most common rock types are fine, medium, and coarse-grained quartzose sandstone. Siltstone units are also common, but do not crop out readily as they are soft-weathering. At the base of the Culvida Sandstone, in BMR Cornish No. 2, is a redbed sequence consisting of earthy red and drab green, interbedded siltstone and minor fine-grained quartzose sandstone. Lenses of pebbles and granules occur in some of the overlying coarser sandstone units together with intraformational claystone clasts.

At Culvida Soak (CORNISH) the unit consists of a sequence of medium to coarse-grained, poorly sorted quartzose sandstone with medium-scale (5 cm - 2 m), high-angle (up to 18°), trough-type cross-bedding. This sequence also contains granule and pebble conglomerate. These coarse units wedge out laterally into a finer sandstone and siltstone rich in plant fossils. The plant-bearing unit, which is bioturbated in places, is also exposed to the south of Culvida Soak; its bedding is mainly thin, with local planar type cross-bedding. The siltstone sequence may correlate with the redbed sequence in BMR Cornish No. 2 as it is lithologically similar.

Thickness The top of the Culvida Sandstone is eroded, so no complete section is known. 26 m of Culvida Sandstone was measured near Culvida Soak (A34). The thickest section encountered so far is 207 m, of which the redbed sequence makes up 75 m in BMR Cornish No. 2.

Rock Stratigraphic Position The lower contact with the Blina Shale is faulted at the surface. In BMR Cornish No. 2, a conformable relation exists with sandstone which may be the Erskine Sandstone. The upper boundary is eroded and/or covered by Cainozoic units.

Fossils and Time-Stratigraphic Position The flora is different from that of the Erskine Sandstone (White and Yeates, in prep.). The most complete flora from the Culvida Sandstone was collected by G. Evans and L. Brown of Mines and Administration Ltd; it was dated late Early to early Middle Triassic (Retallack, in Evans & Brown, 1974). Spores of the zone 'R_3' from BMR Cornish No. 2 confirm this age. White (in Appendix 6 of Veevers & Wells, 1961) assigned a Middle Triassic age.

Environment of Deposition

The significance of redbeds in ancient rocks is a controversial subject (see Glennie, 1970) but most authors agree that they are usually indicative of continental deposition during a relatively warm climate.

The lithology and sedimentary structures of much of the Culvida Sandstone are indicative of river-channel and floodplain deposition. The sandstone and pebbly units with trough cross-bedding are channel deposits, which in places wedge out laterally into thinly bedded fine-grained sandstone and siltstone units which are probably floodplain deposits; some siltstone sequences may be lake deposits formed on the floodplains. Some cyclic bedding suggests meandering river sedimentation, in part. The redbed sequence, which is mainly siltstone, could be a playa lake deposit.

This unit represents the last known interval of sedimentation in the Triassic. It is confined to the axial region of the Gregory Sub-basin and represents the filling of the basin by sediment.

Jurassic

Barbwire Sandstone

The Barbwire Sandstone is a cross-bedded sandstone sequence with siltstone and conglomerate lenses, cropping out in CROSSLAND.

Distribution and Type Locality The Barbwire Sandstone is mainly confined to the Barbwire Range and Worral Range, CROSSLAND where it crops out in mesas and buttes; isolated outcrops of the unit are also present away from the range and in adjacent NOONKANBAH. The type section (Longitude 125°E, Latitude 19°S, NOONKANBAH) was defined by Guppy et al. (1958).

Lithology At the type section, the unit consists of 'fine-grained and poorly sorted, strongly crossbedded to massive coarse sandstone, with some conglomerate and intercalated siltstone lenses; the siltstone is white, weathering to red-brown' (Guppy et al., 1958).

In CROSSLAND, the Barbwire Sandstone consists predominantly of quartzose sandstone with thin interbeds of siltstone increasing in abundance near the top.

The sandstone ranges from fine to coarse-grained and in places is very coarse-grained. The conglomerate contains quartz pebbles up to 5 cm across. The pebbles and smaller grains are subangular to rounded and poorly sorted. The sandstones are generally white or brown, thickly bedded, and prominently cross-bedded.

The siltstone is predominantly white, laminated to thinly-bedded, and in places micaceous.

Petrography The sandstones of the Barbwire Sandstone contain over 90% quartz grains. The quartz is generally non-undulatory, with only a small proportion of strained quartz. Porosity varies considerably. Some grains are packed tightly while others are much less tightly packed. Chert grains are absent. The feldspar (2%) is generally corroded and has been altered to clay by surface weathering.

The sand grains are fine to medium, subangular to rounded, and poorly sorted. Some of the grains are coarse to very coarse and are mostly angular.

The matrix is composed mainly of clay, probably kaolinite; the reddish brown colouration is due to a thin coating of hematite on the grains.

Thickness The thickest measured section (21.5 m) of Barbwire Sandstone is in the type locality where the top is eroded. No section was measured through this unit on CROSSLAND, but it is estimated to be more than 30 m thick in the Barbwire Range.

Rock-Stratigraphic Position The Barbwire Sandstone rests with an angular unconformity of up to 5° discordance on the Lightjack Formation of the Liveringa Group at Lat. 19°00'S, Long. 125°01'E. The top of the unit is eroded. The Barbwire Sandstone has been faulted against the Liveringa Group along the Fenton Fault.

Fossils and Time-Stratigraphic Position Poorly preserved plant remains are present in the finer-grained sandstone and siltstone. These included Otozomites feistmanteli and Pagiophyllum peregrinum which are confined to the Jurassic or Lower Cretaceous (White and Yeates, in prep.).

Guppy et al. (1958) tentatively assigned a Jurassic age to the unit, based on lithology, stratigraphic position, and correlation with other units thought then to be of Jurassic age.

Environment of Deposition The lithology and absence of marine fossils suggest a predominantly non-marine environment of deposition. The abundance of high-angle cross-bedding and coarse grainsize suggest a fluvial environment. Siltstone near the top of the sequence indicates a less active period of sedimentation.

Jarlemai Siltstone

The Jarlemai Siltstone is a laminated siltstone sequence cropping out in CROSSLAND.

Distribution and Type Locality The Jarlemai Siltstone is confined to a small outcrop in the northwest corner of CROSSLAND. The type section is at Mount Jarlemai (Long. 123°45'E, Lat. 18°43'S) in MOUNT ANDERSON.

Lithology In CROSSLAND, the formation consists of pink and purple sandy siltstone which is laminated to poorly stratified.

Thickness No section was measured through the formation but in the adjacent MOUNT ANDERSON it is estimated to be 100 m thick.

Rock-Stratigraphic Position In MOUNT ANDERSON, the formation conformably overlies the Alexander Formation which does not crop out in CROSSLAND. In CROSSLAND, its relations are obscured by sand and weathering.

Fossils and Time-Stratigraphic Position No fossils have been found in the outcrop in CROSSLAND, but rare pelecypods found in the type locality indicate Late Jurassic (middle-Tithonian) age (Brunnschweiler, 1954).

Environment of Deposition The lack of exposure within the mapped area limits the possibility of determining the depositional environment but evidence outside the area suggests a marine environment.



Fig. 29 Aerial photograph of part of Lake Gregory showing strand lines, channels, mudflat, and marginal salt crust. GSWA Negative.

?Jurassic Undivided

Quartzose sandstone outcrops in western DUMMER and in southern HELENA may be equivalents of other Jurassic units such as the Callawa Formation known to occur to the west of the area (Traves et al., 1956). The sandstone is quartzose, cross-bedded, and contain thin lenses of quartz granule and quartz pebble conglomerate.

Cainozoic

Lake Gregory Beds

The Lake Gregory Beds (Yeates et al., in press) are a sequence of fluvial and lacustrine clay, silt, sand, marl, and minor gravel and calcrete deposits. They are the ancestral deposits of Lake Gregory, a large ephemeral lake (Fig. 29).

Distribution and Type Locality The Lake Gregory Beds are exposed in a few localities on the shores of Lake Gregory in sections up to 2 m high (CORNISH). The type section is in BMR Cornish No. 3 a continuously cored hole at Lera yard (CORNISH), 20°11'S, 127°24'E (Fig. B13). Apart from the few exposures on the shores of Lake Gregory, the unit lies beneath aeolian and alluvial sand along the terminal parts of Sturt Creek, its floodout and floodplain in MOUNT BANNERMAN, CORNISH, and probably LUCAS. Exposures occur at 20°15'S, 127°23'E on the eastern side of Bulbi Plain and at Gilwah Waterhole, 20°08'30"S, 127°24'25"E (CORNISH).

Lithology The sediments in BMR Cornish No. 3 consist mainly of interbedded green, brown, and laminated to thin-bedded red calcareous and non-calcareous clay and silt and thin-bedded and cross-bedded white sand. There are rare gravels; the clasts consist of laterite pisoliths. Surface exposures in CORNISH have been leached and partly replaced by calcrete. Minor amounts of gypsum are also present in the corehole and around the margins of Lake Gregory.

In BMR Mount Bannerman No. 1 (B8) drab green and brownish clay, in places calcareous, and thin beds of marl and calcrete up to 30 cm thick are the constituent rock types, indicating a lithofacies change from BMR Cornish No. 3, which was spudded near the axial region of the large depression centred near Lake Gregory. In this well, sands are abundant. In contrast, BMR Mount Bannerman No. 1 was spudded near the margin of this depression and penetrated finer-grained sediments.

Mud on the shores of Lake Gregory is dark-coloured and is associated with gypsum and halite.

Thickness 99.7 m in BMR Cornish No. 3; 64.3 m in BMR Mount Bannerman No. 1.

Rock Stratigraphic Position The Lake Gregory Beds lie with low-angle unconformity on Permian and Triassic units in the subsurface to the southwest of Lake Gregory. They overlie weathered Condren Sandstone in BMR Mount Bannerman No. 1. The Beds interfinger with red aeolian sand at the surface.

Fossils and Time Stratigraphic Position Fossils recovered from surface outcrops of the Lake Gregory Beds in CORNISH include a coquina of gastropods; fish bones were recovered from BMR Cornish No. 3. This unit cannot be precisely dated, and is considered Cainozoic on the basis that it lies on a weathered profile and therefore is no older than Late Cretaceous or Early Tertiary, and that it includes sediments being deposited at present.

Environment of Deposition The Lake Gregory Beds fill a wide internal drainage depression. The sediments include lake deposits (silt and mud), river deposits (sand, gravel, and calcrete), possible aeolian deposits (sand), and evaporitic deposits (gypsum) indicating periods of drying up. Halite was found on the surface mudflat of Lake Gregory.

Lawford Beds

The Lawford Beds (Casey & Wells, 1964) is a sequence about 25 m thick of calcrete with minor calcareous sandstone and calcareous conglomerate. The Beds in places are still being deposited today by stromatolite-building algae (Figs 30, 31, 32). The Lawford Beds crop out as light-coloured densely vegetated low rises, capped by rubble.

Geographic Distribution and Type Locality In MOUNT BANNERMAN, the Lawford Beds are restricted to the area around Wattle Spring Creek and Salt Creek between Dean Hill (eastern edge of CROSSLAND) and Bulka Swamp. The type section (Casey & Wells, 1964) is in a north-flowing tributary of Christmas Creek about 15 km northeast of Bulka Hills in adjacent MOUNT RAMSAY to the north. The tributary is incorrectly named Lawford Creek on the MOUNT RAMSAY 1:250 000 Geological Sheet (Roberts et al., 1968) and on the 1st Edition of Mount Bannerman 1:250 000 Sheet area (Wells, 1960; Casey & Wells, 1964). This tributary is not named; the correct position of Lawford Creek is shown on the Mount Bannerman 1:250 000 topographic sheet a[illegible] the Preliminary to the 2nd Edition Geological Sheet.

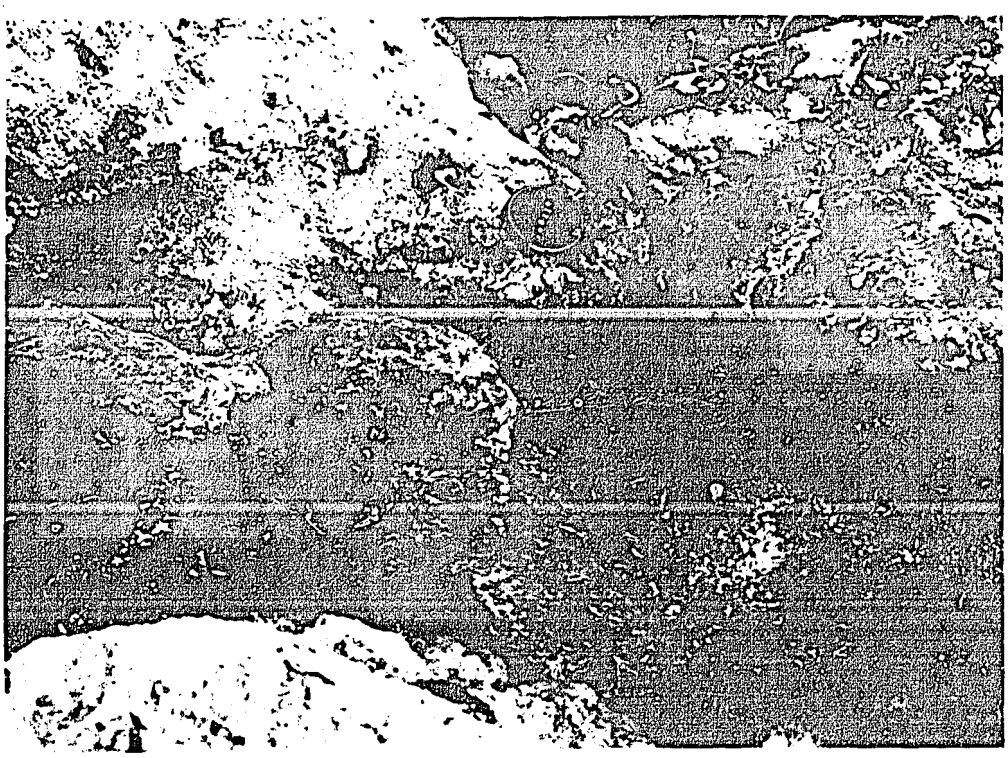


Fig. 30 Stromatolite-building filamentous blue-green algae colonizing areas of turbulent flow in McDonaldson Spring, MOUNT BANNERMAN.
BMR Negative GB/194.

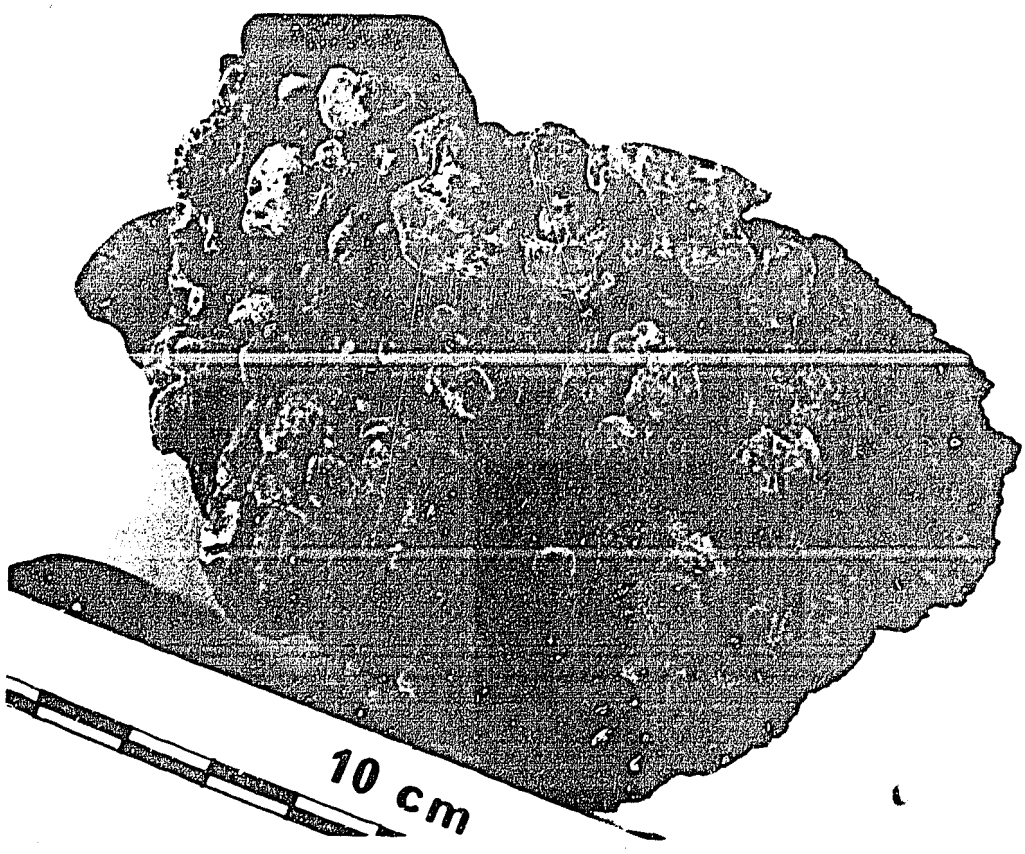


Fig. 31 Stromatolitic calcrete of the Lawford Beds, built by algae. McDonaldson Spring, MOUNT BANNERMAN. See also Fig. 32.
BMR Negative F/5950.

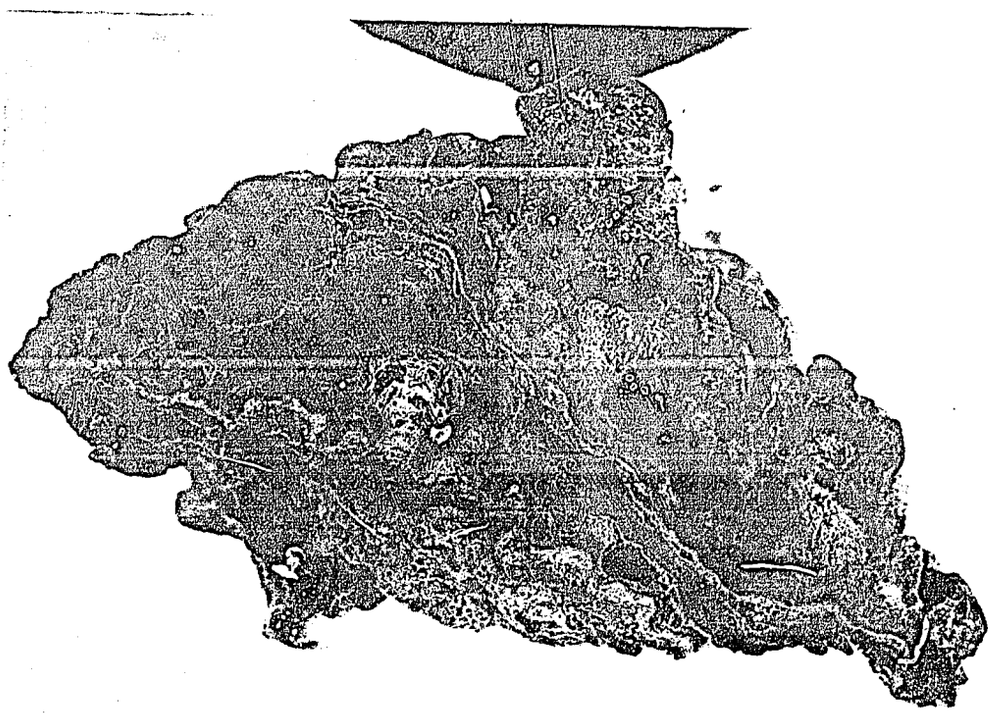


Fig. 32 Cross-section view of stromatolitic calcrete of the Lawford Beds. The specimen which is natural size is the same as Fig. 31, McDonaldson Spring, MOUNT BANNERMAN. BMR Negative F5946.

Lithology Algal and non-algal calcrete, marl, and sandy calcrete with calcareous sandstone, calcareous breccia, and calcareous conglomerate, especially at the base, and massive and laminated chalcedony at the top are the constituent rock types. Of these, calcrete is the most common.

The conglomerates and breccias are composed of an imbricate framework of clasts derived both locally from immediately underlying Permian formations and from Proterozoic outcrops to the northeast. The pebbles and boulders consist mainly of Precambrian quartz and quartzite; clasts forming the breccias are large fragments of locally derived Permian shale and siltstone. The clasts are cemented by calcite. Minor amounts of calcareous sandstone are interbedded with the conglomerates and breccias.

Conglomerate, of which the pebbles consist of laterite pisoliths cemented by calcite, is well developed at Middle Spring and interbedded with calcrete.

The calcrete is composed essentially of calcite with a little sand and clay. It is both massive (non-algal) and laminated to thinly bedded; the laminations include gently undulating (algal mat) and curvi-laminar varieties (derived from the growth of 3-cm wide pustular aggregates of filamentous blue-green, stromatolite-building algae, Figure 30. These algae grow on waterfalls in gullies fed by springs which have dissected parts of the Lawford Beds. By continuous precipitation of carbonate on the face of waterfalls, small rimstone barriers are built laterally, with high initial dip, in the downstream direction, until such growth causes diversion of flow and isolation of these barriers. They form only where the water is fast-flowing. The stromatolites are building rock types identical to those observed in the creek beds. They are best developed at McDonaldson Spring and also at Middle Spring and Wattle Spring (MOUNT BANNERMAN).

Where stream energy is lower, for instance in shallow pools, algal mats cover the floor of the pools. Presumably the algae extract carbon dioxide from the water resulting in precipitation of calcite and formation of calcrete which preserves the undulating algal laminations. In places, algal mats have trapped sand and silt patricles; ensuing carbonate precipitation encloses the particles to form calcareous sandstone, sandy calcrete, and marl. These rock types were also observed in the banks of the creek.

Thickness 24.4 m at type section (Casey & Wells, 1964), and probably similar elsewhere.

Rock Stratigraphic Position The Lawford Beds lie with marked angular unconformity on Proterozoic rocks and with low-angle unconformity on the Upper Carboniferous to Lower Permian Grant Formation, the Permian Noonkanbah Formation, Lightjack Formation, and Condren Sandstone. The Lawford Beds overlie Cainozoic laterite and in places have been lateritized themselves. In places, thin aeolian sand overlies the Lawford Beds.

Fossils and Time Stratigraphic Position The Lawford Beds contain moulds of wood, roots, and leaves. They also contain structures (stromatolites, laminations) built by algae. A Cainozoic age is assigned to the Beds on the basis of their relations with laterite and the Holocene flora they contain.

Environment of Deposition The curvi-linear distribution of the Lawford Beds, the imbricate framework of the conglomerates, and their present-day formation in creeks indicate a fluvial origin.

The conglomerates containing clasts of laterite pisoliths, and the fact that some outcrops of Lawford Beds are lateritized suggests that the lateritization accompanied sedimentation. The association of calcrete with laterite and terra-rosa soils is well known (Goudie, 1973). The lime of the calcrete was derived by leaching from the underlying rock formations, and its redeposition in channels, during the period of weathering in which laterite was being formed by leaching and concentration of it in soils.

Algae which today live in the remnant waters of the drainage system absorb carbon dioxide from the water, thereby inducing carbonate precipitation.

The chalcedony, which in places forms a prominent cap to the Lawford Beds may be diagenetically formed, possibly by dissolution of quartz grains and their subsequent reprecipition in chalcedonic form. Field relations suggest a genetic relationship between chalcedony and calcrete as the two, where exposed, are usually found together in the area.

Calcrete and Chalcedony

Calcrete is consolidated fine-grained carbonate following the terminology of Goudie (1972). In the area, it was previously known as travertine (Casey & Wells, 1964). Chalcedony is often associated with calcrete as a surface capping, void filling, and as a replacement. The calcrete deposits have not been formally named, except those within the Lawford Beds. In the area calcrete has been formed in

both ancient drainage channels, in soils developed on soft-weathering units and around the margins of some salt lakes. The three types were not distinguished in the field.

Distribution Calcrete occurs throughout the area in ancient and present-day drainage channels; it is also present on some outcrops of the soft-weathering Blina Shale, Lake Gregory Beds in CORNISH and the Noonkanbah Formation in DUMMER. Throughout the area, calcrete crops out as a series of light-coloured low mounds and shallow depressions which form a conspicuous pattern on aerial photographs.

Lithology Massive and nodular calcrete are the most common; other rock types mapped with calcrete include marl, minor chalcedony, clayey (milky) chalcedony, moss agate, chalcedonic calcrete, and rare dolomite. Collectively, these rock types have been assigned the same map symbol - Czk - as they are all stratigraphically and genetically related.

The calcrete is composed essentially of fine-grained calcite, with subordinate sand and nodules of chalcedony. The textures in calcrete vary; nodular, massive, vuggy, laminate, and curvi-laminate types were recognized.

One specimen containing dolomite, calcite, and quartz was found in eastern HELENA; this is the first recorded occurrence of dolomite associated with calcrete in the area.

Thickness The thickest section observed was 2 m in the banks of Sturt Creek (BILLILUNA). The maximum thickness is unknown; the large expanse of calcrete in western STANSMORE, eastern HELENA, and eastern CORNISH suggests greater thicknesses in these areas.

Rock Stratigraphic Position Calcrete deposits of fluvial origin rest with low-angle unconformity on Palaeozoic and Triassic formations. Lacustrine calcrete interdigitates with the Lake Gregory Beds and with other unnamed lacustrine, alluvial, evaporitic, and aeolian sand deposits. Calcrete is interbedded with alluvial deposits in parts of Sturt Creek (BILLILUNA).

Soil calcrete lies on the soft-weathering Blina Shale and Noonkanbah Formation, now as a capping or as a thin precipitate lining rills on the slopes of mesas.

Fossils and Time Stratigraphic Position The only fossils recorded (gastropods) were found in calcrete by J.N. Casey (Wells, 1962) 15 km northwest of Lake Isabella (CORNISH). These give no clue to the age of calcrete. On the basis of its relations with other units, a Cainozoic age is assigned.

Environment of Deposition Calcrete in the area is formed in present-day and ancient drainage depressions, both fluvial and lacustrine, and also in soils. In each setting it has formed by precipitation of line leached in solution from underlying rocks in drainage courses and in some soils.

Evaporites

Evaporites, including crystalline gypsum, halite, and powdery caliche occur in the salt lakes associated with terminal drainage; some are interbedded with alluvium in claypans.

Geographic Distribution Evaporites have been mapped in salt lakes and claypans in LUCAS, STANSMORE, WEBB, CORNISH, HELENA, and DUMMER.

Lithology The areas mapped as evaporites have a white salt crust which consists of gypsum, and in places halite and powdery caliche. Shallow auger holes through the salt crust intersected further layers of evaporites interbedded with pale green and pale brown clay and brine-saturated fine red sand (A35 to A38). In Gwenneth Lakes, DUMMER, numerous pisolites of goethite were encountered in a matrix of clayey caliche (A38).

The gypsum and halite are crystalline; the dominant cleavage plane in gypsum from surface samples is at right angles to the salt lake surface, indicating in situ crystallization.

Lake surfaces are fractured by dessication cracks; surfaces are also undulatory owing to curling of the top few centimetres of sediment.

Thickness Thicknesses of evaporite sequences intersected in hand-auger holes are at least 60 and 125 cm in MOUNT BANNERMAN, beneath surface alluvium; at least 253 cm in Gwenneth Lakes, DUMMER (A38), and at least 350 cm in Lake MacKay, WEBB (A36).

Rock Stratigraphic Position Evaporitic sequences lie unconformably on Palaeozoic and Triassic units; they interfinger with calcrete and alluvium and lie adjacent to deposits of aeolian sand.

Time Stratigraphic Position A Quaternary age is assigned on the basis of rock relations and the fact that these deposits are being formed at present.

Environment of Deposition Evaporites are formed in salt lakes coincident with topographic depressions in the terminal parts of past and present drainage systems.

Alluvium

Deposits of gravel, sand, silt, clay, and minor evaporites in drainage depressions, outwash fans, and dry lakes have been mapped as alluvium.

Geographic Distribution Alluvium occurs in most parts of the area. The thickest deposits are those of Sturt Creek (BILLILUNA), the Lake Gregory Beds (LUCAS, MOUNT BANNERMAN, and CORNISH), and Christmas Creek (MOUNT BANNERMAN). The following large claypans consist of alluvium: Lake Hevern (STANSMORE), Lakes Betty, Lanagan, McLernon, Doman, and Jones (MOUNT BANNERMAN), Nicholson Swamp (CROSSLAND), Lakes Gwenneth and Prescott (DUMMER), and Thornton Flat (HELENA). Numerous small unnamed claypans occur in all Sheet areas, in places between longitudinal sand dunes. Claypans are well developed in the broad depressions developed over the subcrop of the soft-weathering Noonkanbah Formation and Blina Shale.

We have not recognized the Wolf Gravel (Casey & Wells, 1964) in BILLILUNA because it has no defined type section, it cannot be distinguished from other alluvial deposits, and it is susceptible to complete erosion by floods. We prefer it to be part of the unit mapped "Qa" (Yeates et al., in press) though we recognize it to be an ancestral deposit of Wolf Creek (see Casey & Wells, 1964).

Lithology In the undercut banks of Christmas Creek, Sturt Creek, and Wolf Creek, poorly sorted cross-bedded sand and gravel occur. The banks and floodplains have a thin cover of silt, or a cover of aeolian sand. Thin interbeds of calcrete are present in places in the sandy units.

In contrast, alluvial deposits of claypans are much finer. The principal sediment grades are fine sand, silt, and clay, mainly the last two. These deposits are thinly bedded to laminated in the sub-surface, as revealed by shallow auger holes (A40) and are mudcracked at the surface. Such deposits may also contain beds of gypsum a few centimetres thick. Claypans may contain water for short periods after ephemeral showers.

Alluvium also occurs in low topographic depressions which delineate past channels. Here it consists of poorly sorted red sand and red-brown silt.

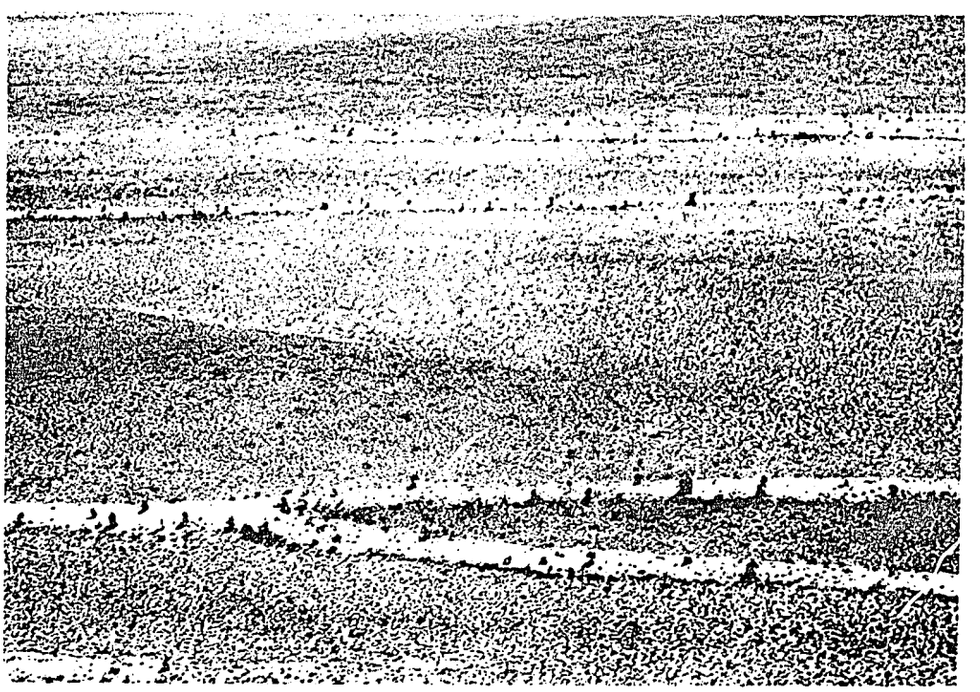


Fig. 33 East-west trending longitudinal sand dunes showing tuning-fork structure opening upwind to the east, western LUCAS. BMR Negative GB/244.

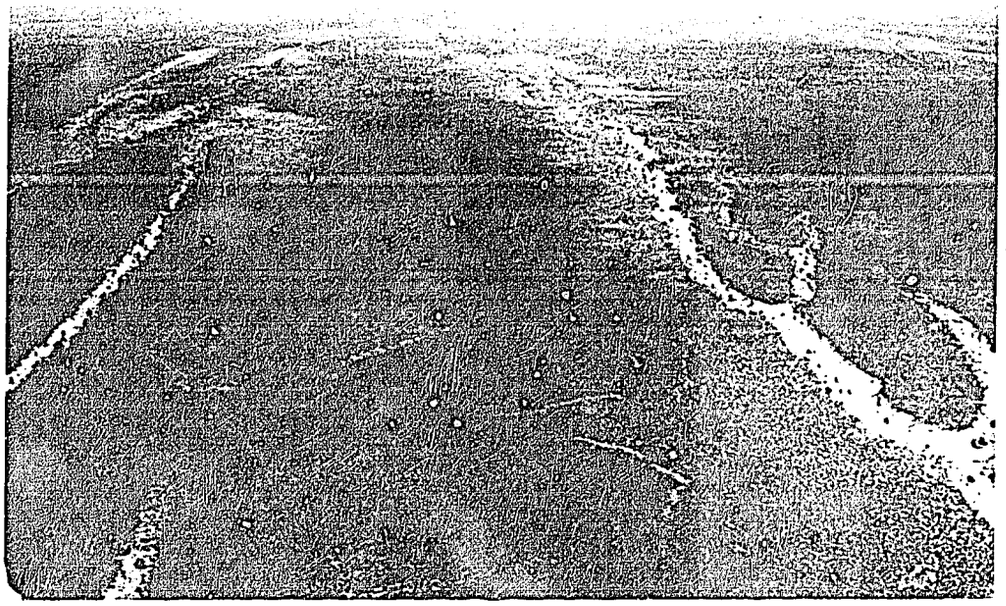


Fig. 34 Upwind view of longitudinal sand dunes showing bifurcation, western LUCAS. The dark and light areas between the dunes are marks made by fire-burns, usually as a result of lightning strikes. BMR Negative GA 7730.

Thickness Auger-hole sections (A40) through claypans in MOUNT BANNERMAN indicate thicknesses varying from 25 cm to 90 cm. Elsewhere, the thickness of other alluvial deposits was not determined.

Rock Stratigraphic Position Alluvial deposits lie with angular unconformity on Palaeozoic and Triassic strata and disconformably on Cainozoic laterite. Alluvium interfingers with one or more of the following: aeolian sand, calcrete, and evaporites.

Fossils and Time Stratigraphic Position Undiagnostic silicified wood fragments perhaps reworked from the Lawford Beds and fossilized logs occur in parts of the Christmas Creek alluvium. A Quaternary age is assigned on the basis of rock relations and the continuation of deposition at present.

Environment of Deposition The river sands and gravels have been deposited during floods. The surface drainage exists only for short periods before it becomes subsurface. The claypan deposits, in contrast, are local terminal drainage deposits and only fine grades of sediment occur in them. Periodic evaporation, after ephemeral showers, may cause any dissolved salts to precipitate to form a very thin discontinuous salt crust. Evaporation also causes shrinkage cracks to develop.

Aeolian Sand

A thin cover of wind blown red quartzose sand constitutes the longitudinal dunes and extensive sand plain which is part of the Great Sandy Desert.

Distribution Aeolian sand occurs throughout most of the area.

Lithology Red quartzose sand, fine to medium-grained; minor reddish-brown silt. The sand is well sorted, especially on dunes, and grains are stained red by a thin coating of earthy hematite. Bedding in the dunes is thin and cross-bedding occurs throughout. The cross-sets are planar and vary from a few degrees to more than 20° in the few exposures of it observed. They are often wedge-shaped. Dune surfaces have a somewhat semi-circular profile and are usually rippled. They do not appear to have an asymmetric profile as in the Simpson Desert of central Australia (see Folk, 1971).

The reddish brown silt is a minor constituent of inter-dune areas. It gives a duller and darker colour to the sand between the dunes compared with that on the dunes.

Figures 33 and 34 show the dune morphology.

Thickness The thickest known section of undoubted aeolian sand was encountered in BMR Mount Bannerman No. 1 where 5 m was intersected. This thickness does not include the height of sand dunes which varies from 3 to 30 m.

Rock Stratigraphic Position Aeolian sand overlies all Palaeozoic, Mesozoic, and some Cainozoic units. It lies adjacent to Quaternary alluvial and evaporitic deposits including the uppermost part of the Lake Gregory Beds.

Time Stratigraphic Position The sand is regarded as Quaternary in age; it is one of the most recent features of the area.

Environment of Deposition The sand sheet has developed in a desert environment following the reworking by wind of surface unconsolidated alluvial sediments deposited from erosion of pre-existing topography in the late Cainozoic.

Field Description The parallel, longitudinal sand dunes are oriented east-west with 'tuning fork junctures' opening upwind to the east. They are obstacles when traversing by vehicle, but are a useful navigational aid when traversing the area by helicopter with aerial photographs at a scale of 1:80 000.

Weathering Products

Chemical weathering has affected Palaeozoic, Triassic, Jurassic, and some Cainozoic outcrops to depths up to at least 130 m. Laterite profiles have developed and silcrete, ferricrete, and calcrete have formed.

Deep weathering may have commenced in the Late Cretaceous or Early Tertiary during a phase of chemical alteration which affected a large part of the continent (Woolnough, 1927). Weathering was probably most rapid in periods of high rainfall, when the land surface was at a stage of low relief and high water-tables were maintained (Taylor, 1966). The decomposition of near-surface rock was caused by leaching of potash, soda, lime, magnesia, and some silica from the underlying parent rock. The residual accumulations of iron oxides and hydroxides formed laterite; organic matter in the original sedimentary rocks was oxidized. Lime was re-precipitated as calcrete, silica as chalcedony, and soda as halite.

Laterite (Czl) Laterite is the indurated plateau-forming ferruginous concentration in the upper part of lateritic profiles (Fig. 35); it is best developed where the underlying parent rock is clay-rich. Typically, it is well developed on the Noonkanbah Formation, the shale units of the Liveringa Group, and on the Blina Shale.

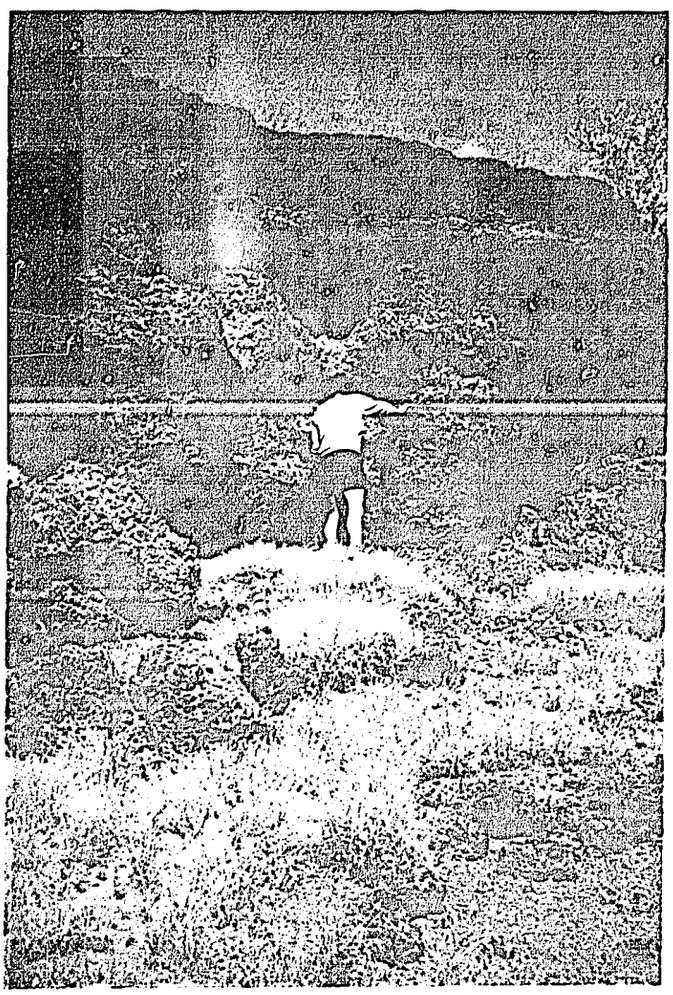


Fig. 35 Outcrop of massive pisolitic laterite forming thick capping in southern HELENA. BMR Negative GB/201.

Laterite profiles consist of an indurated capping of pisolitic or 'honeycomb'-textured goethite-rich rock up to 5 m thick (Fig. 35) which grades downwards through a massive vari-coloured mottled clay rich zone to a basal leached kaolinized zone in which primary sedimentary features can be recognized and which lies on hardened parent rock (A39). Complete laterite profiles are not always exposed. In places there is insufficient relief to observe the lower part of the profile or, in areas of considerable relative relief, the profile or the hard capping and mottled zones may have been stripped off by erosion, thus exposing the kaolinite-rich layer.

The eroded capping may be reworked. It may accumulate as scree surrounding outcrops, or be washed into local drainage depressions and deposited elsewhere. In both these settings continuation of laterite-like processes at intervals during the Cainozoic has caused consolidation of the reworked material to indurated 'detrital laterite'. The 'detrital laterite' on account of its durability may eventually form topographically high features as further erosion of surrounding unconsolidated sediments takes place. The 'secondary laterites' in places have a profile which differs from the trizonal profile of the widespread plateau-forming types.

Ferruginous induration of creek alluvium in creeks along the eastern scarp of the Stansmore Range (Fig. A41) and the creek draining Waterlander Breakaway (STANSMORE) produces another type of detrital laterite.

Silcrete (Czs) Small patches of silcrete are present on some quartzose sandstone units, particularly those in the part of the Erskine Sandstone in MOUNT BANNERMAN. Only the larger outcrops are shown on the maps.

Silcrete consists of fine angular fragments of quartz grains cemented by chalcedonic silica. It has a characteristic exfoliation surface.

Ferricrete (Czf) Ferricrete is a mixture of fine iron oxides and hydroxides and microcrystalline silica, from which all clayey material has been leached. It caps sandstone units in the Noonkanbah Formation (DUMMER) the Kirkby Range Member, CROSSLAND (Fig. 84) and Triassic units (MOUNT BANNERMAN, CORNISH and LUCAS); it also fills some faults and joints, a result of reprecipitation of iron and silica leached during solution activity and deep weathering along fractures. Some ferricrete fault fillings rise above the sand plain especially in DUMMER and CORNISH and delineate the position of faults in areas where there are no other outcrops. Like silcrete, outcrops of ferricrete often exhibit exfoliation surfaces (Fig. 85).

Calcrete (Czk) Soil calcrete (already described) is a product of weathering in places. It is formed when lime was re-precipitated in old soils.

SUBSURFACE INVESTIGATIONS

Although oil companies have been active in the Canning Basin since 1919, their work in the northeastern part was restricted to surface investigations until 1962. Company drilling and geophysical surveys had been concentrated in the more easily accessible western and coastal areas of the basin.

The earliest subsurface investigations of the area were reconnaissance gravity, aeromagnetic, and seismic surveys carried out by BMR from 1952 to 1962; the results which are summarized below (Table 2) show where these surveys were located.

BMR Aeromagnetic Survey

The aeromagnetic survey was flown in 1954 (Quilty, 1960) and was essentially a reconnaissance survey with ten widely spaced flight lines with a more detailed survey being flown in northeast CROSSLAND.

The reconnaissance results suggested that depth to magnetic basement in the Fitzroy Trough ranges from 6000 m below sea level on the northern edge of CROSSLAND, north of the Fenton Fault, to greater than 4500 m below sea level in MOUNT BANNERMAN, south of the Pinnacle Fault. Between these two areas, on the boundary of the two Sheet areas magnetic basement rises to 3000 m below sea level. Basement is also at 3000 m below sea level on the eastern and southern edges of the area. South of the Fenton Fault in CROSSLAND magnetic basement rises to 1500 m below sea level.

The more detailed survey in CROSSLAND suggested that the Fenton Fault is downthrown to the northeast and that depth to basement on the upthrown side is 1500 m below sea level.

BMR Gravity Surveys 1952-1960

Gravity investigations were commenced in the Canning Basin by BMR in 1952 and by 1960 most of the basin had been covered (Flavelle & Goodspeed, 1962). However the density of gravity stations varies greatly owing to the remoteness of some areas. Within the area numerous gravity features were delineated (Fig. 36).

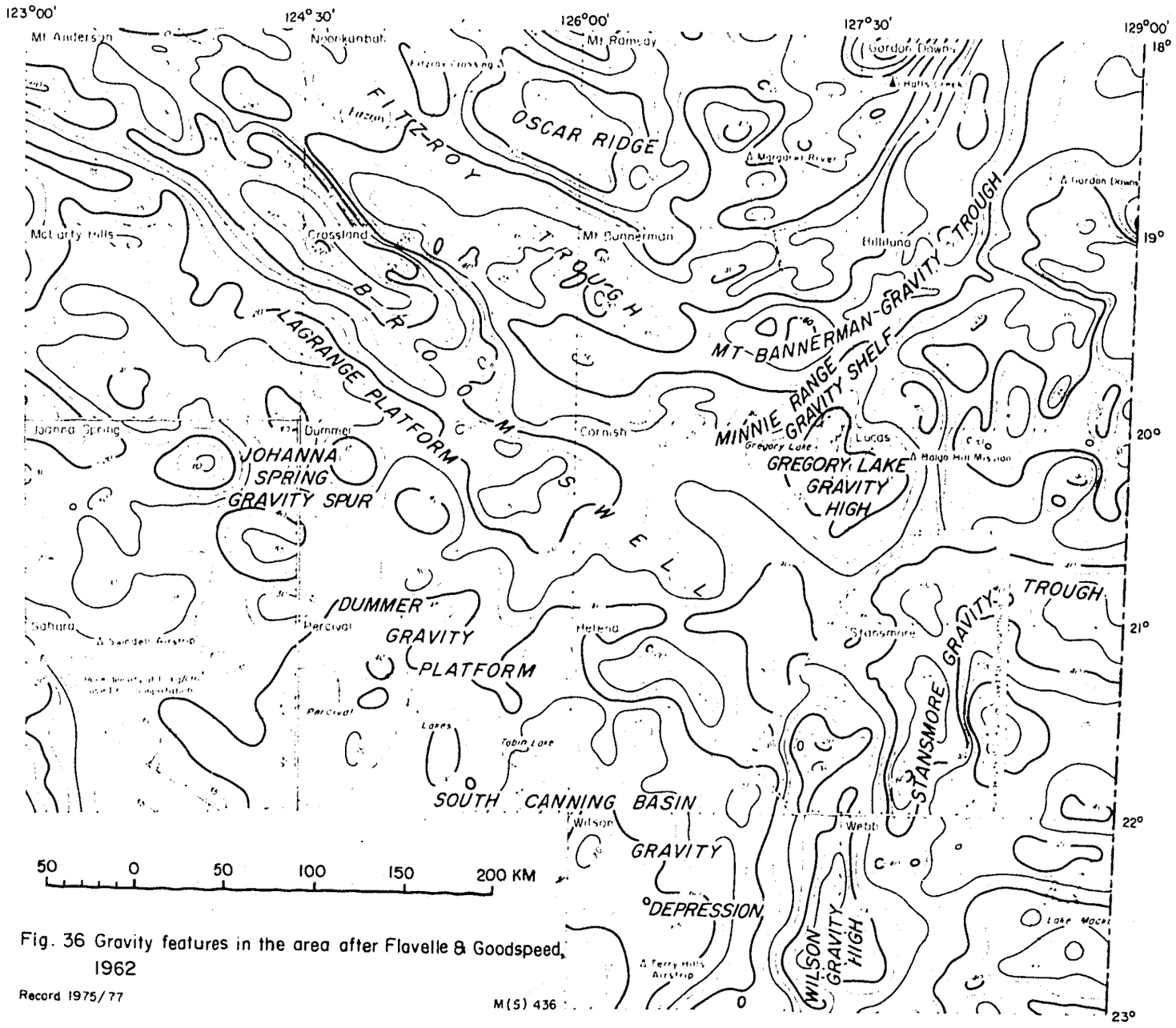


Fig. 36 Gravity features in the area after Flavelle & Goodspeed, 1962

TABLE 1. BMR GEOPHYSICAL SURVEYS IN THE NORTHEAST CANNING BASIN

NAME	Reference	Duration	Extent	Sheet Areas								
				Cross-land	Dummer	Mt Bann-erman	Cornish	Helena	Billi-luna	Lucas	Stans-more	Webb
Canning Basin Aeromagnetic Survey W.A. 1954	Quilty (1960)	13/07/54 to 1/09/54	Total Distance Unknown	x	x	x	x	x	x	x	x	x
Fitzroy and Canning Basin Reconnaissance Gravity, Surveys Western Australia 1952-60	Flavelle & Goodspeed (1962)	1952-1960	Combination of various surveys, both detail and Regional	x	x	x	x	x	x	x	x	x
Poole Range Seismic Survey	CGG, 1974	15/06/62 2/11/62	279.1 km	x								
Reconnaissance Helicopter Gravity Survey, Canning Basin, W.A., 1968	BMR Record 1974/	27/07/68 25/09/68	2523 gravity stations		x		x	x		x	x	x

The Oscar Ridge (a sub-unit of the Lennard Shelf, Veevers & Wells, 1961) appeared as a zone of positive, closed, relatively high Bouguer anomalies in northern and northeast MOUNT BANNERMAN, where it terminates against the Mt Bannerman Gravity Trough. Depths to basement within this region are shallow.

The 'Fitzroy Trough' is bounded to the northeast by the Oscar Ridge and to the southwest by the 'Broome Swell', the boundaries being steep gravity gradients represented by the Pinnacle and Fenton Faults, respectively. The Trough is characterized by a line of negative anomalies trending southeasterly from northern and northeastern CROSSLAND with a relative gravity high in northeastern CROSSLAND near Jones Range. The southeastern extension of the Trough was not clearly defined by the gravity results. It was postulated that the extremely deep part of the Trough (6000 m +) terminates in northeast CROSSLAND. However the gravity expression of the Fenton Fault continues in a southeasterly direction from northwest CROSSLAND to southeast CORNISH passing just south of Godfreys Tank. There is a progressive reduction in the throw on the fault to the southeast.

To the south of the 'Fitzroy Trough', the 'Broome Swell' appears as a line of positive anomalies trending southeasterly from northeast CROSSLAND to Dummer Range where it widens and continues to northeast HELENA. The minimum sedimentary thickness occurs near northwestern CROSSLAND.

To the southwest and south, the Broome Swell is bounded by five features:- The 'Lagrange Platform', an area of alternating gravity maximum and minimum in central western CROSSLAND; the 'Oasis Gravity depression', a gravity low in southwestern CROSSLAND: the 'Johanna Spring Gravity Spur', an area of relatively high gravity anomalies south of the 'Oasis Gravity Depression' in northwestern DUMMER; the 'Dummer Gravity Platform', a broad area of smooth gravity relief between the 'Johanna Spring Gravity Spur' and the 'South Canning Basin Gravity Depression' in southern DUMMER and southwestern CORNISH; and the 'South Canning Basin Gravity Depression', an area of extensive closed gravity lows in the southern part of the area. These last four gravity features are generally more negative than elsewhere in the Canning Basin and the anomalies are smooth with no steep gradients or sudden changes in trends. Overall they become more negative to the southeast.

The 'Mount Bannerman Gravity Trough', a pronounced, elongate belt of negative anomalies occurs in the northeastern part of the area. It tends easterly across central-southern MOUNT BANNERMAN then trends northeasterly

across BILLILUNA, passing near the Wolf Creek Meteorite Crater. It is 'possibly an extension of the Fitzroy Trough', but the authors thought it was more likely that this latter feature terminated in northeastern CROSSLAND. The 'Mount Bannerman Gravity Trough' is bounded to the north by the 'Oscar Ridge' and to the south by the 'Minnie Range Gravity Shelf' and separated from them by a steep gravity gradient.

The 'Minnie Range Gravity Shelf' is an area of reduced gravity gradient between the 'Mount Bannerman Gravity Trough' and the 'Gregory Lake Gravity 'High' and occurs in far southern MOUNT BANNERMAN and the adjacent northern CORNISH.

The Gregory Lake Gravity 'High' centered on Lake Gregory, northeast CORNISH, is a closed positive anomaly, possibly indicating shallower basement. Bifurcating off the 'Mount Bannerman Gravity Trough', near Billiluna homestead, is the 'Stansmore Gravity Trough', a pronounced, elongate low, trending south, parallel to the basin margin through BILLILUNA, LUCAS, STANSMORE, and WEBB. The anomaly, running west of the Stansmore Range, is probably due to a thick Palaeozoic sequence.

The Stansmore Fault is characterized by a steep gradient at its southern end on the eastern margin of the Stansmore Range Gravity Trough, west of the Stansmore Ranges. The throw decreases towards the north and the main variations in basement depth probably run north from the Stansmore Range, following the trend of the Stansmore Gravity Trough.

In western WEBB is part of the 'Wilson Gravity High', a closed positive gravity anomaly centred on eastern WILSON.

BMR - CGG Poole Range Seismic Survey

In 1962 Compagnie Generale de Geophysique (CGG), as contractor for BMR, ran the Poole Range Seismic Survey. The survey, a combined reflection/refraction survey was supervised by the Institut Francais du Petrole (IFP) and consisted of two lines run obliquely to the regional structure in northeast CROSSLAND (CGG, 1974; Ferrand, 1963).

Two traverses were shot and the results varied from poor to reasonable. The northeast-trending traverse (line C) showed a syncline 4 km southeast of Millyit Range in which the depth estimate to the lowest refractor is 7050

m. Southwest of this, the refractors rise over a faulted anticline centered 3 km southeast of Hall Range. The northeastern margin of the syncline has been faulted immediately west of Jones Range and the fault has an estimated downthrow to the southwest of 1200 m. Farther northeast, the refractors rise, indicating another anticline east of Jones Range.

The north-northwest trending line (line A) verified the anticline east of Jones Range and on this line it extends from 2 km west of Yard Bore to 4 km south of Hicks Range. The closure on this structure is about 1200 m. It corresponds to the gravity high in northeast CROSSLAND (Flavelle & Goodspeed, 1962).

Subsidized Operations

Subsurface company investigations did not get underway within the area until after the introduction of the second Commonwealth Petroleum Search Subsidy Act in 1959 when subsidy became available for 50% of acceptable costs of approved geophysical operations and stratigraphic drilling. Before the cessation of the Commonwealth Petroleum Search Subsidy Act 1959-1969 in June 1974, 28 subsidized geophysical operations were carried out and 6 wells were drilled (Tables 3, 4). One unsubsidized seismic survey was also done. The following is a summary of these activities in the area.

WAPET South Canning Basin Aeromagnetic Survey

The first subsidized survey in the area was part of the South Canning Basin Aeromagnetic Survey flown in 1962-1963 by Aero Service Limited for West Australian Petroleum Pty Ltd (WAPET, 1966a). The survey was a regional reconnaissance airborne magnetometer survey with a total of 29 280 line km of traverses flown at 600 m and covering all Sheet areas except STANSMORE and WEBB. The objective of the survey was to delineate the depth and configuration of the South Canning Basin and to reveal other major structural features. Data from a survey flown in 1955 were also incorporated in the results.

Within the area the results from the survey indicated three separate depressions, each of which is a major basin.

In northeast CROSSLAND basement drops to over 7500 m below sea level. This is the southern extension of a depression observed in southeast NOONKANBAH and is apparently a subsidiary feature of the Fitzroy Trough, separated from it by a structural saddle.

TABLE 2. COMPANY GEOPHYSICAL SURVEYS IN NORTHEAST CANNING BASIN

NAME	TYPE	OPERATOR	CONTRACTOR	BMR FILE NUMBER	DURATION	TOTAL EXTENT (km)	SHEET AREAS								
							Cross-land	Dummer	Mt Bann-erman	Cornish	Helena	Billi-luna	Lucas	Stans-more	Webb
South Canning Basin	AM	West Australian Petroleum Pty Ltd	Aero Service	62/1728	30/11/62-4/01/63	29280	X	X	X	X	X	X	X	X	X
Stansmore Range Aeromagnetic Survey	AM	Hackathorn New Zealand Oils Ltd and Australian Oil Corporation	Adastra Hunting Geophysics Pty Ltd	63/1700	15/05/63-30/05/63	3325					X		X	X	
Balgo-Lake Betty Seismograph Survey	S	West Australian Petroleum Pty Ltd	Geophysical Service International	63/1533	27/07/63-6/11/63	424			X				X		
Lake Betty Reconnaissance Gravity Survey	G	West Australian Petroleum Pty Ltd	United Geophysical Corporation	63/1909	17/09/63-29/11/63	1879 Stations	X		X						
Stansmore Range Seismograph Reflection and Gravity Survey	S&G	Hackathorn New Zealand Oils Ltd	Geoseismic (Australia) Pty Ltd	Unsubsidized	1963	Unknown								X	
Stansmore Ranges Gravity Survey	G	Beach Petroleum N.L.	Geoseismic (Australia) Pty Ltd	64/4807						X	X		X	X	
St. Georges Range Reconnaissance Seismic Project	S	Continental Oil Company of Australia Ltd	Ray Geophysics (Australia) Pty Ltd	64/4548	11/09/64 8/05/65	537.4	X								
Poole Range Detail "Vibroseis" Project	S	Continental Oil Company of Australia Ltd	Ray Geophysics (Australia) Pty Ltd	65/11001	9/05/65-9/07/65	259.5	X								

TABLE 2. (Continued)

NAME	TYPE	OPERATOR	CONTRACTOR	BMR FILE NUMBER	DURATION	TOTAL EXTENT (km)	SHEET AREAS								
							Cross-land	Dummer	Mt Bann-erman	Cornish	Helena	Billi-luna	Lucas	Stans-more	Webb
East Canning Seismic Survey	S	West Australian Petroleum Pty Ltd	Geophysical Service International	72/975	9/04/72-22/08/72	900.8	X	X		X					
Dampier Downs (331) - Collins (336) Seismic Survey	S	West Australian Petroleum Pty Ltd	Digicon (Australia) Ltd	72/2545	8/06/72-12/08/72	430.12	X								
Crosslands 3 (358) Seismic Survey	S	West Australian Petroleum Pty Ltd	Geophysical Service International	73/244	21/07/73-3/08/73	110	X								
Jones Range (364) and Hall Range (370) Seismic Project	S	West Australian Petroleum Pty Ltd	Geophysical Service International	73/255	23/08/73-15/09/73	151.79	X								
Barbwire 2 (361) Seismic Survey	S	West Australian Petroleum Pty Ltd	Geophysical Service International	73/263	16/09/73-15/10/73	161 approx.		X		X					
Thornton Seismic Survey	S	Associated Aust-ralian Resources N.L.	Petty-Ray Geophysical Incorporated	72/3362	29/07/73-31/01/74	671.7			X	X	X	X			

TABLE 2. (Continued)

NAME	TYPE	OPERATOR	CONTRACTOR	BMR FILE NUMBER	DURATION	TOTAL EXTENT (km)	SHEET AREAS								
							Cross-land	Dummer	Mt Banner-man	Cornish	Helena	Billi-luna	Lucas	Stans-more	Webb
Stretch Range Seismic and Gravity Survey	S&G	Australian Aquitaine Petroleum Pty Ltd	Ray Geophysics (Australia) Pty Ltd	70/600	1/08/70-14/10/70	182 403 Stations					X		X	X	
Helena (267) Reconnaissance Seismic Project		West Australian Petroleum Pty Ltd	Digicon (Australia) Ltd	70/504	16/06/70-9/08/70	402.2		X	X	X					
Lake Betty (269) Detail/Reconnaissance Seismic Survey	S	West Australian Petroleum Pty Ltd	Digicon (Australia) Ltd	70/657	29/07/70-29/08/70	174.30			X						
Crossland (268) Reconnaissance Seismic Survey	S	West Australian Petroleum Pty Ltd	Digicon (Australia) Ltd	70/687	25/08/70-29/10/70	135.35	X	X							
Crossland Platform (304) Seismic Project	S	West Australian Petroleum Pty Ltd	Geophysical Service International & Digicon (Australia) Ltd	71/150	21/05/71-30/06/71	572	X	X		X					
Billiluna-Helena Aeromagnetic Survey	AM	Australian Associated Oilfields N.L.	Adastra Airways Pty Ltd	71/422	6/10/71-5/11/71	12000 approx.			X	X	X	X	X	X	
White Hills Area High Sensitivity Aeromagnetic Survey	AM	Australian Aquitaine Petroleum Pty Ltd	Adastra Airways Pty Ltd	71/508	6/11/71-16/11/71	4363.2				X	X		X	X	

TABLE 2. (Continued)

NAME	TYPE	OPERATOR	CONTRACTOR	BMR FILE NUMBER	DURATION	TOTAL EXTENT (km)	SHEET AREAS								
							Cross-land	Dummer	Mt Bann-erman	Cornish	Helena	Billi-luna	Lucas	Stans-more	Webb
Broome Swell Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Western Geophysical Company of America	65/11006	8/06/65–7/07/65	95.2	X								
Crossland Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Ray Geophysics (Australia) Pty Ltd	65/11012	11/07/65–15/10/65	370.17	X		X						
Barbwire Range Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Ray Geophysics (Australia) Pty Ltd	65/11041	16/10/65–20/01/66	178.24	X								
Betty Detail Seismic Project	S	West Australian Petroleum Pty Ltd	Geophysical Service International	65/11055	13/06/66–20/08/66	1594.72			X						
Dakota Seismic and Gravity Survey	S&G	Australian Aquitaine Petrol-eum Pty Ltd	Compagnie Generale de Geophysique	67/11161	15/05/67–4/10/67	1081 Stations 512.1					X				
Terry Range Magneto-Telluric Survey	M.T.	Australian Aquitaine Petrol-eum Pty Ltd	Societe Nationale des Petroles d'Aquitane	68/3016	9/05/68–12/10/68	109 Soundings					X			X	X
Ryan Seismic and Gravity Survey	S&G	Australian Aquitaine Petrol-eum Pty Ltd	Compagnie Generale de Geophysique	68/3026	15/06/68–10/10/68	1029 Stations 403					X			X	
Contention Heights Seismic Refraction Survey	S	Australian Aquitaine Petrol-eum Pty Ltd	Compagnie Generale de Geophysique	69/3036	2/06/69–3/08/69	342					X			X	

TABLE 3.

WELLS DRILLED IN NORTHEAST CANNING BASIN

NAME	OPERATOR	BMR FILE NUMBER	SHEET AREA	LATITUDE S LONGITUDE E	G.L. (M) R.T. (M)	DATE SPUDDED TD REACHED	STATUS
Point Moody No. 1	Australian Aquitaine Petroleum Pty Ltd.	65/1474	Stansmore	21°15'34" 127°48'22"	422.8 427.5	2/10/65 20/12/65	Plugged and Abandoned
Crossland No. 1	West Australia Petroleum Pty Ltd.	71/465	Crossland	19°43'10" 125°14'50"	181.1 183.8	31/07/71 17/08/71	Plugged and Abandoned
Crossland No. 2	West Australia Petroleum Pty Ltd.	71/465	Dummer	20°00'45" 124°59'36"	175.0 177.7	22/08/71 4/09/71	Plugged and Abandoned
Crossland No. 3	West Australian Petroleum Pty Ltd.	71/465	Dummer	20°12'12" 125°45'39"	230.7 233.5	24/09/71 15/10/71	Plugged and Abandoned
Lake Betty No. 1	West Australia Petroleum Pty Ltd.	71/441	Mt. Bannerman	19°34'08" 126°19'45"	273.7 278.3	1/10/71 15/12/71	Plugged and Abandoned
Barbwire No. 1	West Australia Petroleum Pty Ltd.	72/2001	Crossland	19°10'38" 125°00'59"	216.4 218.5	18/06/72 6/07/72	Plugged and Abandoned

A second major depression was delineated in western DUMMER. It attains a depth of over 6000 m below sea level in southeastern JOHANNA SPRING adjacent to the west, and its configuration and shape are modified by north-south faulting along its eastern edge in western DUMMER.

The third major depression occurs in eastern CORNISH and southeastern MOUNT BANNERMAN. Although the depression is on the same northwesterly trend as the Fitzroy Trough, it is orientated north-south, and within it the greatest depth estimate to magnetic basement is about 9900 m below sea level near Lake Gregory.

These latter two features were later named the Johanna Springs Sub-basin (WAPET, 1964b) and Gregory Sub-basin (WAPET, 1964c), respectively. Later surveys doubted the validity of the Johanna Springs Sub-basin as a separate entity, and it is more likely to be a part of the Kidson-Willara Sub-basin (WAPET, 1972c).

A persistent, long, irregularly shaped zone of shallow basement extending southeasterly from northwestern CROSSLAND through central DUMMER to the survey margin in central HELENA was also mapped during this survey. It trends roughly parallel to the long axis of the Canning Basin and occurs on the southern margin both of the Fitzroy Trough and the depression delineated in eastern CORNISH. Its depth generally ranges between 1500 and 3000 m below sea level and rises to less than 1500 m in northwestern CROSSLAND near Barbwire Range and in central HELENA near Helena Spring.

This area of shallow basement seems likely to be an extension of the Broome Platform and is tentatively correlated with it. However, it is considerably south of its extrapolated position from its known trend and extent on MOUNT ANDERSON. It is suggested that the Platform may have been affected and displaced by a strong system of north-south transverse faulting, evidence of which was found in the survey.

The northern margin of the Canning Basin was found to be faulted, and a group of abrupt high-frequency anomalies is interpreted as being an extension of the Pinnacle Fault and the uplifted basement to the northeast of it.

Hackathorn and AOC Stansmore Range Aeromagnetic Survey

A much smaller aeromagnetic survey was flown in the southeastern part of the area in 1963 by Adastra Hunting Geophysics Pty Ltd for Hackathorn New Zealand Oils Ltd and Australian Oil Corporation (AOC) (HACKATHORN & AOC, 1963).

It was a reconnaissance airborne magnetometer survey flown at 7500 m and aimed to both delineate the location of the 'Stansmore Range Fault' and to investigate the thickness of Palaeozoic sediments on either side of it.

The results were uncertain owing to the sparse data available and it was not possible to detect magnetically the precise location of the Stansmore Range Fault, although its postulated position appears to coincide with the general magnetic picture. Southwest of the Stansmore Range, crystalline basement is interpreted to be overlain by Palaeozoic sediments and to form a gradual swell which rises to about 15 m above sea level in southeastern HELENA, 38 km west of the Waterlander Breakaway. Depths to magnetic basement north of this swell reach a maximum of 1650 m on the central western edge of STANSMORE, and south of it, basement decreases to 520 m in southeastern HELENA and reaches another maximum of 3150 m in central southern WILSON. The gradient of the basement swell to the southwest is steeper than to the northeast.

WAPET'S Preliminary Surveys in the Lake Betty Region

In 1963 WAPET commenced a series of geophysical surveys in the vicinity of Lake Betty on MOUNT BANNERMAN. These were to culminate in 1971 with the drilling of WAPET Lake Betty No. 1.

The first survey was the Balgo-Lake Betty Seismimograph Survey carried out in 1963 for WAPET by Geophysical Service International (WAPET, 1964c). The survey was in two distinct areas, the Balgo area in northwestern LUCAS and the Lake Betty area in western MOUNT BANNERMAN. About 320 km of continuous reflection coverage and 104 km of reversed refraction were shot.

Surface mapping in the Balgo area had revealed a well defined south-plunging anticline about 9.6 km long, northeast of Dooma Dora Well in LUCAS and the seismic survey aimed to see if it persisted at depth. Data were limited and reflection quality was poor. The anticline has less than 60 m of closure and the survey was abandoned after 2 lines had been shot.

In the Lake Betty area, MOUNT BANNERMAN, surface mapping had indicated the 'Binda' and 'Betty' anticlines separated by a well defined syncline. The 1962 WAPET Aeromagnetic Survey (WAPET, 1966a) had also shown a shallowing of the Fitzroy Trough in this region over an arch which separated it from another deep basin centred on Gregory Salt Lake, which was named in this survey the Gregory Subbasin. Depths to magnetic basement on this arch (later named the 'Bulka Ridge') were calculated to be 3000 to 4500 m. In the Lake Betty region the survey objectives were to test if the two surface anticlines represent structure at depth.

Results were poor, but one horizon tentatively identified as basal Permian indicated two dome-shaped closures surrounded by faults. Depths to the top of these were 960 and 1050 m, respectively and closure to the north and northeast was dubious. In the pre-Permian the two anticlines persist to a depth of 3600 m.

Concurrent with the above survey, United Geophysical Corporation carried out the Lake Betty Reconnaissance Gravity survey for WAPET (WAPET, 1964a). Readings were taken on a reconnaissance grid survey over most of northeast MOUNT BANNERMAN including stations on the Lake Betty seismic survey. The survey was tied to the Virgin Hills area to the northwest by a traverse along the track to Christmas Creek and the Great Northern Highway toward Virgin Hills. Gravity readings were also taken along shot points of the 1962 BMR-IFP Poole Range Seismic Survey in CROSSLAND.

In summary the results showed that there is no overall regional gravity gradient in the Lake Betty area and the major gravity features are the minima attributed to the Fitzroy Trough and the Gregory Sub-basin and the maxima to the Bulka Ridge and Jones Arch.

The Bulka Ridge maximum corresponded to the arch separating the minima associated with the Fitzroy Trough and Gregory Sub-basin. The maximum was a 48 x 24 km northwest-trending gravity high of moderate relief. The Binda and Lake Betty surface anticlines corresponded to two maxima located on the western flank of the Bulka Ridge. Several other anomalies are also located here.

The Jones Arch maximum in northeast CROSSLAND trends north-northeasterly and appeared to be cutting across the Fitzroy Trough similar to the Bulka Ridge. It corresponds to the gravity and seismic anomalies located in northeast CROSSLAND (Flavelle & Goodspeed, 1962; CGG, 1974; Ferrand, 1963).

In the northern part of the survey area the Pinnacle Fault, on the northern edge of the Fitzroy Trough, was partly delineated but not uniquely defined. It could be interpreted as two major down-to-the-south faults en echelon with the main Pinnacle Fault or it may be a southeasterly-trending fault downthrown to the southwest, or a combination of both.

Preliminary Surveys in the Stansmore Area

In the central Stansmore Range, Geoseismic (Australia) Pty Ltd carried out the Stansmore Range Seismiograph Reflection and Gravity Survey of Hackathorn New Zea-

land Oils Ltd. This survey was unsubsidized and no report was released, but according to Beach Petroleum NL (BEACH, 1965) the seismic survey obtained poor reflection records and results were inconclusive. The gravity survey did not substantiate any large vertical displacement across the Stansmore Fault.

After this survey, Beach Petroleum NL entered into a farm-in agreement with Hackathorn New Zealand Oils Ltd in the Stansmore Range area. The first survey by Beach Petroleum N.L. was the Stansmore Range Gravity Survey run in 1964 by Geoseismic (Australia) Pty Ltd (BEACH, 1965). It was both a reconnaissance and detailed survey which aimed to select areas that may be suitable for follow-up seismic work with the ultimate aim of selecting a drill site.

The Stansmore Range area was shown to be at the intersection of two gravity minima trending north and northwest. The northerly trend is considered to reflect Upper Proterozoic to Palaeozoic sedimentary developments at depth and the northwesterly trend is parallel to the Stansmore Fault structure and fold belt. Surface geological evidence showed that folding and faulting are best developed in and immediately to the west of the Stansmore Range. However, individual fold structures developed in Permian sediments are not reflected at depth. A more detailed gravity survey near the 'Point Moody Anticline' showed there was no correlative to this surface feature in the subsurface Bouguer anomaly. The north-northwesterly gravity gradient between Point Moody and Thomas Peak, LUCAS was interpreted as corresponding to the supposed subsurface Stansmore Fault. This conflicts with the surface mapping which continued the Stansmore Fault through the Stretch Range, LUCAS.

West of the Waterlander breakaway in southeast HELENA a broad gravity maximum is interpreted to reflect shallow basement and corresponds to the position of the crystalline basement swell delineated by Stansmore Range Aeromagnetic Survey (HACKATHORN & A.O.C., 1963). Depth to basement is interpreted from the gravity survey to be 285 to 345 m below the surface. Farther west of this maximum, east of the Waterlander breakaway near Carnegie Bluff, a gravity minimum is believed to represent a north-trending graben fault bounded on both the east and west. This corresponds to a gentle syncline developed in Permian sediments on the surface. Sediments in this graben are believed to be 3000 m deep.

Another minimum immediately west of the Stansmore Fault and east of Point Moody was taken to represent a basin in which sediments exceed 2400 m and may be 9000 m thick.

Continental Seismic Surveys in CROSSLAND 1964-1966

In 1963 Continental Oil Company of Australia Ltd entered into a farm-in agreement with WAPET and from 1964 to 1966 carried out a series of five seismic surveys, parts of which covered northern CROSSLAND.

The first survey was the St George Range Reconnaissance Seismic Project (CONTINENTAL, 1965a) the southern half of which was located in northwest CROSSLAND near the Worral Range and also south of the Kirkby Range. The survey was a continuous reflection seismic survey using the Vibroseis method and the objectives were to determine the relation of the Fenton Fault to the 'Fitzroy Depression', the thickness of the 'Fitzroy Depression' sedimentary sequence and also that of the adjacent 'Broome Swell'.

Reflections in the 'Fitzroy Depression' were good to poor, whereas the reflection quality on the Broome Swell was poor, a fact attributed to the thin sedimentary section.

The results showed that the 'Fitzroy Depression' is a structural graben, asymmetrical in form to the southwest with the deepest part north of and parallel to the Fenton Fault. The basin "deep" may be in excess of 7500 m. The 'Broome Swell' to the south of the Fenton Fault appeared to be a broad platform having minor closures and a hinge belt of down-to-the-north step faults. The sedimentary section on the 'Broome Swell' was much thinner, being 1500 to 3000 m.

Two anomalies near the Barbwire Range were situated on an anticlinal trend that strikes northwesterly parallel to the Fenton Fault.

Near the Fenton Fault record quality was from fair to very poor and there was no reliable correlation of reflection events across the fault. The 'B' horizon, tentatively identified as near the base of the Grant Formation, is either too shallow to map south of the fault or does not continue across it.

The second survey was the Poole Range Detail Vibroseis Project (CONTINENTAL, 1965b) run by Ray Geophysics. The most southern part of four lines of this survey were in northeast CROSSLAND and MOUNT BANNERMAN. The objective was to determine if the Poole Range Anticline, a surface feature to the north of the area, is present in the subsurface. In the Poole Range the survey delineated 3600 to 4500 m of Permian to Carboniferous sediments, and in the survey area revealed a rise of the sedimentary horizons into the adjacent CROSSLAND. A few northwesterly-trending faults were also delineated within the area.

The survey proposed to examine the geological section of the 'Broome Swell' and from the scattered refraction probes, to gather information relating to the thickness of the sedimentary section, the regional dip, and the character and identity of the sedimentary section.

The results showed that the 'Broome Swell' appears to be an uplifted area containing a relatively thin sedimentary section and separated by abrupt and complex structures from the Fitzroy Trough which contains at least 15 000 m of sediments. The thickness of the sedimentary section was only mapped in Probe VIII in southwestern CROSSLAND where basement is at depths from 600 to 1500 m.

A 'ridge' believed to occur in the centre of the 'Broome Swell' in central CROSSLAND may be an uplifted fault block with some thickening occurring to the southwest of the 'Swell' towards the Mount Bannerman Gravity Trough (Flavelle & Goodspeed, 1962).

Regional dip of the sedimentary section was not clearly established. However certain evidence indicated the dip was possibly to the northwest until near the close of the Devonian, after which slight easterly tilt occurred.

The fourth survey, Crossland Area Seismic Survey (CONTINENTAL, 1966a) was a Vibroseis reflection survey which mainly covered the area north and east of the Millyit, Jones, and Hicks Ranges in northeast CROSSLAND and northwest MOUNT BANNERMAN. Some of the lines were continuations of the Poole Range Vibroseis Project lines.

The survey aimed at seeking a subsurface framework for the Crossland area of the 'Fitzroy Graben' and was regional in nature except for some detailed work near Poole Range and Arundel Bore, CROSSLAND.

Three anomalies were detected near Arundel Bore and are elements of a major anticlinal feature which plunges both northwest and southeast and is elongated approximately parallel to the Fenton Fault. It trends northwesterly for about 70 km from just north of Jones Range through Arundel Bore to southern NOONKANBAH. The feature is modified by two systems of post-Lower Carboniferous faulting which formed one fault parallel to the anticlinal axis and south of it, and two easterly-trending faults. All three combined produce three distinct areas of closure along the axis. The anomalies were structural highs in the pre-Lower Carboniferous, and the Lower Carboniferous sediments lap on to the postulated Devonian. Complete Lower Carboniferous and

Devonian sections are not present and the two major reflectors converge on this anticline. Five other anomalies delineated in the survey were similar to the 'Arundel Anticline'.

Depth to basement along the crest of the 'Arundel Anticline' is estimated to be 4800 to 5100 m whereas depths to basement of 6000 to 10 500 m are calculated within the greater part of the 'Fitzroy Trough'.

The final Continental Oil survey was a Vibroseis reflection survey, the Barbwire Area Seismic Survey (CONTINENTAL, 1966b) in 1965-1966. The survey proposed to confirm a structure for drilling an area of a lead previously determined by Bouguer gravity, by the St George Range Reconnaissance Seismic Survey and air-borne magnetometer data on the north flank of the 'Broome Swell' adjacent to the Fenton Fault. The survey was located in northwest CROSSLAND, south of the Barbwire, Worral, and Hall Ranges.

The results showed that no less than 900 m and no more than 3000 m of prospective sediments exists in the Barbwire Range on the 'Broome Swell'. The depositional and structural history of these sediments is distinctly different from that of Fitzroy Trough to the north.

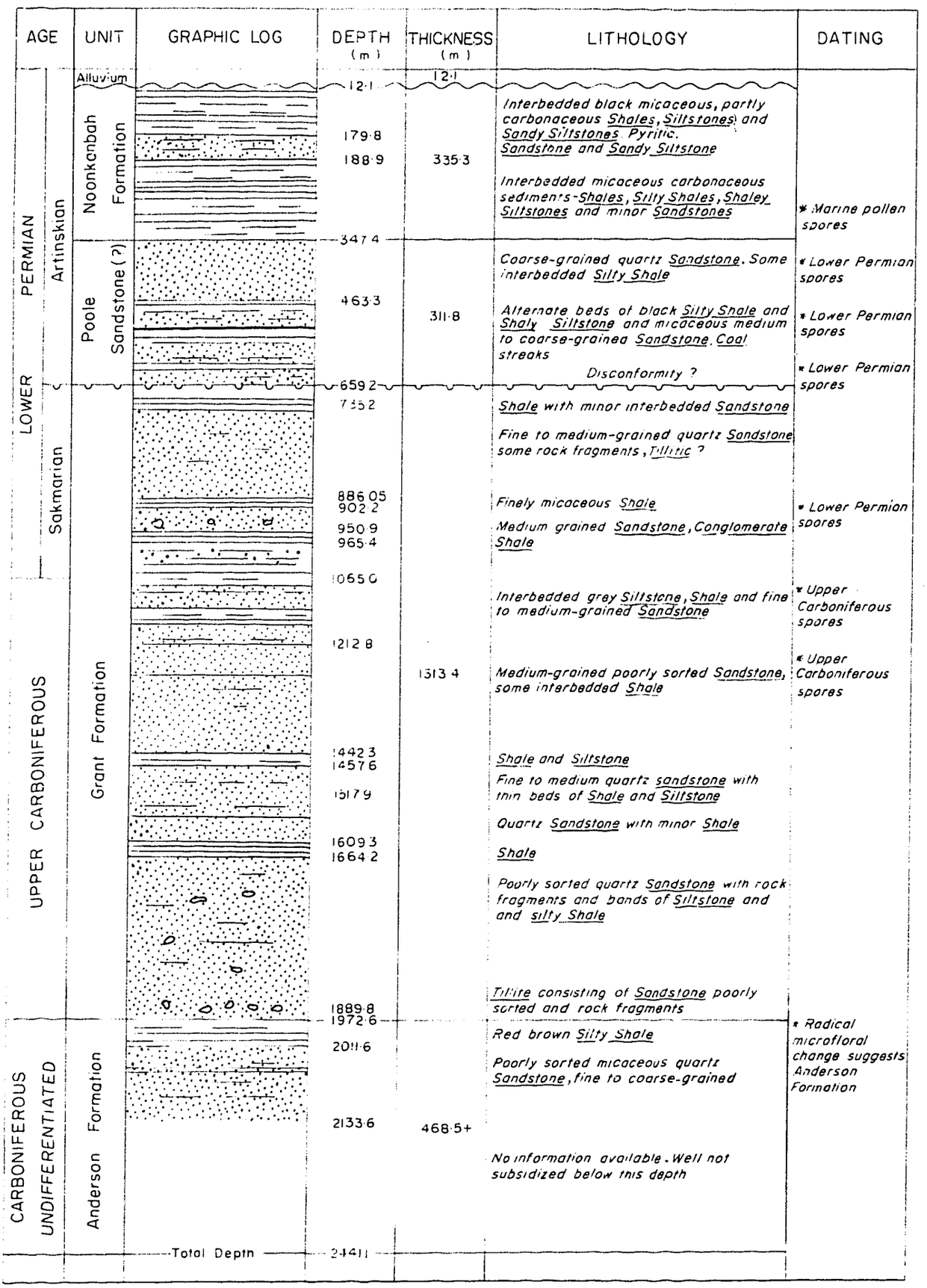
AQUITAINE Point Moody No. 1

Concurrent with this activity in the northwestern part of the area, more work was carried out in the southeast near the Stansmore Range. In 1965 Hackathorm New Zealand Oils interests were attained by General Exploration of California, and both Beach Petroleum NL and Australian Aquitaine Petroleum had a 60% working interest, General Exploration 40%, and AAP in return for working the permits could attain a 55% interest. This began a period of activity by AAP in the southeastern part of the area.

In October 1965, AAP commenced Point Moody No. 1, the first deep test well in the area (AAP, 1966). The well was sited on the crest of an easterly-trending surface anticline developed in the central portion of the Stansmore Gravity Trough of Flavelle & Goodspeed (1962). On the surface the anticline trended 19.2 km east-west by 3.2 to 4.8 km north-south and closure to the north was not well defined. The well was also located in the area where a detail gravity survey (BEACH, 1965) had not confirmed the persistence of the anticline at depth. AAP anticipated finding a Lower Permian section including the Grant Formation resting either unconformably on Precambrian or Palaeozoic.

Fig. 37 AQUITAINE Point Moody No.1.

Scale: 1cm = 125m.



Record
1975·77

M(S)388 PD

The well was spudded in the Noonkanbah Formation and penetrated the Poole Sandstone, Grant Formation, and bottomed in the Carboniferous ?Anderson Formation at 2441 m. The detailed stratigraphy is summarized in Figure 37.

The thickness of the Lower Permian and Upper Carboniferous sediments suggests that the well is in a deep part of the Canning Basin, and it is probable that a thick sequence of Lower and Middle Palaeozoic exists below 2441 m at Point Moody.

WAPET Betty Detail Seismic Project

During 1966 WAPET continued work in the Lake Betty area and completed the Betty Detail Seismic Project (WAPET, 1966b) in an area east of Mt Erskine, MOUNT BANNERMAN. The survey was a 600% dinoseis - reflection survey and was designed to verify east and northeast closure on the Lake Betty Anticline, and to extend regional reflection lines across the 'Bulka gravity arch' to determine whether regional structural closure existed northeast of the 'Binda' and 'Betty' trends.

The 'Lake Betty Anticline' was found to have closure to the northeast and east at the basal Permian level but not below it. In the anticline the closure in the Permian sediments was shown to cover an area of about 42 km^2 with a possible vertical closure of 105 m. The crest of it was 558 m below the surface.

The 'Binda' anomaly is better developed in pre-Permian beds. On 'Horizon B' (pre-Permian) 90 m of vertical closure is contoured in an area of 78 km^2 trending northwesterly with the crest 870 m below sea level.

Northeast of the 'Binda' and 'Lake Betty' trends the regional survey showed that no structural closure of magnitude exists at depth.

In the Lake Betty area sedimentary section of at least 7800 m was inferred. This places the 'Lake Betty' and 'Binda' Anomalies in an area of a considerably thick sedimentary section and well down on the northeast flank of the 'Fitzroy Trough'.

AAP Geophysical Surveys 1967-71

In 1967 AAP commenced a series of geophysical surveys in the southeastern part of the area.

The first of these was the Dakota Seismic and Gravity Survey (AAP, 1968) part of which covered southeast HELENA. It was a seismic reflection and refraction survey with gravity readings at each seismic shot point and also along an access track.

The main objective was to investigate a gravity maxima situated west of the Waterlander breakaway which was located by the Stansmore Range Gravity Survey (BEACH, 1965).

The reflection results were very poor and correlation from one line to the other was very difficult owing to lack of continuity. The area appears to be highly faulted and the sedimentary sequence is thin. The refraction results were poor, but confirmed the shallow sequence. The gravity results showed a broad gravity maximum also indicating that basement was very shallow.

The second AAP survey was the Terry Range Reconnaissance Magneto-Telluric Survey run in 1968 by technicians of the Societe Nationale des Petroles d'Aquitaine (AAP, 1969a). This method, relatively unused in Australia at that time, is designed to delineate the gross features of sedimentary basins by measuring the relative amplitudes of the telluric currents and the magnetic field inducing them within a large frequency range.

The survey aimed to improve the knowledge of the shape of the basin west of the Stansmore Range. In the area, 22 stations were set up representing a cross section through the basin, with a tie to the Point Moody well.

A tentative configuration of basement was presented in the results, and broadly there is decrease in basement within the Fitzroy Trough and south of this, the Helena-Pollock Hill Ridge was mapped as an extension of the 'Broome Swell' trend. However, more detailed results did not agree with those obtained with more conventional geophysical surveys.

Simultaneously with the magneto-telluric survey AAP also ran the Ryan Seismic and Gravity Survey (AAP, 1969b). The objectives within the area were to delineate the shape of the Fitzroy Trough and its flanks, and to determine its depth in the central zone. The depth was to be compared with the sedimentary section encountered in Point Moody No. 1 to determine whether there were significant pre-Permian units in the area.

The gravity results agreed with the previous Stansmore Gravity Survey (BEACH, 1965) and with the associated seismic work. The Bouguer anomaly map showed a minimum immediately west of the Stansmore Range corresponding to the probable extension of the 'Fitzroy Trough' (Gregory Sub-basin) and two maxima in central western STANSMORE and eastern HELENA, confirming the presence of the 'Broome Swell'.

The seismic reflection and refraction results showed a thick geological section thinning towards the edge of the basin. The area had been affected by reasonably intense structural movement with steep dips and unconformities or erosional surfaces occurring.

A minor part of the Contention Heights Seismic Refraction Survey (AAP, 1969d) covers southern HELENA and STANSMORE. In the area basement becomes shallower in the north.

The fifth AAP survey in the area was the Stretch Range Seismic and Gravity Survey, a combined reflection, refraction, and gravity survey (AAP, 1971). The specific purpose of the seismic survey was to trace the reflections existing below Point Moody to higher structural positions and to find closed structures for drilling targets. The other objectives were to trace these horizons onto the southeast extension of the 'Broome Swell' and to look for possible pinchouts within the sequence. A refraction program was conducted across the 'Stretch Range Fault' to determine if the thick basin sequence to the west of the fault was present to the east.

The results of the gravity survey gave more detailed information in the area, but in general confirmed the main trend of the previous Stansmore Ranges Gravity Survey (BEACH, 1965).

The refraction results were inconclusive owing to common faulting along the whole refraction profile.

The reflection survey data ranged from good to nil and two main features both possibly anticlines were delineated, one north of Point Moody and the other near White Hills, STANSMORE. Some stratigraphic pinchout was observed towards the 'Broome Swell'.

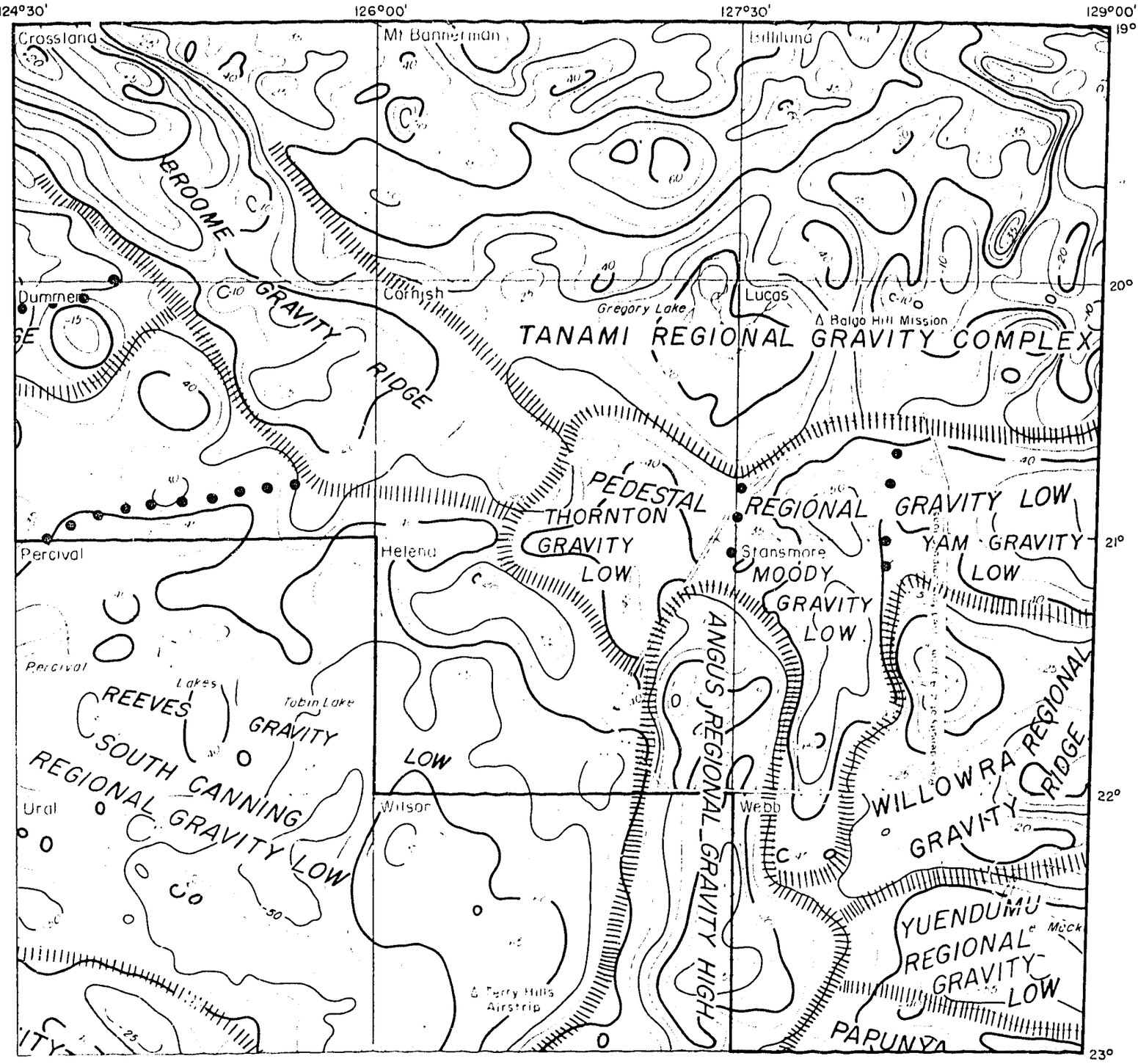


Fig. 38 Gravity features in the area after Darby & Fraser (in press)

BMR Systematic Gravity Survey 1968

In 1968, under contract to BMR, Wongela Geophysical Pty Ltd carried out a systematic gravity survey over the southern part of the area (Darby & Fraser, in press).

The 'cell' method of flying was used to establish more detailed gravity stations over DUMMER, CORNISH, LUCAS, HELENA, STANSMORE, and WEBB. The following gravity features were named and some of the revision of the terminology of Flavelle & Goodspeed (1962) was made (Fig. 38).

The Tanami Gravity Complex (Whitworth, 1970) is continued onto northern CORNISH and LUCAS and is characterized by high-intensity short-wavelength Bouguer anomaly features. To the east this province correlates broadly with the Granites-Tanami Block and it is suggested that it extends westward beneath the Canning Basin as basement. This area was formerly the Minnie Range Gravity Shelf and the Gregory Lake Gravity High (Flavelle & Goodspeed, 1962).

The Broome Gravity Ridge, a unit of the Fitzroy Regional Gravity Complex (Darby & Vale, 1969), occurs in northwestern DUMMER and western CORNISH. It is similar to the Broome Swell outlined by Flavelle & Goodspeed (1962) except that Darby & Fraser (in press) terminated the feature in central CORNISH.

In northwestern DUMMER the Johanna Gravity Ridge, a unit of the Munro Regional Gravity Platform (Darby & Vale, 1969) is an east-west trending Bouguer anomaly high. It almost coincides with the Johanna Spring Gravity Spur of Flavelle & Goodspeed (1962).

The South Canning Regional Gravity Low province (Darby & Fraser, in press) fully delineated and divided into two units, the Sahara Gravity Shelf in western DUMMER and the Reeves Gravity Low in western HELENA. The Sahara Gravity shelf is an area of low Bouguer anomalies, ranging from -30 to -40 mGal. The Reeves Gravity Low is a broad Bouguer anomaly depression in which values vary from -40 to -70 mGal.

The Pedestal Regional Gravity Low (Whitworth, 1970) is situated in southern CORNISH and LUCAS, northern HELENA and WEBB, and western STANSMORE and is subdivided into 3 units, the Thornton Gravity Low, the Moody Gravity Low, and the Yam Gravity Low. These latter two features were formerly the Stansmore Gravity Trough (Flavelle & Goodspeed, 1962).

The Yam Gravity Low is an east-trending gravity depression in southern LUCAS, and the Moody Gravity Low is a south-trending gravity depression bounded by steep gradients in its southern half in southern STANSMORE and northern WEBB. The Thronton Gravity Low is a shallow gravity depression bounded by mainly northwest-trending gradients.

The Argas Regional Gravity High in western WEBB and STANSMORE and eastern HELENA, originally called the Wilson Gravity High (Flavelle & Goodspeed, 1962) was made a unit of the Barons Gravity Plateau (Lonsdale & Flavelle, 1968). It is an elongate north-trending high of about 50 mGal amplitude which is caused by a basement high. However, as a basement inlier in southwestern WEBB is not associated with high Bouguer anomalies it is apparent that the dense rocks within the basement may also be affecting this feature.

WAPET's Reconnaissance Work in CROSSLAND and DUMMER

In 1970 WAPET began concentrating their work in the area on the Crossland Platform in CROSSLAND, DUMMER, and CORNISH, with the aim of finding suitable structures for drilling. The first series of surveys comprised three reconnaissance seismic surveys run consecutively in the northeastern part of the area.

Before the surveys began, WAPET reviewed the previous geophysical surveys; a more detailed interpretation of the 1952-1960 BMR gravity surveys (Flavelle & Goodspeed, 1962) and the 1962-63 WAPET Aeromagnetic Survey (WAPET, 1966a) suggested that within the area the 'Mid-basin Platform' (also known then as 'Broome Swell') may be separated into two elements, the Crossland and the Helena Platforms. The dividing feature is the Tina Springs Hingeline, and the Crossland Platform to the northeast is structurally higher than the Helena Platform to the southwest. The Tobin Hingeline was thought to separate the Helena Platform from the Kidson Sub-basin to the south.

The first survey was the Helena (267) Reconnaissance Seismic Project (WAPET, 1970a) and the objective was to establish the structural attitude of the Crossland and Helena Platforms and to determine the nature of the deformation associated with the Fenton Fault and the Tina Springs and Tobin Hingelines. Two southwesterly-trending reconnaissance reflection lines were shot, commencing in northern CORNISH and passing diagonally across DUMMER. Five northwest-trending faults were delineated and were downthrown to the north, except the fault postulated to be the expression of the Tina Springs Hingeline which is downthrown to the southwest. Two anticlinal features were defined, one west of

Dummer Range, DUMMER, and the other east of Point Massie, CORNISH, and the northwestern flanks of these anticlines plunge steeply into the Fitzroy Trough. Northeast of Tina Springs Fault a broad low relief anticlinal structure is also present, and southwest of the Tina Springs Fault on the Helena Platform the dip is mainly to the southwest. The throw of the Fenton Fault decreases somewhat to the southeast near Well 48, CORNISH and is replaced by extreme northeast dips into the Fitzroy Trough. The Tobin Hingeline was not detected within the area.

As a follow up to this survey the Crossland (268) Reconnaissance Survey (WAPET, 1971a) was run. It consisted of one southwest-trending reflection line, parallel to, and 80 km north of, the Helena (267) lines.

A series of northwest-trending faults which were downthrown to the northeast were mapped and three anticlines were shown to exist on a deeper horizon, horizon 'B', which was possibly Ordovician to Devonian.

The most important of these anticlines occurred 4.8 km southwest of Jones Range and showed closure on horizon 'B' as well as on horizon 'A', a pre-Permian unconformity. The other two anticlines in central CROSSLAND did not show marked closure on the horizon 'A'. One of these anticlines was later drilled, as WAPET Crossland No. 2. There is marked thinning of the section over the three anticlines.

Combining the results of the Crossland (268) and Helena (267) surveys, the Crossland Platform was shown to be an upfaulted block with regional southwest dip and separated from a terrace to the north by the Dummer Range Fault which had a down-to-the-north throw of 2100 m. The terrace, separated from the Fitzroy Trough by the Fenton Fault, widened in the southeast to become a north-dipping shelf with consequent reduction of the down-to-the-north throw of the Fenton Fault. The terrace is intermediate in depth between the Crossland Platform and the Fitzroy Trough. The data were too poor in the south to delineate the Helena Platform as a separate structural entity.

WAPET's Final Survey in the Lake Betty Region

Simultaneously with these two surveys on the Crossland Platform WAPET carried out its final reflection survey in the Lake Betty region, the Lake Betty (269) Detail/Reconnaissance Seismic Survey (WAPET, 1970b). The detailed part of the survey aimed to delineate a drill site by improving data quality at pre-Permian levels so that northeast closure could be delineated and the Lake Betty faulting could be clarified, and the reconnaissance survey was aimed at investigating the north flank of the Gregory Sub-basin and the adjacent 'Betty Terrace'.

As the detail work was to culminate in the drilling of Lake Betty No. 1, WAPET had reinterpreted the previous geophysical work and had modified the previous interpretations of tectonic features in the area. The Lake Betty area occurs on the southern edge of the eastern continuation of the Lennard Shelf, which extends 620 km from Lake Betty to the offshore Canning. The Lennard Shelf is separated by the Pinnacle Fault on the south from the Fitzroy Trough and the Gregory Sub-basin, and the latter two features are separated by the northeast-trending Jones Arch which in northeast Crossland changes strike through east to southeast to merge with the Betty Terrace. The Lake Betty area lies immediately basinwards of the fault which separates the Gregory Sub-basin from the Betty Terrace. To the north of the area, the Pinnacle Fault has downthrown basement 1500 m to the south to 3000 m below sea level. Basement dips south-southwest from this to 5100 m at Lake Betty. The Betty structure itself lies on the west flank of the Betty Terrace Gravity maximum previously a part of the Bulka Ridge Gravity maximum (WAPET, 1964a).

The results of the detail survey showed that there was insufficient dip on the Lake Betty structure to provide reliable stratigraphic closure but closure is provided by three northwesterly-trending down-to-the-southeast major faults which traverse the structure. One area of fault-bounded closure was selected and was drilled as WAPET Lake Betty No. 1 in late 1971.

The reconnaissance survey consisting of two nearly north-trending lines in central MOUNT BANNERMAN shows a marked thickening of the section from the Betty Terrace into the Gregory Sub-basin near Lake Doman, south of Casey Range. The results also indicated a possible continuation of the regional faulting present in the Lake Betty area and an anticlinal feature, on the Betty Terrace 4 km west of Chungla Well, developed on the base of the Carboniferous 'Horizon', which was relatively shallow there.

Further work by WAPET in CROSSLAND and DUMMER

In 1971 WAPET, encouraged by the two previous seismic surveys on the Crossland Platform continued reconnaissance work with the Crossland Platform (304) Seismic Project (WAPET, 1971b). Six more northeasterly-trending reflection lines were shot in CROSSLAND, DUMMER, and CORNISH with the aim of further defining the structural elements of the Crossland Platform. In northwest CROSSLAND additional lines were shot with the aim of defining an anticlinal feature near the Barbwire Range (Continental, 1966b) and defining the location of the Fenton Fault.

The survey mapped three northwest-trending major fault and fault systems - the Fenton Fault System, Dummer Range Fault, and Tina Springs Fault.

The Fenton Fault System consists of a well defined series of downthrown-to-the-north faults. Trending to the southeast, the throw on the fault decreases and in central CORNISH the fault is partly replaced by steep northeast dips into the 'Fitzroy Trough' (Gregory Sub-basin). The Dummer Range Fault is downthrown to the northeast, with throw decreasing to the southeast. The Tina Springs Fault trends parallel to the Dummer Range Fault but is downthrown to the southwest.

Several anticlines were delineated on the three horizons mapped which were Horizon 'C' near top of Ordovician, conformable beneath Horizon 'B' near top Devonian and Horizon 'A' Pre-Permian unconformity. Horizons tended to thin over anticlines and thicken in associated synclines.

The results of the survey could be divided into three stratigraphic areas.

The first area is on the southern flank of the Fitzroy Trough bounded to the south by the Fenton Fault Zone. Two anticlinal features, one southwest of Jones Range and one northeast of Kirkby Range, were clearly mapped on all three horizons.

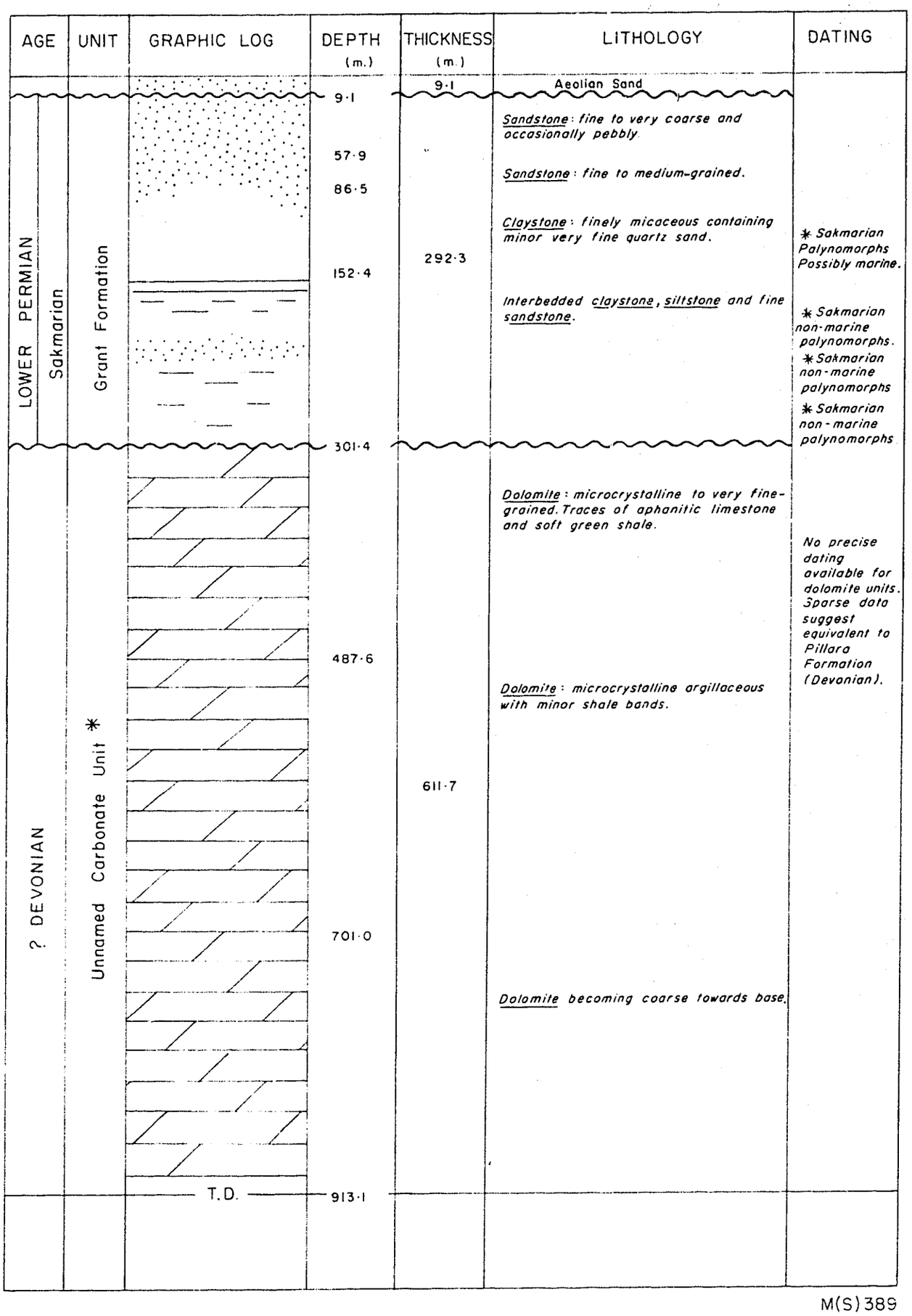
The second area was a terrace area bounded by the Fenton Fault System and the Dummer Range Fault and intermediate in depth between the Crossland Platform and the Fitzroy Trough. On the Ordovician and Pre-Permian unconformity horizons two anticlinal features were mapped, the Barbwire Structure and another feature west of Dummer Range. These features were later drilled by WAPET Barbwire No. 1 and WAPET Crossland No. 3, respectively. The Pre-Permian was mapped as a broad northwest-trending anticlinal feature along this terrace.

The third area defined was the Crossland Platform, formerly 'Broome Swell', which lies south of the Dummer Range Fault and has a gentle regional dip to the southwest. In central-western CROSSLAND, the Devonian and Silurian are absent and the Permian rests directly on the Ordovician. The existence of the Helena Platform as a separate entity was extremely doubtful.

Overall the sediments thinned over anticlinal features and thickened in associated synclines. Regional thickening occurs away from the Fenton Fault zone into the

Fig. 39 WAPET Crossland No.1

Scale: 1cm = 50m

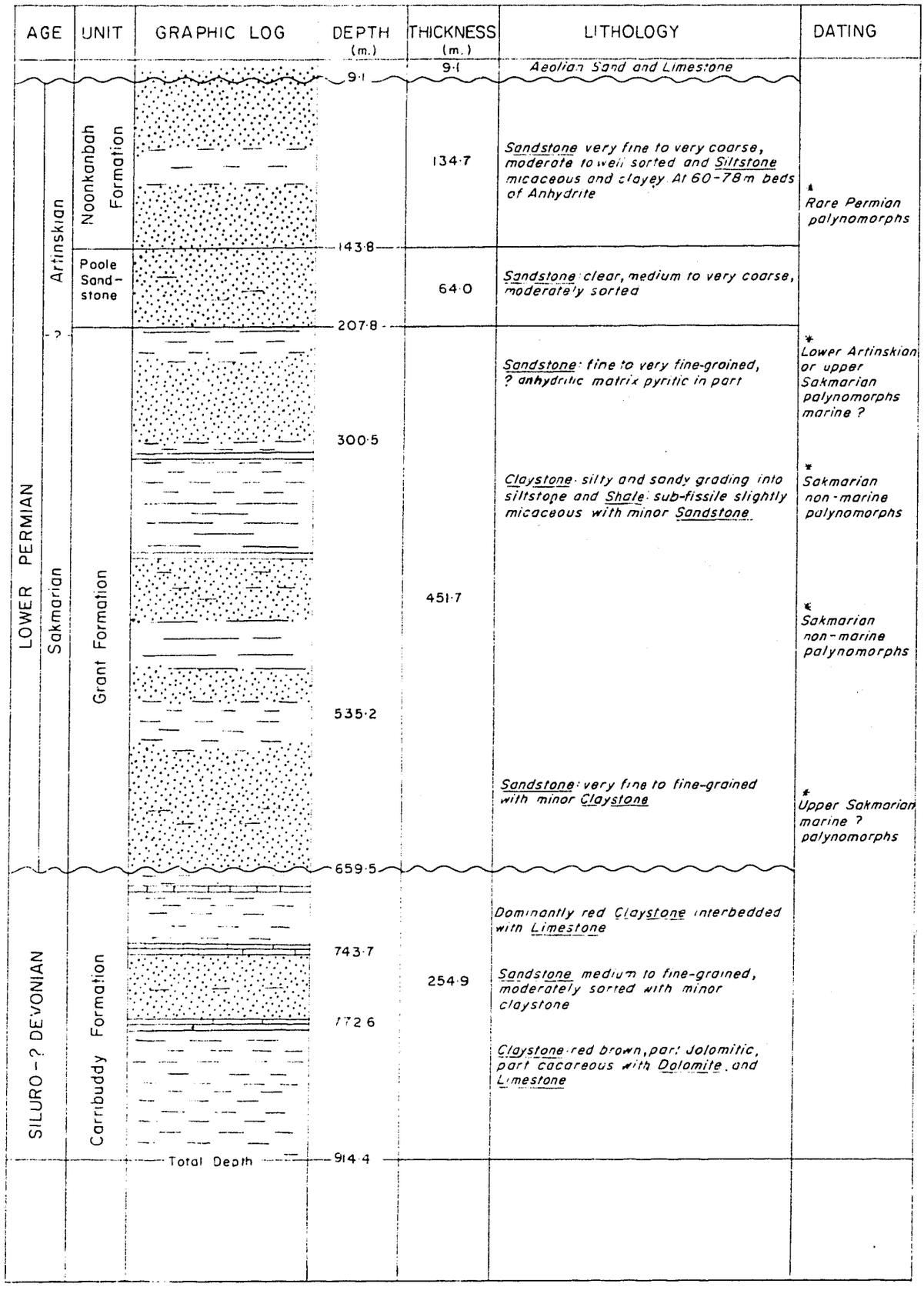


M(S) 389
G.G

Record
1975·77

Fig. 40 WAPET Crossland No. 2

Scale: 1cm = 50m.

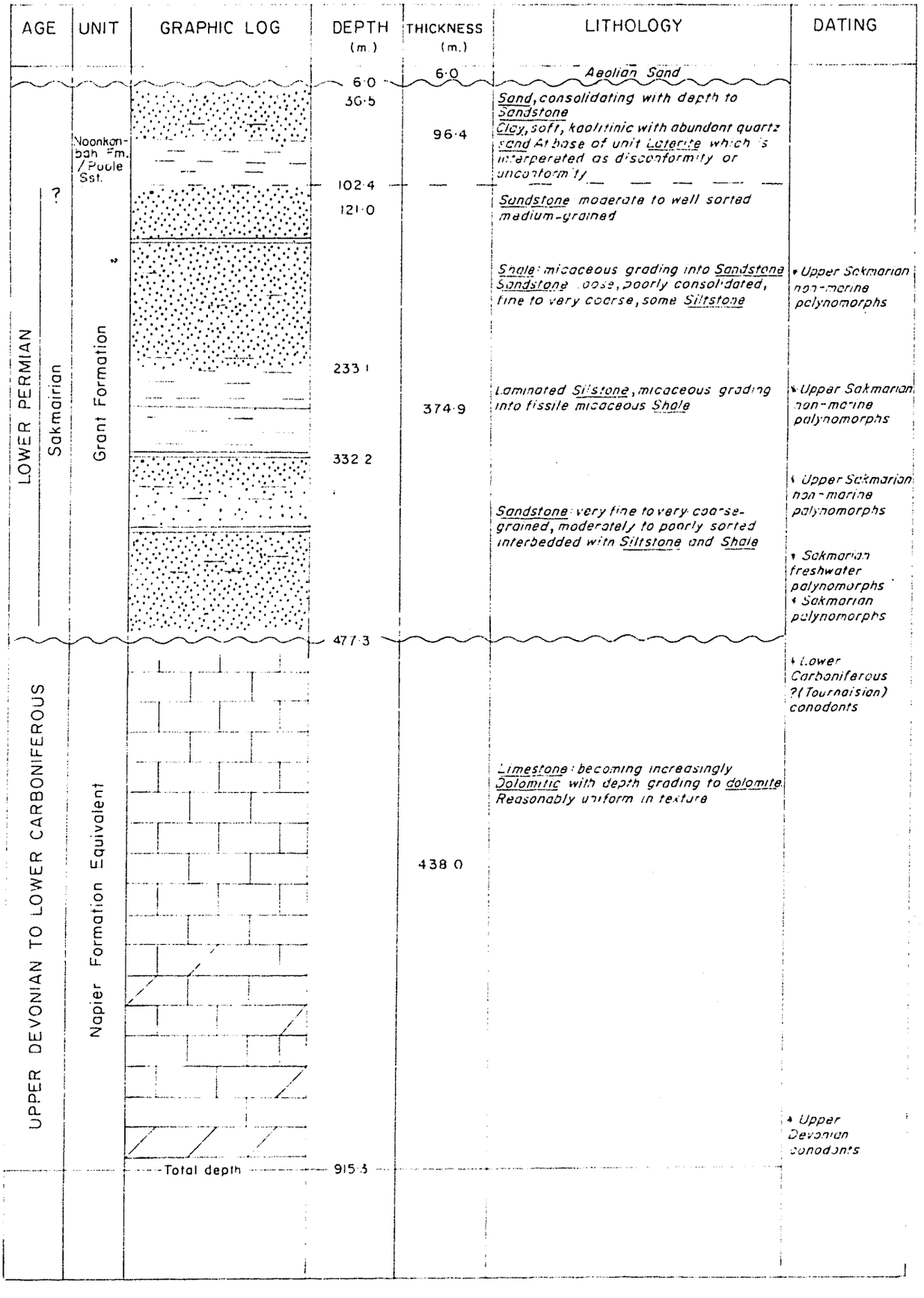


M(S)390
PD

Record
1975·77

Fig. 41 WAPET Crossland No.3

Scale: 1cm. = 50m.



M(S)387
PD.

Record
1975-77

Fitzroy Trough, especially in the Devonian sequence and some thickening also occurs south of the Dummer Range Fault. Major fault movement and structural growth occurred before and during the Devonian.

WAPET Drilling Program 1971

Following on from this survey WAPET drilled three stratigraphic coreholes in the Crossland Platform area (WAPET, 1971c). The wells were specifically sited to determine the ages and lithologies below the Permian unconformity and to obtain velocity data and Permian stratigraphic control in an area devoid of any well control. To date, identification of subsurface horizons had been speculative and any velocity data had been determined from wells often 320 km away. There were no direct ties of any seismic lines to wells.

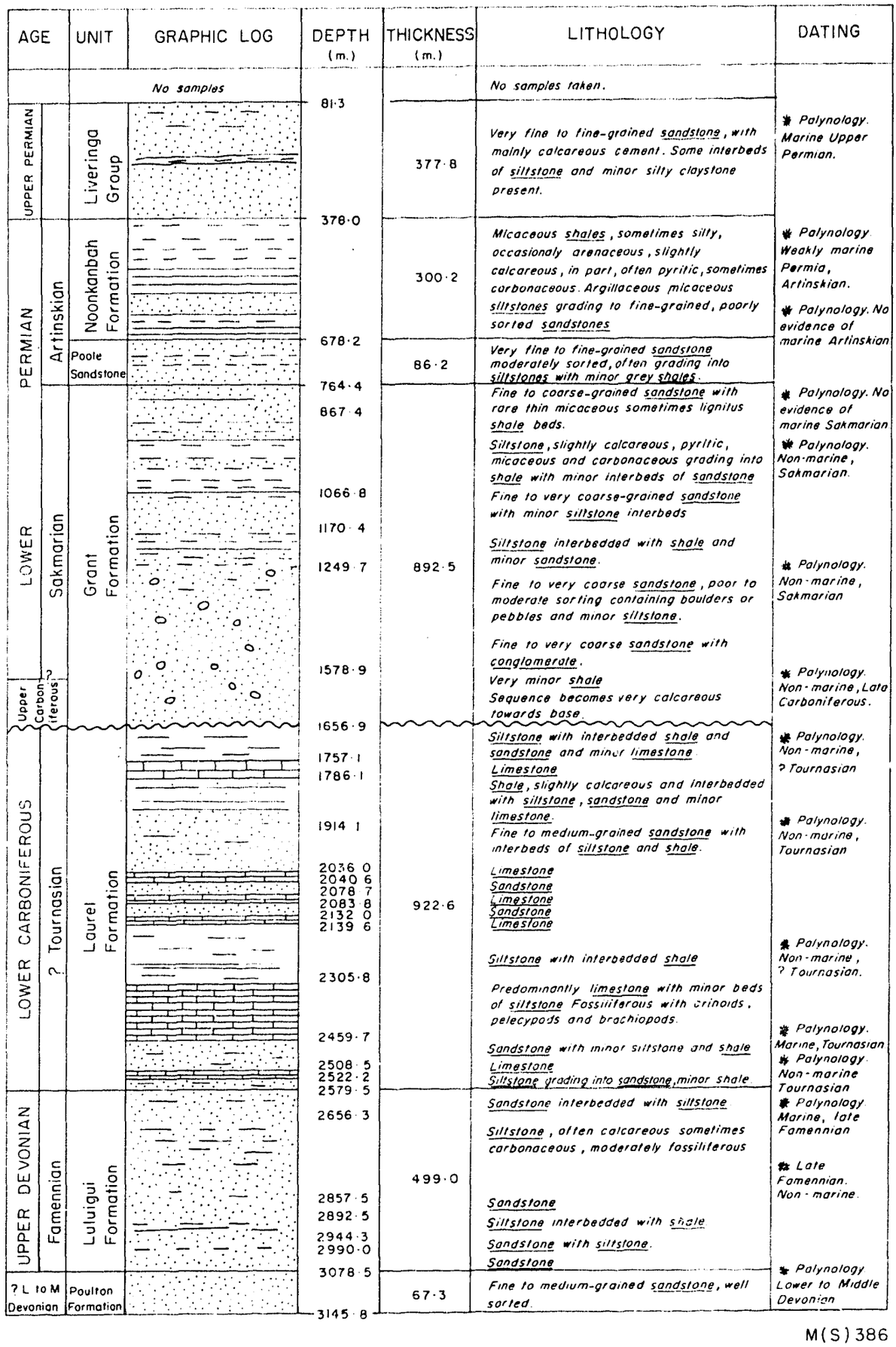
Crossland No. 1 was drilled on an anticlinal feature on the terrace north of the Crossland Platform. The 'terrace' was termed in this report the Barbwire Terrace and defined as a structurally complex area constituting the southern flank of the Fitzroy Trough and Gregory Sub-basin and featuring relatively intense folding. It is bounded to the northeast by the Fenton Fault System and to the southwest by what is now termed the Dummer Range Fault System. Crossland No. 2 was sited on the Crossland Platform south of the Dummer Range Fault System in an area where seismic sections have shown numerous small and poorly defined structures. Crossland No. 3 was located on a large fault block within the Dummer Range Fault System.

As previous seismic surveys had shown thinning of the sections over anticlines all wells were located off structure so as to obtain maximum section thickness. The detailed stratigraphy of the wells is shown in Figure 39, 40, 41. All three wells spudded in Permian, No. 1 in Grant Formation, the others in Noonkanbah Formation. Below the Permian unconformity, Crossland Nos 1 and 3 entered ?Devonian or ?Devonian-Carboniferous carbonate sequences, and Crossland 2 entered Ordovician-?Devonian evaporitic Carribuddy Formation.

The results were important in that they showed that the Crossland Platform, which lies farther south than previously interpreted, has the Ordovician-Devonian evaporite sequence preserved directly beneath the base of the Grant Formation. This implies that the small, poorly defined structures within the northern platform area are possibly the result of salt solution within and at the top of the evaporitic sequence. The other major result is that

Fig. 42 WAPET Lake Betty No.1

Scale:- 20mm = 300m



M(S) 386
G.G.

Record
1975·77

the Barbwire Terrace has a thick Upper Devonian carbonate sequence preserved and that in the Dummer Range area it forms a series of down-to-the-north, normal fault blocks.

Towards the end of 1971 WAPET drilled Lake Betty No. 1, their first petroleum exploration well in the area (WAPET, 1972a), aimed to test Devonian shelf carbonates. Again WAPET reinterpreted the previous geophysics and concluded that the Lake Betty structure was located in a southward continuation of the Lennard Shelf area on a prominent projection into the adjacent Gregory Sub-basin where the transition from shelf to basin takes place along a zone of faulting and down warping. Detailed stratigraphy is in Figure 42. The well spudded in Millyit Sandstone and the base of the Grant Formation unconformably overlies the Lower Carboniferous Laurel Formation at 752.4 m. The well reached total depth of 3096 m in Middle Devonian Poulton Formation. No major hydrocarbons were found and the primary target, Upper Devonian shelf carbonates, were absent and the Upper Devonian was represented by a clastic facies, the Luluigui Formation. The carbonates were believed to be faulted out at 3003 m.

AAO Billiluna-Helena Aeromagnetic Survey 1971

In 1971 a consortium of companies comprised of Associated Australia Oilfields NL, (AAO), Australian Aquitaine Petroleum Pty Ltd, Abrolhos Oil NL, Ashburton Oil NL, Flinders Petroleum NL, Longreach Oil NL, and Pursuit Oil NL took up two Exploration Permits in the eastern and northern Canning Basin. AAO, as the operators in the area, in late 1971 flew the Billiluna-Helena Aeromagnetic Survey over most of the eastern part of the area (AAO, 1972).

The survey showed that basement was characterized by a dominant series of faults trending northwest and a subordinate, possibly older, series of faults trending northeast. Eleven major anomalies were delineated and broadly the results are as follows :-

On the 'Billiluna Shelf', a zone of subsidence where basement reaches 6000 m below sea level is delineated 13 km north of Falconer Hills. This is a basin-like feature surrounded by major faults or steeply dipping margins which may also be fault zones. However, it acted as a shelf after the Late Devonian.

Several fractures were delineated on the Betty Terrace and, combined, they showed that magnetic basement varies considerably in amplitude from 9000 to 3000 m below sea level. The northern margin, 2 km northeast of Mt

Bannerman, is a down-to-the-southwest fault, the Mueller Fault, which is possibly an extension of the Pinnacle Fault. Southwest of Mt Bannerman, in a downthrown fault wedge basement reaches 9000 m below sea level.

The southwestern margin of the Betty Terrace is a series of northeast-trending, down-to-basin, en echelon faults occurring between Balgo Mission and Old Balgo Mission. Across them basement drops from 3000 to 9000 m below sea level. Some structures in the Balgo area may be the result of post-Permian movements over these faults.

Near Chungla Well, MOUNT BANNERMAN, is an upthrown basement block where depth to basement rises to 3000 m below sea level. This high was also delineated by seismic surveys (WAPET, 1970b).

The Fitzroy Trough (Gregory Sub-basin) reaches 9000 m below sea level 4 km south of Bishop Range, southeast CORNISH. Its northern margin appears to be either a zone of very steep dip or a series of major faults. There were no major irregularities in basement configuration in the survey area. Near Farewell Lakes, northeast HELENA, a fault-bounded indentation of the Fitzroy Trough (Gregory Sub-basin) occurs in which 7500 m of sediments are preserved; on the adjacent platform area the sedimentary rocks were interpreted as only 3000 m thick.

The Platform area was shown to be an area of relatively undisturbed shallow magnetic basement, with sedimentary thickness varying from 1500 to 3000 m below sea level. The Tina Springs Hingeline was delineated as a down-to-the-south fault. In southwest HELENA a zone of intense faulting may be the postulated Tobin Hingeline which is supposedly developed between the Platform to the north and the Kidson Sub-basin to the south (WAPET, 1970a). However, seismic work in this area has failed to substantiate this (WAPET, 1970a, 1971a, 1971b).

AAP Aeromagnetic Survey 1972

In the adjacent exploration permit to the east AAP flew the White Hills area High Sensitivity Aeromagnetic Survey (AAP, 1972). The survey covered the southeast extensions of the 'Broome Swell' and the Fitzroy Trough as well as an unnamed elevated area of basement to the north of the Trough.

Within the Fitzroy Trough, southwest of Stansmore Range, two anticlines and one syncline, all fault-bounded, are present. Although their axes are orientated easterly, the bounding faults mainly trend northwesterly. The great-

est depth to magnetic basement is 12 000 m in a syncline developed west of Point Moody. However, because the fault blocks were orientated at 45° to the magnetic and flight profile lines this could yield depth-to-basement estimates greater than expected. Northeast of this, a sequence of parallel northwest-trending fault structures have uplifted a section of the magnetic basement to about 300 m below sea level. The eastern margin of the Fitzroy Trough occurs east of the Stansmore Range where the throw of a northwesterly-trending changing to northerly-trending fault uplifts basement from 4500 to 3000 m below sea level.

The 'Broome Swell' occurs in the southern part of the survey area and depth to magnetic basement varies from sea level to 6000 m below sea level. The 'Broome Swell' here is divisible into two parts, a northern portion near the central part of the boundary of HELENA and STANSMORE and a southern portion to the south of this, the boundary between the two parts of the Swell being an area of inferred faulting trending northwesterly. In the northern portion of the 'Broome Swell', magnetic basement is from 3750 to 6000 m below sea level, and two prominent ridge-like features occurring west of Point Alphonse, western LUCAS, protrude into the Fitzroy Trough from the Swell. Depth to magnetic basement in the southern portion of the 'Broome Swell' is much less, varying from 1500 m below sea level to sea level in central-western HELENA.

WAPET'S Semi-Detailed Seismic Survey, 1972-3

In 1972 WAPET returned to the northwestern part of the area to carry out the East Canning Seismic Survey (WAPET, 1972b) which aimed at providing additional detailed coverage on structures determined by the earlier reconnaissance surveys as well as a northwesterly tie line across the northeasterly-trending reconnaissance survey lines.

The survey was divided into four reflection projects: Barbwire Terrace (332), Arundel (337), Christmas Creek (338), and Crosslands D1 (339).

In the Arundel area the survey aimed to provide modern coverage over the defined Arundel Structure (Continental, 1966a). Data were of poor quality but confirmed the previous interpretation of the structure as a northwest-trending anticline. Additional seismic work is required to confirm mapped and implied closure.

In the northern part of the Barbwire Terrace the survey delineated the previous feature noted southwest of Jones Range (WAPET, 1971a, 1971b). The feature, named the

Jones Range Structure, was mapped as a large fault-divided anticline trending east-west. Depth to the top of the Ordovician was 3690 m and to near top of Devonian Pillara Formation was 2820 m. Two other anticlines were noted, one northwest of Kirkby Range and the other 32 km southwest of the Jones Range Structure.

The Barbwire Terrace program consisted of one northwesterly-trending line along the extent of the Barbwire Terrace in CROSSLAND and a detailed program near WAPET Crossland No. 1. The Barbwire Structure was defined, as well as an anticline located 4 km northeast of WAPET Crossland No. 1 on a fault block.

The Crossland Platform Program obtained fair to good data, and the Devonian Horizon was found to be truncated. An anomalous feature 1.6 km northwest of Clapp Ridge in southern CROSSLAND is believed to be caused by salt solution in the Carribuddy Formation and the fault-bounded anticline discovered 5 km south of Dummer Range, DUMMER will require further semi-detailed seismic coverage to confirm closure.

Concurrent with this survey WAPET ran the Dampier Downs (331) - Collins (336) Seismic Survey (WAPET, 1972b) the more eastern part of which covered a small area in northwest CROSSLAND. The objectives of the survey were mainly on the 'Broome Platform' and the 'Jugurra Terrace', western equivalents of the Crossland Platform and the Barbwire Terrace, respectively. The survey defined the Barbwire Structure drilled by WAPET Barbwire No. 1 as an anticline cut by a series of down-to-the-north, northwest-trending faults. The survey also mapped the rise in depth of the horizons over the Barbwire High which supposedly forms the boundary between the Jugurra and Barbwire Terraces. About 7 km northwest of the Barbwire Range, the Fenton Fault and the Dummer Range Fault coalesce.

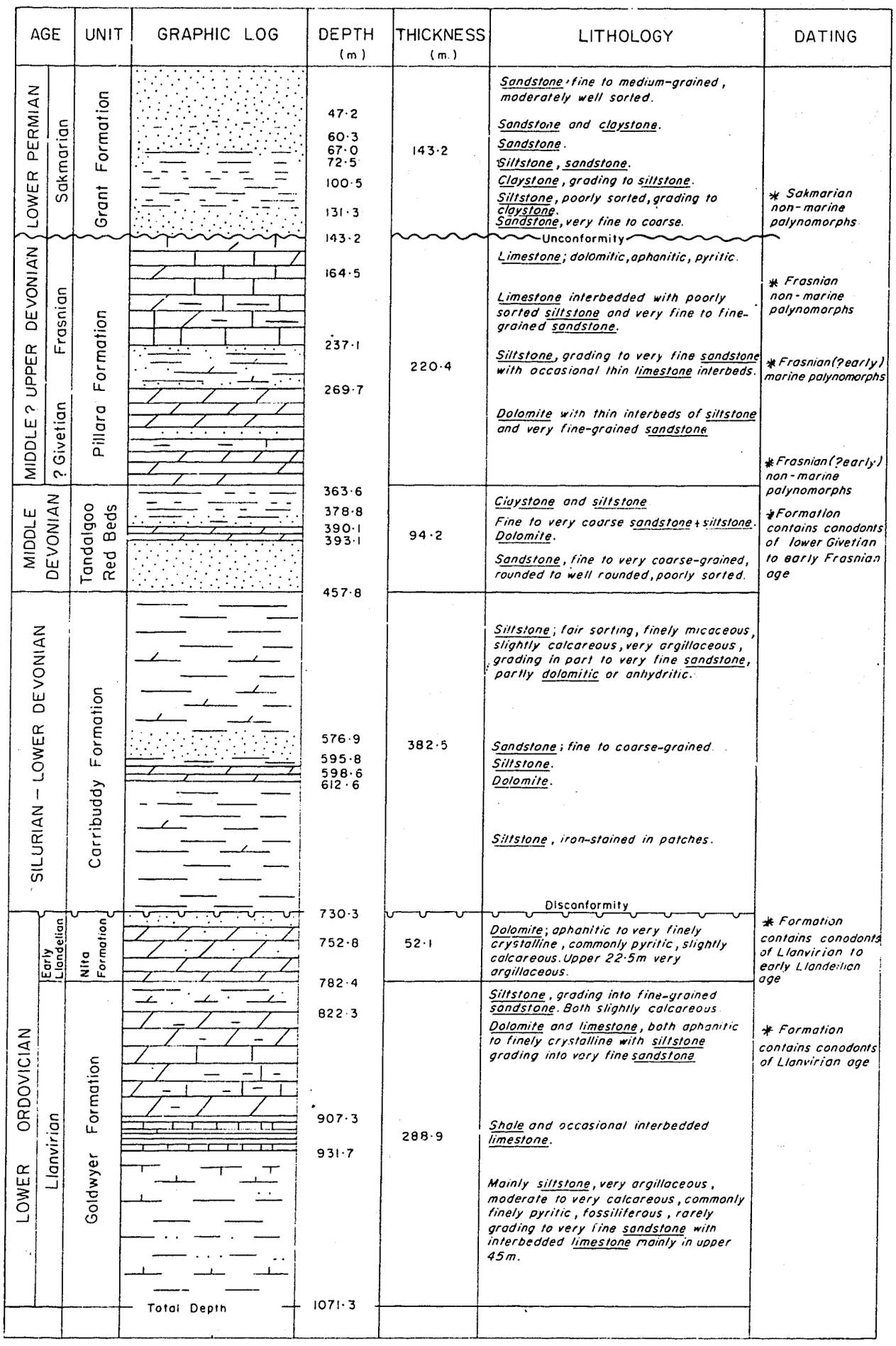
WAPET Barbwire No. 1

In 1972, WAPET drilled Barbwire No. 1 as a stratigraphic corehole with the primary aim of determining the age and nature of the stratigraphic column to assist in the interpretation of the regional structure and stratigraphy, and also to do a velocity survey to assist in the interpretation of seismic surveys (WAPET, 1972b). The detailed stratigraphy is summarized in Figure 43.

The well was located on a basement high which separates the Barbwire Terrace to the southeast from the Jugarra Terrace to the northwest. The Terrace is inter-

Fig. 43 WAPET Barbwire No.1

Scale: 1cm = 50m



M(S) 391
G.G.

Record
1975·77

mediate in depth between the Fitzroy Trough and the Crossland Platform and is separated from these by the Fenton Fault and the Dummer Range Fault respectively. The well penetrated 138 m of Permian unconformably overlying Middle to Upper Devonian carbonates and bottomed at 1054.5 m in Ordovician carbonates (Fig. 43). Temperature gradient studies in Barbwire No. 1 suggest that in the area basement may be at a depth of 1650 m. The presence of Devonian carbonates in the well confirmed the continuity of the Devonian carbonates along the Barbwire and Jugurra Terraces. Previously it was thought they had been removed by erosion over this basement high.

WAPET detailed Surveys 1973

During 1973 WAPET carried out three detail surveys in the northwestern part of the area aimed at defining well sites.

The first was the Crosslands 3 (358) Seismic Survey, a semi-detailed digital seismic reflection survey part of which covered the central western edge of CROSSLAND. The survey aimed to map in detail a feature noted on the western edge of McLARTY HILLS by the Crossland D-1 program of the East Canning Seismic Survey (WAPET, 1972c). Although several anomalies on 5 major northwest-trending anticlinal axes were mapped, none could be recommended as a well site as the mapped closures were thought to be caused by salt solution within the evaporite sequence. Three major northwest-trending down-to-the-north faults were mapped and their age is thought to be Permian.

The second survey was the Jones Range (364) and Hall Range (370) Seismic Projects (WAPET, 1974a) carried out in CROSSLAND.

The Jones Range (364) Project was located on the 'Jones Arch' (Jones Rise), a northeast-plunging gravity maximum anomaly which separates the Fitzroy Trough from the Gregory Sub-basin. The survey, a detail reflection survey, aimed at confirming a well site on the previously defined Jones Range structure (WAPET, 1971a, 1971b, 1972c). The structure was located on a large closed anticline located within a northwest-trending fault-bounded anticline, the Fenton Fault forming the southern boundary and a down-to-the-southwest fault forming the northern boundary. The anticline was also developed in the pre-Permian unconformity horizon and was cut by the two major northwest-trending faults between which are several faults with no preferred orientation. Between these minor fault-bounded blocks a well site was chosen. It was

believed that the Jones Range structure with at least 500 km^2 of closure could be one of the best petroleum prospects in the Fitzroy Trough provided any accumulated hydrocarbons had not escaped along the faults. The well would have Devonian carbonate objectives. This feature is presently being drilled as WAPET Jones Range No. 1.

The Hall Range (370) Project was carried out on the Barbwire Terrace in an area bounded by the Fenton and Dummer Range fault systems. The survey was detail follow-up work of an anticline delineated 4 km northwest of Crossland No. 1 by the Barbwire (331) Project of the East Canning Seismic Survey (WAPET, 1972d). A northwest-trending faulted anticline was mapped and three prospective well sites with Ordovician objectives were delineated. There is thinning of the sequence over the highs.

The final 1973 WAPET survey was the Barbwire 2 (361) Seismic Survey in the eastern portion of the Barbwire Terrace and aimed to provide semi-detailed seismic coverage of the features previously noted south of Dummer Range (WAPET, 1974b). Thirteen faults, mostly trending north-westerly, were located on the near top of the Ordovician Horizon, and it was suggested that the formation of the faults occurred between the Ordovician and the Permian, perhaps during the Devonian. The Barbwire Terrace was mapped as a northeast-dipping block on which three features occurred. The first was an anticline on the western flank of which Wapet Crossland No. 3 was located. The other two features were located on a northwest-trending anticlinal axis and separated from one another by a down-to-the-north fault running near parallel to the crest of the anticline. The work was not detailed enough to define sufficient closure for a well site.

The pre-Permian unconformity horizon was a featureless map showing northeast regional dip. No faults mapped on the lower horizon were detected and in the southern part of the survey area, southeast of WAPET Crossland No. 3 the pre-Permian unconformity reflector becomes too shallow to map. Below this, the pre-Permian section shows thickening over the synclines and thinning over the anticlines. This is believed to be caused by erosion before the deposition of the Permian rather than by structural growth of these highs during the Devonian.

AAO Seismic Survey 1973-74

The last subsidized survey in the area was the Thornton Seismic Survey carried out by Petty-Ray Geophysical, Incorporated for Associated Australian Resources NL

(AAR, formerly AAO) (AAR 1974) in the eastern and southeastern part of the area. The survey was an extensive regional reflection survey aimed at obtaining high-quality reflection data in a virtually unexplored part of the Canning Basin. The survey aimed to define the boundaries of the following major structural elements:- The Billiluna 'Shelf', Betty Terrace, Fitzroy Trough, Crossland Platform, and Helena Platform. It also aimed to define future drilling locations with emphasis on reef prospects. Three horizons were mapped. These were base of Grant Formation, top of Carribuddy Formation, and Basement.

The base of Grant Formation is a fairly strong, continuous, and easily identified reflector. In the north of the survey area it rises to the surface near Balgo Mission, LUCAS and also 4.5 km west of Mt Mueller, BILLILUNA. It also rises to the surface in the south, 8 km southwest and 5.5 km west of Farewell Lakes, HELENA. Structural highs were located between Weriaddo Well and Gregory Salt Lake, as well as 30 km west of Lake Isabella, CORNISH. One high was located 3 km northwest of Farewell Lakes. On the Billiluna 'Shelf' only minor faulting occurs suggesting that the 'Shelf' became stable before the Upper Carboniferous with only minor post-Permian disturbance. The regional dip is to the southwest.

The top of the Carribuddy Formation reflector was reasonably continuous except across the Fitzroy Trough (Gregory Sub-basin) where it became weak. The Carribuddy Formation is intensely faulted especially on the Billiluna 'Shelf', indicating that tectonic movements occurred in the mid-Palaeozoic. The fault pattern shown was somewhat conjectural with north and northwest-trending faults which appear to curve along the basin edge. Several well-defined structural highs were delineated on top of Carribuddy Formation reflector, with additional high closures existing against the faults. On seismic sections several possible reef structures were indicated. The surface topography around Mt Mueller, BILLILUNA, coincided with an anticlinal structure on both the Carribuddy and Basement horizons.

The Basement horizon was not well defined over part of the prospect. Faults were more numerous on the Basement level than the Carribuddy and are mostly normal faults; a few are low-angle faults. In the Fitzroy Trough (Gregory Sub-basin) the fault pattern appeared as a series of large step-down block faults into the 'Trough' and a curved pattern appears to exist around the basin edge on the Billiluna 'Shelf' area.

In HELENA, basement is affected by a series of complex north-south faults which on the southern margin of the Sheet area appear to be downthrown to the west towards

the Kidson Sub-basin. The Fitzroy Trough (Gregory Sub-basin) was well defined on the basement, with depth to the known deepest part being about 1800 m occurring 5 km west of Lake Isabella, CORNISH. This depth, greater than previously estimated, could be a slight over-estimation as velocity curves become less reliable with depth. The isochron maps showed thickening towards the centre of the Fitzroy Trough (Gregory Sub-basin) and the isochron map between Top of Carribuddy and Basement Horizon showed thickening towards the Kidson Sub-basin.

The Fenton Fault System appears on all three horizons as a series of northwest-trending, down-to-the-north faults curving near French Hills, southern CORNISH. A series of complementary faults 2 km farther east may be associated with this system. The Stansmore Fault System does not show on the Base of Grant Horizon.

TECTONIC ELEMENTS AND STRUCTURAL GEOLOGY

Eight tectonic units of the Canning Basin are present in the area. They can be distinguished on the basis of both surface and subsurface stratigraphy and on the results of aeromagnetic, gravity, and seismic surveys.

They are

(a) Billiluna Shelf
(b) Betty Terrace
(c) Gregory Sub-basin
(d) Jones Rise
(e) Fitzroy Trough
(f) Barbwire Terrace
(g) Crossland Platform

Small parts of the Lennard Shelf and the Fitzroy Trough are present in the northern part of the survey area. The distribution of the tectonic units and a section across them are shown in Figure 2. Table 5 gives the subsurface stratigraphy of deep wells and Table 6 lists the surface stratigraphy in the tectonic elements. Table 7 lists the subsurface geophysical surveys carried out in the various elements. The results of the surveys have been described earlier.

The description, location, stratigraphy, structure, and probably history of the tectonic units are described below.

(a) Billiluna Shelf

Description The Billiluna Shelf occurs on the far north-eastern margin of the Canning Basin, and is bounded to the west, north, and east by Precambrian basement and to the south by the Betty Terrace. Devonian and Ordovician rocks are the main units exposed.

Derivation The term was coined by Paten et al. (1972a) for an area which 'exhibits major relief in aeromagnetic basement' and which 'probably became stable before the Late Carboniferous'. This area was formerly part of the 'Bannerman Shelf', a term now discarded. The Bannerman Shelf was defined on the basis of known gravity results as a shelf area with thin sedimentary and little tectonic disturbance and separated by the north-trending Lonergan Hinge from the 'Fitzroy Trough' which had thick sedimentary rocks and greater tectonic disturbance (Wells, 1960; Casey & Wells, 1960; Henderson, Condon, & Bastion, 1963). Later geophysical surveys failed to substantiate this interpretation and Casey & Wells (1964 p. 34) questioned the existence of the Lonergan Hinge.

Structure Geophysical work tends to suggest that the Billiluna Shelf is not really a shelf, but more a basin. It, however, acted as a shelf after the Carboniferous, and the term shelf is retained on that basis.

Aeromagnetic data have shown that magnetic basement on the Billiluna Shelf forms a basin surrounded on all sides by major faults or steeply dipping margins which may correspond to faults (AAO, 1972). The greatest depth to magnetic basement is 6000 m below sea level, occurring 13 km north of Falconer Hills. The area also corresponds in part to a major gravity low termed the Mount Bannerman Gravity Trough (Flavelle & Goodspeed, 1962). Most negative Bouguer Anomaly values correspond to greatest depths to magnetic basement.

Seismic results indicate that basement is extensively faulted with a system of step-down curved faults which parallel the margin of the Billiluna Shelf. The 'Top of Carribuddy Horizon' was traced on to the Shelf and was also faulted.

TABLE 4. SUBSURFACE STRATIGRAPHY OF EXPLORATION WELLS IN THE GREGORY SUB-BASIN AND ADJACENT AREAS

Age	Unit	Lake Betty No. 1 (m)	Point Moody No. 1 (m)	Barbwire No. 1 (m)	Crossland No. 1 (m)	Crossland No. 3 (m)	Crossland No. 2 (m)	Wilson Cliffs No. 1 (m)	Contention Heights No. 1 (m)
Quaternary/Tertiary	Sand dunes, alluvium	+273.7 (81.3+)	+422.8 (12.1+)	x	+181.1 (9.1+)	+230.7 (6.9+)	+174.9 (9.1+)	+440.1 (12.2+)	418.4 (9.1+)
Mesozoic (?Jurassic)	Undifferentiated	-	-	x	-	-	-	+427.9 (169.2)	409.3 (74.1)
Upper to Lower Permian	Liveringa Group	+192.4 (377.8)	-	x	-	-	-	-	-
Lower Permian	Noonkanbah Formation	-185.4 (300.2)	+410.7 (335.3)	x	-	+224.7	+224.7 (134.7)	+258.7 (192.0)	335.2 (86.9)
	Poole Sandstone	-485.6 (86.2)	+75.4 (311.8)	x	-	(96.4)	+31.1 (84.0)	+66.7 (205.7)	248.3 (222.5)
Lower Permian to Upper Carboniferous	Grant Formation	-571.8 (892.5)	-236.4 (1313.4)	+216.4 (143.2+)	+172.0 (292.3+)	+128.3 (374.9)	-32.9 (451.7)	-139.0 (387.7)	+25.8 (435.5)
Lower Carboniferous	Anderson Formation	-	-1549.8 (468.5+)	-	-	-	-	-	-
	Laurel Formation	-1464.3 (922.6)	x	-	-	-	-	-	-
Lower Carboniferous to uppermost Devonian	Unnamed carbonate (Nullara Limestone)	-	x	-	-120.3 (611.7+)	-246.6 (438.0+)	-	-	-
Upper Devonian	Lulu1gui Formation	-2386.9 (499.0)	x	-	x	x	-	-	-
Upper Devonian to Upper Middle Devonian	Pillara Formation	-	x	+73.2 (220.4)	x	x	-	-	-
Upper Devonian to Middle Devonian	Mellingerie Limestone	-	x	-	x	x	-	-526.7 (127.4)	-409.7 (17.7)

TABLE 4 (CONT.)

Age	Unit	Lake Betty No. 1 (m)	Point Moody No. 1 (m)	Barbwire No. 1 (m)	Crossland No. 1 (m)	Crossland No. 3 (m)	Crossland No. 2 (m)	Wilson Cliffs No. 1 (m)	Contention Heights No. 1 (m)
Middle Devonian	Poulton Formation	2885.9 (67.3+)	x	-	x	x	-	-	-
Lower Devonian to ?Upper Silurian	Tandalgoo Redbeds	x	x	-147.2 (94.2)	x	x	-	-654.1 (684.3)	-426.4 (60.7)
?Silurian	Carribuddy Formation	x	x	-241.4 (382.5)	x	x	-484.6 (254.9+)	-1338.4 (754.4)	-487.1 (431.6)
Lower Ordovician	Nita Formation	x	x	-623.9 (52.1)	x	x	x	-	-
	Goldwyer Formation	x	x	-676.0 (288.9+)	x	x	x	-2092.8 (970.5+)	-918.7 (444.3+)
	Total Depth	-2953.2	-2018.3	-964.9	-732.0	-684.6	-739.5	-3063.3	-1363.0
	Tectonic Unit	Betty Terrace	Gregory Sub-Basin	Barbwire Terrace	Barbwire Terrace	Barbwire Terrace	Crossland Platform	Kidson Sub-Basin	Kidson Sub-Basin
	Reference	WAPET 1972a	AAP 1966	WAPET 1972b	WAPET 1971c	WAPET 1971c	WAPET 1971c	AAP 1969c	AAP 1974

Legend

x unit not penetrated in well
- unit absent in well, usually between an unconformity or disconformity
-2386.9 Top figure is depth to top of unit above (+) or below (-) sea level
(499.0) Figure in brackets is thickness of unit
Underlined figure is bottom unit in well

TABLE 5. SURFACE OCCURRENCE OF STRATIGRAPHIC UNITS IN GREGORY SUB-BASIN AND ADJACENT AREAS

Age	Unit	Crossland Platform	Barbwire Terrace	Gregory Sub-basin	Jones Rise	Fitzroy Trough	Betty Terrace	Billiluna Shelf	Lennard Shelf
Jurassic	Barbwire Sandstone		?			X			
	Callawa Formation	X							
	Culvida Sandstone			X					
Lower to Middle Triassic	Erskine Sandstone			X			X		
Lower Triassic	Blina Shale			X			X		
	Millyit Sandstone			X		X	X		
Upper Permian	Cherrabun Member				X	X			
	Hicks Range Sandstone Member				X	X			
	Kirkby Range Member			X	X	X			
	Godfrey Beds			X			X		
	Condron Sandstone			X	X	X	X		
Lower Permian	Lightjack Formation	X	X	X	X	X	X		
	Noonkanbah Formation	X	X	X	X	X	X		
	Poole Sandstone	X	X	X			X		
Lower Permian to Upper Carboniferous	Grant Formation		X	X			X	X	X
Upper Devonian	Knobby Sandstone							X	
Lower Ordovician	Carranya Beds							X	

TABLE 6. TECTONIC ELEMENTS COVERED BY GEOPHYSICAL SURVEYS

NAME	TYPE	OPERATOR	REFERENCE	Billiluna Shelf	Betty Terrace	Fitzroy Trough	Jones Rise	Gregory Sub-basin	Barbwire Terrace	Crossland Platform	Kidson Sub-basin
Canning Basin Aeromagnetic Survey	AM	BMR	BMR Record 1960/11	X	X	X	X	X	X	X	
Fitzroy and Canning Basin Reconnaissance Gravity Surveys, W.A.	AG	BMR	BMR Record	X	X	X	X	X	X	X	
Poole Range Seismic Survey	AS	BMR	BMR Record 1974/43			X	X	X			
South Canning Basin Aeromagnetic Survey	AM	West Australian Petroleum Pty Ltd	WAPET 1966a	X	X	X	X	X	X	X	X
Stansmore Range Aeromagnetic Survey	AM	Hackathorn New Zealand Oils Ltd and Australian Oil Corporation	Hackathorn and A.O.C., 1963		X			X	?	X	
Balgo-Lake Betty Seismograph Survey	S	West Australian Petroleum Pty Ltd	WAPET 1964c		X			X			
Lake Betty Reconnaissance Gravity Survey	S	West Australian Petroleum Pty Ltd	WAPET 1964a	X	X	X	X	X			
Stansmore Range Seismograph Reflection and Gravity Survey	S&G	Hackathorn New Zealand Oils Ltd	Beach, 1965		X			X			

TABLE 6. (Continued)

NAME	TYPE	OPERATOR	REFERENCE	Billiluna Shelf	Betty Terrace	Fitzroy Trough	Jones Rise	Gregory Sub-basin	Barbwire Terrace	Crossland Platform	Kidson Sub-basin
Crossland Platform (304) Seismic Project	S	West Australian Petroleum Pty Ltd	WAPET, 1971b			X	X		X	X	
Billiluna-Helena Aeromagnetic Survey	AM	Australian Associated Oilfields N.L.	A.A.O., 1972	X	X			X	X	X	
White Hills Area High Sensitivity Aeromagnetic Survey	AM	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1972		X			X	X	X	
East Canning Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1972d			X	X	X	X	X	
Dampier Downs (331) - Collins (336) Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1972c			X			X	X	
Crosslands 3 (358) Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1973b							X	
Jones Range (364) and Hall Range (370) Seismic Project	S	West Australian Petroleum Pty Ltd	WAPET, 1974a			X	X		X	X	
Barbwire 2 (361) Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1974b					X	X	X	
Thornton Seismic Survey	S	Associated Australian Resources	A.A.R., 1974	X	X			X	X	X	X

TABLE 6. (Continued)

NAME	TYPE	OPERATOR	REFERENCE	Billiluna Shelf	Betty Terrace	Fitzroy Trough	Jones Rise	Gregory Sub-basin	Barbwire Terrace	Crossland Platform	Kidson Sub-basin
Terry Range Magneto Telluric Survey	M.T.	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1969a		X			X	X	X	
Ryan Seismic and Gravity Survey	S&G	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1969b		X			X	X	X	
Contention Heights Seismic Refraction	S	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1969c							X	X
Stretch Range Seismic and Gravity Survey	S&G	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1971		X			X	X	X	
Helena (267) Reconnaissance Seismic Project	S	West Australian Petroleum Pty Ltd	WAPET, 1970a					X	X	X	
Lake Betty (269) Detail/Reconnaissance Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1970b	X	X			X			
Crossland (268) Reconnaissance Seismic Survey	S	West Australian Petroleum Pty Ltd	WAPET, 1971a			X			X	X	

TABLE 6. (Continued)

NAME	TYPE	OPERATOR	REFERENCE	Billiluna Shelf	Betty Terrace	Fitzroy Trough	Jones Rise	Gregory Sub-basin	Barbwire Terrace	Crossland Platform	Kidson Sub-basin
Stansmore Ranges Gravity Survey	G	Beach Petroleum N.L.	Beach, 1965		X			X	X	X	
St Georges Range Reconnaissance Seismic Project	S	Continental Oil Company of Australia Ltd	Continental, 1965a			X			X	X	
Poole Range Detail Vibroseis Project	S	Continental Oil Company of Australia Ltd	Continental 1965b			X					
Broome Swell Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Continental 1965c			X			X	X	
Crossland Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Continental 1966a			X	X				
Barbwire Range Area Seismic Survey	S	Continental Oil Company of Australia Ltd	Continental 1966b			X			X		
Betty Detail Seismic Project	S	West Australian Petroleum Pty Ltd	WAPET 1966b		X			X			
Dakota Seismic and Gravity Survey	S&G	Australian Aquitaine Petroleum Pty Ltd	A.A.P., 1968					X	X	X	

Within this area the 'Base of Grant Horizon' was too shallow to map (AAR, 1974). The sedimentary section on the Billiluna Shelf averages about 3000 m in thickness.

Stratigraphy The known stratigraphic succession on the Billiluna Shelf consists of the Lower Ordovician Carranya Beds (outcrop), the Silurian Carribuddy Formation (seismic evidence, AAR, 1974), the Upper Devonian Knobby Sandstone (outcrop), and the Upper Carboniferous to Lower Permian Grant Formation (outcrop).

The interval from the Lower Ordovician Carranya Formation to the Upper Devonian has not been penetrated in well sections and may also consist of equivalents of the Lower to Middle Ordovician Willara Formation described by Playford et al. (in press), the Middle Ordovician Goldwyer Formation (Elliott, 1961), the Lower Devonian Tandalgoo Redbeds, and the Middle Devonian Poulton Formation. There are no known Lower Carboniferous units, and the Grant Formation is restricted to the southern margin of the Billiluna Shelf. The remaining Lower Permian units, ubiquitous throughout the rest of the area, as well as the Upper Permian to Triassic units present in the adjacent Betty Terrace and Gregory Sub-basin, are absent.

(b) Betty Terrace

Description The Betty Terrace is an area of downfaulted basement, intermediate in depth between the Billiluna Shelf to the northeast and the Gregory Sub-basin to the southwest, and in this sense it is a terrace-like feature. It is separated from the last two features by a series of subsurface northwest-trending faults the Mueller Fault and the Stansmore Fault, respectively. It is bounded to the east by basement outcrops and the the northwest by the Jones Rise.

The Betty Terrace is an area where basement, consisting of a series of ?faulted structural high and low features, varies in depth from 9000 to 3000 m below sea level. The sediments appear to thicken into the adjacent Gregory Sub-basin and the Lower Carboniferous Anderson Formation is absent.

Derivati n The name was first used by WAPET in their Lake Betty (269) Detail/Reconnaissance Seismic Survey (WAPET, 1970b) for a terrace-like basement feature on the north

flank of the Gregory Sub-basin near Lake Betty. The name was later applied by Mines Administration Pty Ltd (MINAD) to an area north of the Gregory Sub-basin and south of the Billiluna Shelf where the aeromagnetic and gravity data suggest a series of structural high and low features in the basement (Paten et al., 1972a).

Stratigraphy Rocks exposed at the surface consist of the Triassic Erskine Sandstone, Blina Shale, and Millyit Sandstone and the Permian Godfrey Beds, Condren Sandstone, Lightjack Formation, Noonkanbah Formation, Poole Sandstone, and the Upper Carboniferous to Lower Permian Grant Formation. The units tend to young in from the northern, northeastern, and eastern margin of the Betty Terrace with the Lower Triassic Erskine Sandstone occurring mainly adjacent to the Stansmore Fault, in LUCAS, CORNISH, and MOUNT BANNERMAN. After the deposition of the Upper Permian Condren Sandstone, the Betty Terrace and most of the Gregory Sub-basin appear to have merged to form a broader basin in which both the Upper Permian to Triassic units were deposited.

From subsurface drilling information in WAPET Lake Betty No. 1, the Grant Formation is unconformable on the Lower Carboniferous Laurel Formation, which is disconformable on the Upper Devonian Luluigui Formation which was faulted against the Lower to Middle Devonian Poulton Formation. The Lower Carboniferous Anderson Formation, present in the neighbouring Gregory Sub-basin was absent, and the Middle to Upper Devonian Pillara Formation, the carbonate objective of the well, was supposedly faulted out (WAPET, 1972a). Below the Poulton Formation the sequence could possibly consist of the Tandalgoo Redbeds, the Carribuddy Formation, and a Lower to Middle Ordovician sequence.

Surface Exposures The Permian sequence exposed consists of Poole Sandstone Noonkanbah Formation, Lightjack Formation, Condren Sandstone, and Godfrey Beds. A complete Lower Triassic sequence is also preserved.

Structure Aeromagnetic and gravity data indicate that basement on the Betty Terrace consists of a series of ?faulted structural high and low features with displacement in the order of 6000 m. Aeromagnetic data delineated several fractures on the Betty Terrace between which basement varied from 9000 to 3000 m. The northern margin 2 km northeast of Mt Bannerman is the down-to-the southwest Mueller Fault, possibly an extension of the Pinnacle Fault. The eastern margin in the subsurface is a series of down to the south faults which displace basement from 3000 to 9000 m below sea

level. The southeastern margin is the Stansmore Fault, which on the surface can be mapped from the Stansmore Range northwest through the Stretch Range and Bishop Range to the Culvida Soak area, northern CORNISH. The Thornton seismic survey indicated that it extends 3 km east of Culvida Soak (AAR, 1974) and major down-to-the southwest faults detected by the Lake Betty (269) Detail/Reconnaissance Seismic Survey in the Lake Betty area and the Chungla Well-Lake Doman area in MOUNT BANNERMAN could be extensions of it. The northwestern margin of the Betty Terrace is believed to merge with the Jones Rise (WAPET, 1970b).

Seismic work (WAPET, 1970b, AAR, 1974) suggests that the sequence thickens towards the Gregory Sub-basin. The Carribuddy Horizon was traced onto the Terrace and faulting extensively affects the Carribuddy Horizon but not the overlying Permian horizons. (AAR, 1974).

(c) Gregory Sub-basin

Description The Gregory Sub-basin is an elongate northwest-trending fault-bounded, trough-shaped feature bounded to the northeast by the Stansmore Fault and to the southwest by the Fenton Fault System. These features separate it from the Betty Terrace and the Barbwire Terrace, respectively. The Gregory Sub-basin is continuous with the Fitzroy Trough across the northeast-trending Jones Rise. Sediments in the Gregory Sub-basin are thicker and a more complete section is preserved than in the adjacent elements.

Derivation The feature was first revealed by the 1962 WAPET aeromagnetic survey (WAPET, 1966a) as a basin 9000 m deep centred on Lake Gregory and was named the Gregory Sub-basin by WAPET in their 1963 Balgo-Lake Betty Seismograph Survey (WAPET, 1964c).

The area had been regarded as being a continuation of the Fitzroy Trough but it is regarded here as a separate element. Originally it was defined as being separated from the Fitzroy Trough by the Bulka Arch, a northwest-trending gravity high in MOUNT BANNERMAN near Lake Betty (WAPET, 1964a). More detailed work (WAPET, 1970b) suggested that the 'Jones Arch', farther to the west, is more likely to be the boundary feature.

Stratigraphy Units exposed on the Gregory Sub-basin consist of the Upper Carboniferous to Lower Permian Grant Formation, the Lower Permian Poole Sandstone, Noonkanbah Formation, Lightjack Formation, the Upper Permian Condren Sandstone, Hardman Formation, and its possible correlative the Godfrey Beds, and the Triassic Millyit Sandstone, Blina Shale, Erskine Sandstone, and Culvida Sandstone.

The units tend generally to young inwards from the southwestern, southern, and southeastern margins with the Grant Formation occurring adjacent to the Stansmore Fault, STANSMORE, and the French Hills and Fisher Bluff, CORNISH, and the Triassic units cropping out along the axial region of the Sub-basin. One exception is the Lightjack Formation, which in southern STANSMORE and northern WEBB appears to transgress the older Permian units. The upper Permian and Triassic units have left no record in the southeastern third of the Gregory Sub-basin.

Subsurface drilling in AQUITAINE Point Moody No. 1 in the Gregory Sub-basin showed that the Grant Formation overlies the Anderson Formation. In this well 468.5 m of the latter unit was penetrated and the base was not reached.

Below the Anderson Formation the sequence is likely to consist of the Devonian Fairfield Group or its equivalents and the basinward equivalents of the reef complexes that are exposed along the Lennard Shelf (Luluigui Formation). The equivalents disconformably overlie the Poulton Formation and the Tandalgoo Redbeds or their equivalents which are also likely to be present. The Carribuddy Formation has been shown on seismic evidence to extend across the Gregory Sub-basin and disconformably overlie the Ordovician sequence which possibly consists of the Nita Formation (in the west), Goldwyer Formation, Willara Formation, and the Nambeet Formation or their equivalents.

Structure The Gregory Sub-basin is bounded by the Stansmore Fault to the northeast and the Fenton Fault system to the southwest; the major displacement on these faults occurs in the subsurface in the Pre-Permian section.

The Stansmore Fault can be traced on the surface from the Stansmore Range to the Bishop Range. Seismic work (AAR, 1974) shows that it is continuous to the Lake Betty region. On the surface, this fault appears mainly as a series of lineaments north of Bishop Range. The throw appears to decrease to the northwest.

The Fenton Fault System is likewise only mapped in the sub-surface although lineaments may be an expression of this fault. The throw on the Fenton Fault decreases to the southeast, being replaced by a monoclinal flexure. With the exception of the Stansmore Fault in the southeast, the major movement on these faults occurred before the deposition of the Grant Formation.

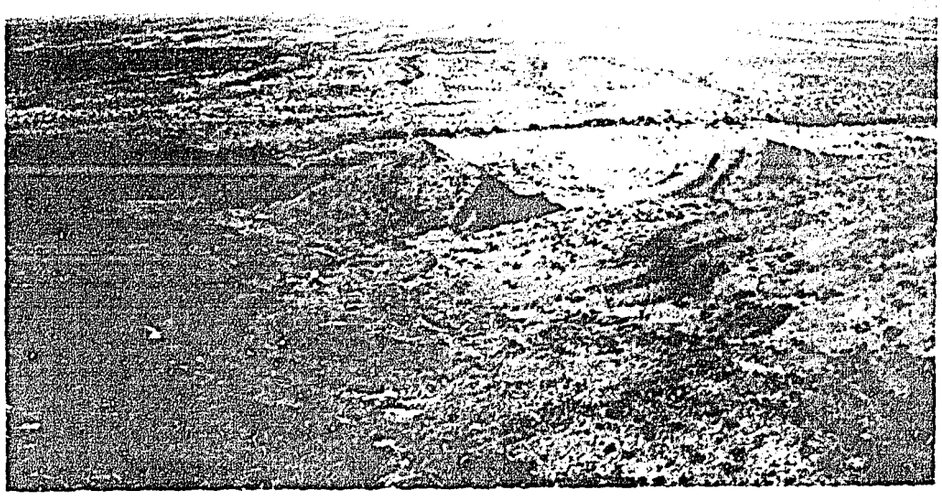


Fig. 44 Aerial view eastwards of the southern Stansmore Range showing steep tilting of beds in the background which are truncated sharply against the Stansmore Fault. The area east of the Fault is covered mainly by sand plains. BMR Negative GB/240.

Magnetic basement appears to be smooth with no major abrupt irregularities as are present in the adjacent Betty Terrace to the north, although a series of east-west trending anticlines may be present in basement. The Gregory Sub-basin is the deepest tectonic unit in the study area and depths to basement estimates are 9000 m south of Lake Gregory (WAPET, 1966a), 12000 m east of Point Moody (AAP, 1972), and 18000 m near Lake Isabella, CORNISH (AAR, 1974).

Recent seismic work (AAR, 1974) has enabled the tracing of the extension of the Carribuddy Horizon into the Gregory Sub-basin, and isopach data indicate a relatively thicker section in the interval from Top of Carribuddy to Base of Grant Formation than in the other tectonic elements.

Most surface faults in the Gregory Sub-basin trend north-south, a feature common with the Fitzroy Trough. However, there are no major east-west trending surface anticlines in the Gregory Sub-basin similar to those developed in the Fitzroy Trough and described by Guppy et al. (1958, p. 66), except possibly for the small easterly-trending Point Moody anticline in STANSMORE. Along the Stansmore Fault, outcrops are steeply tilted (Fig. 44). Folding dies out away from the Fault.

(d) Jones Rise

Description The Jones Rise is an area of elevated basement trending east-northeast from the Fenton Fault in northeast CROSSLAND, across northwest MOUNT BANNERMAN, then swinging into the east-trending Proterozoic outcrops of Bulka Hills.

Derivation The Jones Rise was first detected by BMR gravity surveys (Flavelle & Goodspeed, 1962) as a 'relative gravity high' possibly forming the north-western boundary of the 'Mt Bannerman Gravity Trough'. The elevated area of basement was also detected by the 1962 Poole Range Seismic Survey (CGG, 1974) and the WAPET South Canning Basin Aeromagnetic Survey (WAPET, 1966a). The 'Jones Arch' was named during the Lake Betty Reconnaissance Gravity Survey (WAPET, 1964a) as an east-northeast-trending basement feature cutting across the Fitzroy Trough. It is now regarded as separating the Fitzroy Trough and the Gregory Sub-basin and has been termed the Jones Rise.

Stratigraphy The stratigraphic section on the Jones Rise, of Ordovician to Permian, is probably a condensed version of the sequence in the adjacent Fitzroy Trough and Gregory Sub-basin to the northwest and southeast, respectively. All sections appear conformable over the

Arch. The Lower Permian Noonkanbah Formation and Lightjack Formation and the Upper Permian Condren Sandstone and Hardman Formation crop out on the Jones Rise and below these units the section is likely to consist of the Lower Permian Poole Sandstone and Upper Carboniferous to Lower Permian Grant Formation. The depth to the base of the Grant Formation is estimated to be 300 m in northeast CROSSLAND (J. Rasidi, BMR, pers. comm.). Upper Devonian carbonate beds have been tentatively identified by WAPET (1971c) and the Carribuddy Formation has also been identified. Triassic rocks do not crop out on the Jones Rise.

Structure The Jones Rise has been detected as a basement high by both aeromagnetic (WAPET, 1966a) and gravity surveys (Flavelle & Goodspeed, 1962). Seismic sections show the sedimentary sequence to be thinning over the Arch and in places to be extensively faulted. Depth to magnetic basement is at least 3000 m (Quilty, 1960).

(e) Fitzroy Trough

Description The Fitzroy Trough is fault-bounded and trends northwest from the Jones Rise to beyond the present coastline. The Pinnacle Fault to the northeast separates it from the Lennard Shelf and the Fenton Fault to the southwest separates it from the Jugurra Terrace, the Crossland Platform, and the Barbwire Terrace (from the northwest).

Derivation The feature was first named by Reeves (1951) as the Fitzroy Basin. It has been variously referred to as the Fitzroy Depression, the Fitzroy Trough, and the Fitzroy Graben. Most authors have included the Gregory Sub-basin in the Fitzroy Trough (Casey & Wells, 1964; AAP, 1969a, 1969b, 1972; AAO, 1972; AAR, 1974). The Fitzroy Trough is the most commonly accepted term and here includes only that feature northwest of the Jones Rise.

Stratigraphy The units exposed on the Fitzroy Trough in the area are the same as those on the Jones Rise. Apart from the Millyit Sandstone no other Triassic rocks crop out in the area, though they occur to the northwest, and the Hardman Formation section in Millyit Range is the most complete section of Hardman Formation recorded so far. The sub-surface (pre-Permian) section is presumably similar to that of the Gregory Sub-basin.

Structure Geophysical data show within the area that the Fitzroy Trough is both an aeromagnetic low and a gravity low. Seismic results indicate a possible Palaeozoic sequence of at least 7500 m (Continental, 1965a) and that

the Fitzroy Trough appears to be assymetrical, with the deepest part adjacent to the Fenton Fault. Major sub-surface anticlines trend northwest, in contrast to the major surface structures (Millyit Syncline, Kirkby Range Syncline, and Halls Range Anticline) which trend almost east-west. North-south faults in the Fitzroy Trough are common, but appear to have only minor displacements at the surface, like those of the Gregory Sub-basin.

(f) Barbwire Terrace

Definition The Barbwire Terrace is a narrow down-faulted block along the southwest flanks of the Fitzroy Trough and the Gregory Sub-basin. It is bounded to the northeast by the Fenton Fault System and to the southwest by the Dummer Range Fault System; basement along the terrace is intermediate in depth between the Crossland Platform to the southwest and the Fitzroy Trough and the Gregory Sub-basin to the northeast.

The Barbwire Terrace is located almost entirely within the area. About 7 km northwest of the Barbwire Range, northwest CROSSLAND, the Fenton and Dummer Range Fault System coalesce in NOONKANBAH.

The Terrace was only a terrace sensu stricto from the late Middle Devonian to Early Carboniferous when the rate of subsidence in it was slower than in the adjacent Trough and Sub-basin, when carbonates were deposited. However, the term terrace is preferred to other terminology.

Derivation The Terrace was first detected by WAPET seismic Helena (267) (WAPET, 1970a) and Crossland (268) (WAPET, 1971a) reconnaissance seismic surveys. It was initially considered part of the Crossland Platform, but when drilling the Crossland wells, WAPET delineated the Terrace as a separate feature (WAPET, 1971c).

Stratigraphy There are no known outcrops of Upper Permian or Triassic units on the Barbwire Terrace in the area. The major units exposed are the Lower Permian Noonkanbah Formation and Poole Sandstone with minor outcrops of the Upper Carboniferous to Lower Permian Grant Formation and also the Lower Permian Lightjack Formation. Seismic work has shown that below the Grant Formation the Lower Carboniferous Anderson and Laurel Formations are likely to occur, and to pinch out onto the Terrace from the adjacent Trough and Sub-basin areas to the northeast. Below these is a sequence of Upper Middle Devonian to Lower Carboniferous carbonates disconformably overlying the Tandalgoo Redbeds and then the Carribuddy Formation. In the northwest part of

the Barbwire Terrace the Ordovician Nita Formation is likely to be present. Elsewhere the Ordovician sequence consists of the Goldwyer Formation and probable correlatives of the Willara and Nambeet Formations.

Structure Geophysical data suggest that the Barbwire Terrace is a down-faulted fault-bounded terrace on the edge of the Fitzroy Trough - Gregory Sub-basin.

Temperature gradient studies in WAPET Barbwire No. 1 suggest that basement is within 1500 m of the surface in the northwestern part of the Terrace (WAPET, 1972b). Depth to basement increases to the southeast and aeromagnetic data indicate magnetic basement to be 6000 m below sea level west of Lake Hevern, STANSMORE.

Seismic evidence in northeast HELENA and northwest STANSMORE suggest that the throw on the Fenton Fault System decreases to the southeast and the Barbwire Terrace becomes less distinct here, where faults are replaced by steep monoclinal flexures along the margin of the adjacent Gregory Sub-basin. The throw on the Dummer Range Fault System, however, appears to increase to the southeast.

(3) Crossland Platform

Description The Crossland Platform is an area of relatively shallow basement with respect to the other tectonic elements. The sediments in it show regional dip to the southwest towards the Kidson Sub-basin. The boundary between the Kidson Sub-basin and the Crossland Platform is arbitrarily taken as the Tobin Hingeline, and the Platform is separated from the Barbwire Terrace to the north by the Dummer Range Fault System. Within the known sedimentary sequence Upper Devonian and Lower Carboniferous carbonate and clastic sediments are absent and basal Permian units rest directly on Middle Devonian and older rocks.

The Crossland Platform is a platform with respect to the adjacent Barbwire Terrace. It appears to have a more shelf-like relation to the Kidson Sub-basin. However, the name "platform" is used in this report. The preserved sedimentary sequence is much thinner than in the adjacent tectonic elements. This is due to erosion of part of the pre-Middle Devonian sequence during the late Middle Devonian to latest Early Carboniferous when the area was emergent. The Upper Carboniferous to Lower Permian sequence (Grant Formation) is relatively thin; it thickens towards the southwest.

Derivation The term was introduced by WAPET (1970a). Before the Helena (267) Reconnaissance Seismic Project (WAPET, 1970a) the available aeromagnetic and gravity data were reinterpreted. Results suggested that the 'Broome Swell' (Veevers & Wells, 1961) south of the Fenton Fault could be divided into the Crossland and Helena Platforms. The Crossland Platform to the north was thought to be structurally higher and was thought to be divided from the Helena Platform to the south by the Tina Springs Hingeline. The Helena Platform was thought to be separated from the Kidson Sub-basin to the south by a down-to-the-south flexure, the Tobin Hingeline. Seismic surveys (WAPET, 1970a; WAPET, 1971a, 1971b) did not support the existence of the Helena Platform as a separate entity, and the Crossland Platform was delineated as an area of shallow basement south of the Dummer Range Fault system having gentle regional dip to the southwest (WAPET, 1971b). The area has previously been referred to as the Broome Swell (Veevers & Wells, 1961) and Mid-basin Platform (company use).

Stratigraphy Surface exposures on the Crossland Platform are sparse, but sufficient to show that the sedimentary sequence is younging from the Barbwire Terrace to the Kidson Sub-basin. The Lower Permian Noonkanbah and Lightjack Formations crop out in the Crossland Platform, as well as limited exposures of Upper Jurassic fluviatile sandstone.

Units in the subsurface consist of the Lower Permian Poole Sandstone and the Upper Carboniferous to Lower Permian Grant Formation unconformably overlying from the northeast the ?Silurian Carribuddy Formation, the Lower Devonian Tandalgoo Redbeds, and the Middle Devonian Mellinjerrie Limestone. Below the Carribuddy Formation, the Ordovician sequence is apparently similar to that of the Barbwire Terrace.

Structure Seismic work shows that all formations dip gently to the southwest, with those below the unconformity at the base of the Grant Formation dipping at a slightly steeper angle than those above.

The Dummer Range Fault System which forms the northern boundary, has been traced by WAPET seismic from northeast CROSSLAND, to south of Dummer Range and to near Well 46, CORNISH. Southeast of this there has been insufficient seismic work to delineate the fault precisely but aeromagnetic evidence (AAO, 1972; AAP, 1972) and seismic work (AAR, 1974) have detected a major down-to-the-north southeast-trending fault on strike with the Dummer Range Fault system. It can be traced to 45 km northwest of the

Waterlander breakaway (STANSMORE, WEBB). The basement 'Swell' detected by early gravity and aeromagnetic surveys west of the Stansmore Range area (BEACH, 1965; HACKATHORN & A.O.C., 1963) is a possible extension of the Crossland Platform.

One other major fault was detected, the Tina Springs Fault, which trends parallel to the Dummer Range Fault, but south of it and is downthrown to the southwest.

In central-western HELENA, magnetic basement is from sea level to 1500 m below sea level.

Explanation of Surface Structures

Stresses causing right lateral regional coupling between major northwest-trending basement lineaments produced fractures with major down-to-basin displacement at intervals during the Palaeozoic (Rattigan, 1967). Such movements culminated during the Late Triassic or Early Jurassic with the generation of north-trending en echelon normal faults in the Fitzroy Trough, Gregory Sub-basin, Barbwire Terrace, and Betty Terrace and with the generation of a series of major east-trending en echelon anticlines in the Fitzroy Trough (Smith, 1968).

The Fitzroy Trough is separated from the Gregory Sub-basin by the Jones Rise, a basement high that is continuous with Precambrian outcrops at Bulka Hills (MOUNT BANNERMAN) and which continues northwards as part of the Halls Creek Mobile Belt. The Jones Rise, which terminates abruptly against the Fenton Fault, therefore trends at right angles to the large northwest-trending faults. The Rise may account for the absence of major east-trending surface folds in the Gregory Sub-basin in that it may have accommodated some of the movement necessary for generation of such structures. A feature supporting this possibility is the absence of small igneous intrusions in the Gregory Sub-basin. These are common in part of the Fitzroy Trough; their intrusion there may have been initiated by stronger deformation than in the Gregory Sub-basin. However, there is doubt on the age of these intrusions and therefore their relation to the Late Triassic or Early Jurassic movements is questionable. Also, the Triassic section in the Fitzroy Trough to the northwest is unconformable on the Permian Liveringa Group (Guppy et al., 1958). In the Gregory Sub-basin, the Permo-Triassic boundary is both conformable and disconformable. Therefore, the Jones Rise may be responsible for the difference.

GEOLOGICAL HISTORY

Sedimentation commenced in the Ordovician when the sea flooded the Precambrian basement of the area.

In the Early Ordovician, sands (Carranya Beds) were deposited near the northeast margin of this shallow sea within which invertebrates flourished. Marine sedimentation continued into mid-Ordovician time, during which time silt, mud, and carbonates (Goldwyer, Nita Formations) accumulated, some probably in coastal lagoons.

Evaporites, carbonate, clay, and sand (Carribuddy Formation) accumulated in playa lakes as evaporitic conditions became established when the sea regressed in the Late Ordovician. These conditions prevailed into the Early Devonian when sand, silt, and clay (Tandalgoo Redbeds) accumulated in much the same environment. During this time the area was periodically submerged by the sea, and carbonates were deposited.

By mid-Devonian time, carbonates were accumulating in the south (Mellinjerie Limestone) at about the same time that sand silt and clay (Poulton Formation) were being deposited in the north. During this time crustal stresses had built up and were relieved by earthquakes which generated movement along fractures now known as the Dummer Range Fault System, the Fenton Fault System, the Stansmore Fault, the Mueller Fault, and other faults. Minor folding accompanied these movement.

The Crossland Platform southwest of the Dummer Range Fault System emerged and may have formed a land area until the Late Carboniferous.

The area northeast of the Dummer Range Fault began to subside at a greater rate in the Gregory Sub-basin than in the flanking Barbwire Terrace and the Crossland Platform. The sea was apparently clear throughout Late Devonian time as carbonate deposition predominated except in the far northeast (Billiluna Shelf) where rivers spread sand (Knobby Sandstone). Fish thrived in the rivers and plants colonized the land.

In the Early Carboniferous, sand, silt, mud, and minor carbonate (Laurel Formation) accumulated, followed by more sand and mud (Anderson Formation) mainly in the Gregory Sub-basin.

By Late Carboniferous time, the depositional surface of the entire area was close to sea level and all areas except the Barbwire Terrace and the Billiluna Shelf

began to further subside. As subsidence proceeded, large quantities of sand and silt were deposited in the sea (Grant Formation). The sands eventually covered the Barbwire Terrace and also part of the Billiluna Shelf where rivers flowed. Mixed with sand at times was debris derived by glacial action; some large boulders accumulated on the muddy and sandy sea floor after release from ice rafts.

By late Sakmarian time, shallow seas with marginal coastal plains covered much of the area and sand (Poole Sandstone) was deposited on beaches, coastal plains, and in lagoons along the northeast margin. Rivers may have deposited sand on the Crossland Platform. Plants colonized the swampy areas in the north. Climatic conditions became gradually warmer than those that existed during deposition of the Grant Formation, and invertebrates and fish flourished in the warm shallow sea in which mud, silt, and lime accumulated (Noonkanbah Formation) by late Artinskian time. These conditions continued as terrigenous-derived sand and silt (Lightjack Formation) were deposited mostly north of the Dummer Range Fault System. South of the fault system, there was no known accumulation of sediment until the Jurassic.

The sea shallowed during deposition of the Lightjack Formation and burrowing invertebrates colonized muddy tidal flats and lagoons while sand was deposited on some beaches.

The sea gradually retreated northwestwards, and by the Late Permian sand and silt (Condren Sandstone) were being deposited in deltas and river channels, and on flood plains. Land plants thrived in a climate of warm summers and cool winters.

In the Tartarian, the sea entered the Gregory Subbasin and its immediate marginal areas as far south as the Stretch Range. Mud, silt, and sand were deposited and burrowing invertebrates flourished (Hardman Formation and Godfrey Beds). Subsidence accompanied deposition in northern CROSSLAND at this time, and similar sediments were deposited (Kirkby Range Member) in a very shallow sea which then retreated from the area for a short time. Rivers deposited sand (Hicks Range Sandstone Member) on this newly emerged land. The northern CROSSLAND area was again submerged, and with continued subsidence, mud, silt, and sand of the Cherrabun Member were deposited in the shallow sea that blanketed the earlier land area. Invertebrates flourished in these conditions. The sea regressed once again.

With little break in sedimentation southeast of the Jones Rise, but following minor movements in the Fitzroy Trough, rivers deposited sand (Millyit Sandstone) probably in the earliest Triassic. Plants colonized the land.

The sea entered the area soon after; it became confined to the Gregory Sub-basin and Betty Terrace. Mud, silt, and sand accumulated (Blina Shale) filling the shallow sea, which became a large brackish-water mudflat adjacent to areas of low topography landward. Invertebrates and fish thrived on mudflats. Plants colonized swamps which developed, and reptiles colonized the adjacent land.

Later in the Early Triassic, rivers prograded over the mudflat depositing sand (Erskine Sandstone) and the swamps gradually filled. Again, plants thrived.

River deposition continued in late Early to early mid-Triassic time when sand and silt (Culvida Sandstone) were deposited, at first in playa lakes and then in channels and on floodplains. The climate was probably warm at the time. Plants flourished.

During Late Triassic or Early Jurassic time, right lateral movement along the major northwest-trending faults produced a series of north-south trending fractures along which small folds were locally generated. In the Fitzroy Trough, long east-trending folds were generated. Small igneous plugs were also intruded (NOONKANBAH) but their age is not known. No such long fold axes nor intrusions developed in the Gregory Sub-basin. Uplift occurred close to the fault zones; some reverse movement may have taken place along the Fenton Fault as is thought to have happened northwest of the area.

Since the Late Triassic or Early Jurassic, erosion has been dominant except perhaps in the Late Jurassic and Early Cretaceous when rivers deposited sand and gravel in the extreme south of the area (Undivided Jurassic) and in the west (possible equivalents of the Callawa Formation) and in the northwest (Barbwire Sandstone), and when the sea entered the northwest of CROSSLAND and deposited the Jarlemai Siltstone in the Jurassic.

By the Late Cretaceous and Early Cainozoic much of the area had been reduced to a plain. At least one period of humid climate resulted in chemical weathering and laterite formation. Subsequent erosion of the laterite has produced mesa and butte topography; alluvial derivatives of the profile were deposited on the adjacent flats. Lateritic processes continue today in places.

During an arid phase which has persisted to the present, drainage became terminal and subterranean; rivers flooded out into large lakes such as Lake Gregory, into which fine-grained sediments were deposited (Lake Gregory Beds). Lime leached from the underlying formations was precipitated in drainage depressions (Lawford Beds and calcrete), in large lakes (calcrete), and in some soil profiles (as calcrete) that had developed on the soft-weathering Blina Shale, Lake Gregory Beds, and Noonkanbah Formation.

Sparseness of vegetation made alluvium susceptible to wind erosion; fine sediment was blown away as dust and coarse particles were left behind as sand and thin lag gravels to be buried mainly by fine red sand which spread over most of the area. Under the strong easterly wind, which prevails today, a system of mainly longitudinal sand dunes was produced.

On deflation flats developed over the soft-weathering Noonkanbah Formation and Blina Shale, and in areas of terminating drainage, claypans developed; in some, evaporites were deposited.

GROUNDWATER, PETROLEUM POTENTIAL AND MINERAL OCCURRENCES

Groundwater

Because of the prevailing arid climate, surface water is rare. Rainfall is transitory and erratic; average annual precipitation is probably less than 250 mm (Department of Minerals and Energy, 1973). There is a minimal run-off from the isolated low ranges and small rises. Evaporation greatly exceeds precipitation.

However, the groundwater potential of some areas is excellent. The present distribution and depth of waterbores has by no means adequately tested the reserves. An assessment of the potential of each rock unit is discussed below, beginning at the base of the sedimentary sequence.

The sandstones of the Ordovician Carranya Beds have not been tested for water. Though slightly silicified at the surface, these sandstones show some visible porosity and hence may form a local aquifer in the subsurface.

The limited petroleum exploration and stratigraphic wells drilled to date have indicated mainly saline water from most pre-Permian units encountered. However the Devonian Tandalgoo Redbeds contained fresh water in AQUITAINE Wilson Cliffs No. 1 (AAP, 1969c) to the south.

BMR Billiluna No. 3 (B1) encountered water in Upper Devonian Knobby Sandstone, but the quality and quantity is not known. The thick sequence of porous clean quartzose sandstone intersected is suitable for a freshwater aquifer.

Outcrops of medium to coarse quartzose sandstone units of the Grant Formation are extensive and are good aquifers. The Grant Formation has produced water at Billiluna homestead (Casey & Wells, 1964) and in BMR Billiluna No. 1 (Crowe, 1973; B2 this report) where the well tested the top 50 m of the Grant Formation near Mount Mueller. Fresh water rose to a depth of 40 m in the bore. Cores 3 and 4 gave high porosity and permeability determinations (Crowe, 1973). BMR Mt Bannerman Nos 3 and 4 also intersected the Grant Formation in the Mount Bannerman area, but instrument failure precluded an assessment of any water encountered in these bores. The following petroleum exploration and stratigraphic wells have intersected intervals in the Grant Formation which electric logs suggest contain fresh water: WAPET Crossland Nos 2 and 3 (WAPET, 1971c), AQUITAINE Point Moody No. 1 (AAP, 1966), and WAPET Lake Betty No. 1 (WAPET, 1972a). The Grant Formation is a good prospective source of fresh groundwater.

The overlying Poole Sandstone is also an excellent freshwater aquifer. It yielded fresh water in AQUITAINE Point Moody No. 1, STANSMORE (AAP, 1966), and WAPET Lake Betty No. 1, MOUNT BANNERMAN (WAPET, 1972a). Analyses of water from 2 bores drilled in the Poole Sandstone by Petty Ray Geophysical Inc. during their seismic survey for Associated Australian Resources in 1973 indicated that it as potable in the Southesk Tablelands (CORNISH) and Thornton Flat areas (HELENA) (AAR, 1974). The supply of fresh water at Balgo Mission is probably from Poole Sandstone.

The shale, siltstone, and thin fine-grained limestone of the Noonkanbah Formation are of low porosity and permeability, and of unsuitable lithology as aquifers. Any occurrence of water would be volumetrically small, and saline on account of high salt content in the formation. However, perched water tables may produce some freshwater. The Noonkanbah Formation provides confining beds for the underlying aquifers of the Poole Sandstone.

The Lightjack Formation throughout the area contains a fine-grained sandstone member along its outcrop on the southern flank of the Gregory Sub-basin and coarse sandstone units in the southeast of the area. These sandstone units could be considered potential reservoirs. Micha

Bore, LUCAS may have intersected another sandstone aquifer; the water quality from it is variable. The sandstone unit intersected between 97.5 m and 100.0 m in BMR Mt Bannerman No. 2 (B9) gave an electrical log response indicating relatively fresh water. The siltstone in the remainder of the Lightjack Formation, being similar to the Noonkanbah Formation, would be largely unprospective.

The Condren Sandstone contains a high percentage of quartzose sandstone with varying amounts of clay. The quality of its water is variable. Some of the bores near Lake Gregory homestead (LUCAS) possibly tap this formation. Electric log responses in BMR Mt Bannerman No. 1 (B8) and BMR Mt Bannerman No. 2 indicate relatively saline water. The most prospective parts of the Condren Sandstone would be in STANSMORE and southeast CORNISH where thick units of clean quartzose sandstone are present.

The overlying Hardman Formation is not a prospective source of fresh water. In CROSSLAND, the Hicks Range Sandstone Member is the most suitable rock type for an aquifer, but its known distribution in the area is above the water table. However, it may occur in the subsurface of the Fitzroy Trough, outside the area. The only area where its equivalent, the Godfrey Beds, lies beneath the water table is in the axial region of the Gregory Sub-basin in MOUNT BANNERMAN, LUCAS, and CORNISH, where its prospects for groundwater are unknown.

The Triassic Millyit Sandstone and Culvida Sandstone are prospective sources for groundwater.

The Millyit Sandstone, which crops out in LUCAS, CORNISH, CROSSLAND, and MOUNT BANNERMAN, was penetrated in BMR Lucas No. 13 (B11). Instrument failure precluded an assessment of the water intersected, but the clean quartzose sandstone appears most suitable for a freshwater aquifer. The fresh water known in Margies Bore, MOUNT BANNERMAN, may be tapping the Millyit Sandstone. The Millyit Sandstone in CROSSLAND occurs above the water table. The overlying Blina Shale provides confining beds for the aquifers of the Millyit Sandstone.

The shale, siltstone, and fine-grained sandstone of the Blina Shale are considered to be largely unprospective. The abandoned dud bores such as Betts Bore and Bobbys Bore (MOUNT BANNERMAN) testify to this.

The Erskine Sandstone, being quite silty, and mainly above the water table, is not considered to be a prospective source of groundwater in this area. It does,

however, provide freshwater in the Fitzroy Trough to the northwest of the area (Veevers & Wells, 1961).

The Culvida Sandstone is of excellent lithology for an aquifer. Reasonably fresh water was intersected in BMR Cornish No. 2. Potable seepage water occurs at Culvida Soak from which the name Culvida Sandstone was derived (Casey & Wells, 1964).

The Barbwire Sandstone (CROSSLAND) is above the water table.

The potential of the ?Jurassic sandstone unit at Newberry Peaks (DUMMER) is unknown. The potential of Mesozoic sandstone and conglomerate in southern HELENA is also unknown; these units, however, are aquifers in adjacent WILSON to the south (AAP, 1969c) where they are probably much thicker.

The Cainozoic alluvial and aeolian deposits contain aquifers at shallow depth in some areas. In calcrete on Billiluna, Lake Gregory, and Carranya stations, groundwater suitable for stock has been intersected at shallow depth. Wells, 49, 47, 46, and 45 on the now abandoned Canning Stock Route (CORNISH) produce water from calcrete at about 7 m. The water from these wells is potable. Calcrete, being permeable and cavernous and being restricted to old drainage depressions probably contains considerable quantities of water of generally good quality. Many pastoralists in this and neighbouring areas have drilled reliable bores for stock where bloodwood gums grow within areas of calcrete. The Lake Gregory Beds contain water of considerable salinity. Salinity in the Lake Gregory Beds is variable and partly depends on the level of water in Lake Gregory.

The Holocene alluvial deposits along Sturt Creek and parts of Christmas Creek contain near-surface supplies of water.

Any further developments in the use of groundwater should be restricted to areas down-dip from those outcrops of confined Permian and Triassic quartzose sandstones that can be intersected at reasonably shallow depths below the water table. The most prospective aquifers are in the Grant Formation, Poole Sandstone, Millyit Sandstone, Culvida Sandstone, and possibly the Upper Devonian Knobby Sandstone and Lower Devonian Tandalgoo Redbeds. Further supplies of variable quality water could be obtained from the large areas of calcrete, and from alluvial deposits along Sturt Creek and some parts of Christmas Creek.

TABLE 7. SUMMARY OF POROSITY-PERMEABILITY DATA FOR UNITS IN THE CROSSLAND PLATFORM

Age	Stratigraphic unit	Porosity	Permeability	Remarks
Mesozoic	Undivided	high	high	Unprospective; flushed with fresh water; deposited in oxidizing conditions
Lower Permian	Noonkanbah Formation	low	low	Potential cap rock
Lower Permian	Poole Sandstone	high	high	Excellent reservoir; flushed with fresh water
Upper Carboniferous to Lower Permian	Grant Formation	high	high	Potential reservoirs; flushed with fresh water; lacks generative shale
Middle Devonian	Mellinjerie Limestone	moderate	moderate	Porosity in sandstone reservoirs
Lower Devonian	Tandalgoo Redbeds	high	high	Potential reservoirs; flushed with fresh water; deposited mainly in oxidizing conditions
Silurian to ?Lower Devonian	Carribuddy Formation	low to moderate	moderate	Evaporitic; low source potential; some reservoir potential; if diapiric folding exists, it could provide suitable structure
Ordovician	Undivided - includes Goldwyer Formation and informally named units in Aquitaine Wilson Cliffs 1 and Aquitaine Contention Heights 1	low	low	Reasonable source potential; known sandstones lack good porosity and are water saturated; traces of methane recorded (AAP, 1969c; 1974)

Petroleum Potential

Crossland Platform

Porosity and permeability data for the stratigraphic units are summarized in Table 8.

The Ordovician sequence is the most prospective as it contains potential source rocks and cap rocks. Drilling outside the area has shown that it lacks reservoir rocks; if these could be found, the prospects of finding oil would be much greater.

The overlying Silurian Carribuddy Formation, being largely an evaporitic sequence deposited mainly in oxidizing conditions has low source potential. Diapiric folding, often typical of evaporite sequences, has yet to be demonstrated in the area; if found, it may provide suitable structures for petroleum to migrate into. Above the Carribuddy Formation is the Lower Devonian Tandalgoo Redbeds, another unit deposited under mainly oxidizing conditions, which is also probably unprospective. The overlying Mellinjerie Limestone has been demonstrated to contain potential sandstone reservoirs. However, it has low source potential and must be regarded as having little prospect in the area.

Though both the Grant Formation and Poole Sandstone are excellent reservoirs, they are flushed with fresh water and lack generative source rock units; much of the Permian, being fluvial or shallow marine, was probably deposited in oxidizing conditions. The Noonkanbah Formation, though it contains abundant carbonaceous matter, is tight and has only cap rock potential. The Mesozoic sandstones and conglomerates in the extreme south of the area are weathered and may be flushed with fresh water; they are unprospective.

The Crossland Platform is a broad regional basement 'high' bounded to the northeast by the Dummer Range Fault System. On this Platform, Phanerozoic units dip at a very low angle (the Permian units - possibly depositional dip) to the southwest. These sedimentary rocks continue into the Kidson Sub-basin probably outside the area where the sedimentary sequence is thicker. No anticlinal structures have been found following seismic surveys; it follows that if oil exists in these areas, it would most likely be confined to stratigraphic traps. The Ordovician probably has the best source potential and a search for reservoirs in this sequence is recommended.

Much oil prospecting in the Canning Basin has been based on the assumption that equivalents of the Upper Devonian carbonates, supposedly reefs, of the Lennard Shelf (to the northwest of the area) occur in the subsurface. In the Crossland Platform, no rocks of this age or of 'reef' lithology are known from the area, nor are Carboniferous rocks older than the base of the Grant Formation.

Gregory Sub-Basin and adjacent Betty Terrace and Barbwire Terrace

Porosity and permeability data for the stratigraphic units are summarized in Table 9.

As in the Crossland Platform, the Ordovician has prospects. Small shows were encountered in several shallow drill holes in the Prices Creek Group to the north of the area; basinal equivalents of these carbonates, if they occur in the subsurface of the area, would be potential source rocks. Little is known of the Ordovician in the subsurface of the area as it has not been drilled. The relation of the potential reservoir sandstones of the Carranya Beds to the subsurface units is also unknown. Within the Gregory Sub-basin, the top of the Ordovician has been interpreted at depths between 5000 and 6000 m which at present are considered too deep to warrant active exploration.

The unprospective Carribuddy Formation has been interpreted by the Basin Studies Group (BMR) to lie on the Ordovician. The relations between this unit and known younger units is uncertain. At the base of WAPET Lake Betty No. 1, a unit called the Poulton Formation has been dated Lower to Middle Devonian. It and the overlying non-marine Upper Devonian Luluigui Formation (WAPET, 1972a), a possible equivalent of the Knobby Sandstone, are both non-prospective. The objective Upper Devonian carbonate sequence is 'faulted out' at this locality (WAPET, 1972a). Upper Devonian carbonate sequences intersected in WAPET Crossland Nos 1 and 3 on the Barbwire Terrace have encouraging reservoir potential and could be prospective in suitable structures. During the deposition of these carbonates, it is likely that a shoreline existed to the south in the approximate position of the Dummer Range Fault. Further prospecting for carbonates similar to those on the Lennard Shelf is recommended; the Barbwire Terrace lies in an ideal structural position. On the other side of the Gregory Sub-basin the known Upper Devonian unit of the Billiluna Shelf has non-marine terrigenous affinities but it may merge laterally into more prospective marine rocks in the Gregory Sub-basin.

The Devonian is capped by a Carboniferous sequence which includes both the Laurel and the Anderson Formations, both of which contain ideal cap rock sequences. These units, or their equivalents, are not known in the Crossland Platform. The Laurel Formation has some source rock potential; its prospects would improve if reservoir sandstones were to be located.

The Permo-Triassic units which crop out extensively at the surface are not considered very prospective in this area. Though some units have good reservoir potential, they were deposited under oxidizing conditions. The Noonkanbah Formation would, however, be of cap rock potential.

Structurally, the Gregory Sub-basin is bounded on both sides by fault-bound terraces which are structurally higher. Regional dips are towards the axis of the Gregory Sub-basin; this could allow any oil generated in the Gregory Sub-basin to migrate into structurally higher positions. Accordingly, the Barbwire Terrace and Betty Terrace are perhaps in the most prospective structural position; prospects would improve if Devonian carbonate reservoirs could be located within the prospective source rock sequences, already indicated from scanty drilling (see WAPET, 1971c). Folding indicated from seismic surveys in the Gregory Sub-basin and its marginal terraces is of suitable amplitude and closure for anticlinal traps. Together with the stratigraphic trap potential of the terraces, and the possibility of finding Devonian carbonate reservoirs, the margins of the Gregory Sub-basin appear the most prospective areas for finding petroleum in the area.

Rocks rich in Iron, Phosphorus, and Manganese

Impersistent beds of sedimentary ironstone and phosphatic ironstone occur in the Noonkanbah and Lightjack Formations near Balgo Mission, but thick beds are unlikely to be present. The iron is present in the ochreous form goethite; analyses revealed values of up to 55% Fe_2O_3 (Table 9). Two ochreous rocks contained fluorapatite and yielded 12.6 and 13.7% P_2O_5 (Table 9). Other samples yielded lesser amounts of P_2O_5 but these were considerably in excess of usual P_2O_5 values for detrital sedimentary rocks. Concretions of ochreous goethite containing similar percentages of iron oxide to the beds (Table 9) occur at intervals in both these formations.

Another phosphatic bed found in the Blina Shale near Lake Jones (MOUNT BANNERMAN) yielded 15.6% P_2O_5. The phosphate is present as apatite in fossil vertebrate bones in an intraformational conglomerate. The bone bed is 5 cm

TABLE 8. SUMMARY OF POROSITY-PERMEABILITY DATA FOR UNITS IN THE GREGORY SUB-BASIN AND ITS ADJACENT TERRACES

Age	Stratigraphic Unit	Porosity	Permeability	Remarks
Middle Triassic	Culvida Sandstone	high	high	Contains redbed sequence deposited mainly in oxidizing conditions; reservoirs flushed with fresh water
Lower Triassic	Erskine Sandstone	moderate	moderate	Deposited mainly in oxidizing conditions; exposed and weathered in most localities
Lower Triassic	Blina Shale	low	low	Potential source rock and cap rock sequence. Exposed and weathered in much of this area
Lower Triassic	Millyit Sandstone	high	high	Potential reservoir; flushed with fresh water
Upper Permian	Hardman Formation	variable	variable	Occurs mainly above water table and hence is weathered
Upper Permian	Condren Sandstone	moderate	moderate	Possible reservoir potential, though reservoirs water-saturated
Lower to ?Upper Permian	Lightjack Formation	variable	variable	Reservoirs water-saturated
Lower Permian	Noonkanbah Formation	low	low	Potential cap rock; possible source rock

TABLE 8. (Continued)

Age	Stratigraphic Unit	Porosity	Permeability	Remarks
Lower Devonian to Upper Devonian	Undivided - includes unnamed carbonate sequences in WAPET Crossland Nos 1 and 3 (WAPET, 1971) Poulton and Lulu igui Formations in WAPET Lake Betty No. 1 (WAPET, 1972).	low, but moderate in places	generally low	Potential if reef carbonates in sequences; Barbwire Terrace is in most suitable structural position; possible cap rock sequence
?Upper Ordovician to ?Lower Devonian	Carribuddy Formation	-	-	Characteristics unknown; interpreted in subsurface from seismic data
Lower Ordovician	Carranya Beds	moderate	moderate	Potential reservoir, but may be water-saturated
Lower Ordovician	Prices Creek Group	variable	variable	Has yielded several small shows from several wells north of the area; equivalent units in subsurface have good source potential; search for reservoirs is recommended, especially in areas marginal to Gregory Subbasin where depth to Ordovician is not as great
Ordovician	Undivided	-	-	Characteristics unknown; interpreted in subsurface from seismic data; if time equivalents of other Ordovician units, these rocks may have source potential

TABLE 8. (Continued)

Age	Stratigraphic Unit	Porosity	Permeability	Remarks
Lower Permian	Poole Sandstone	high	high	Excellent reservoir; flushed with fresh water
Upper Carboniferous to Lower Permian	Grant Formation	variable	variable	Excellent reservoir sandstone but flushed with fresh water. Abundant shale units of possible source potential; traces of gas associated with lignite in AQUITAINE Point Moody 1 (AAP, 1966)
Carboniferous	Anderson Formation	low	low	Clay matrix and silicification in sandstones, which otherwise may be potential reservoirs. (AAP, 1966)
Lower Carboniferous	Laurel Formation	low	low	Potential source rock unit; show of gas in WAPET Lake Betty No. 1 (WAPET, 1972a); prospects would improve if reservoir sandstones were located in the unit
Upper Devonian	Knobby Sandstone	high	high	Potential reservoir, but likely to be flushed with fresh water; time equivalent of Lennard Shelf carbonates

TABLE 9. CHEMICAL ANALYSES OF ROCKS RICH IN IRON, PHOSPHORUS, AND MANGANESE

SAMPLE	72130081	72130082	72130083	72130084	72130085	72130086	73120016
SiO_2	14.2	27.5	15.7	14.0	12.9	19.8	12.87
Al_2O_3	5.6	7.8	5.6	6.6	5.3	4.7	4.90
Fe_2O_3	65	49	70	37	30	60	59.67
FeO	-	-	-	-	-	-	0.05
CaO	0.73	0.64	0.47	19.8	24.7	0.39	0.11
MgO	0.83	0.67	0.1	0.32	1.25	0.52	1.84
Na_2O	0.03	0.03	0.03	0.03	0.03	0.03	0.42
K_2O	0.25	0.36	0.21	0.45	0.45	0.22	0.68
TiO_2	0.28	0.52	0.30	0.28	0.20	0.25	0.25
MnO	0.71	1.02	0.50	0.37	0.22	0.81	1.34
P_2O_5	0.53	0.53	0.53	12.6	13.7	0.42	0.13
H_2O+	-	-					10.74
H_2O-	-	-					4.50
L.O.I.	12.0	11.7	6.1	8.7	10.9	12.4	-
TOTAL	100.1	99.7	99.4	100.1	99.6	99.5	97.45

TABLE 9. (Continued)

SAMPLE	73120017	73120038	731200176	73121067	73121575	73122021
SiO_2	18.42	29.47	41.11	55.98	54.67	20.07
Al_2O_3	7.30	6.47	6.73	12.36	6.52	2.68
Fe_2O_3	2.21	50.88	28.44	22.72	27.01	28.43
FeO	0.81	0.13	0.05	0.35	0.24	0.05
CaO	35.81	0.44	0.75	0.07	1.01	21.26
MgO	1.14	0.16	0.33	0.12	0.40	0.45
Na_2O	0.22	0.03	0.10	0.01	0.08	0.65
K_2O	1.14	0.36	1.39	0.36	2.06	0.67
TiO_2	0.31	0.33	0.66	0.52	0.77	0.25
MnO	0.63	0.22	9.61	0.05	0.10	1.35
P_2O_5	3.14	1.87	0.39	0.05	0.33	15.56
H_2O^+	2.21	8.74	5.18	5.83	5.09	4.64
H_2O^-	0.85	0.32	0.90	0.72	0.36	0.66
L.O.I.	-	-	-	-	-	-
TOTAL	74.18	99.42	95.58	99.14	98.64	99.06

TABLE 9. (Continued)

SAMPLE NUMBER	D E S C R I P T I O N
72130081	ochreous ironstone, Lightjack Formation, near Micha Bore, LUCAS
72130082	ochreous ironstone, Lightjack Formation, near Micha Bore, LUCAS
72130083	hematite-bearing siltstone, Lightjack Formation, near Micha Bore, LUCAS (Ferruginization by weathering)
72130084	phosphatic ironstone, Lightjack Formation, near Micha Bore, LUCAS
72130085	phosphatic ironstone, Noonkanbah Formation, near Balgo Mission, LUCAS
72130086	ochreous ironstone, Lightjack Formation, near Micha Bore, LUCAS
73120016	ochreous concretion, Noonkanbah Formation, Salt Creek, MOUNT BANNERMAN
73120017	calcareous concretion, Noonkanbah Formation, Salt Creek, MOUNT BANNERMAN
73120038	bone bed, Blina Shale 4 km northwest of Bobbys Bore, MOUNT BANNERMAN
73120176	manganese-rich concretion, Lightjack Formation, Roberts Range, CORNISH
73121067	pisolitic laterite, near Christmas Creek, MOUNT BANNERMAN
73121575	ochreous concretion, Noonkanbah Formation, about 8 km south of Scrivener Hills, CROSSLAND
73122021	bone bed, Blina Shale, Lake Jones, MOUNT BANNERMAN

thick and appears to be restricted to two localities - Lake Jones and a mesa 4 km northwest of Bobbys Bore (MOUNT BANNERMAN).

One concretion from the widespread regional marker bed of fossiliferous concretionary ironstone at the base of the Lightjack Formation yielded 9.6% MnO. The concretionary layer, which is generally less than 50 cm thick, occurs throughout the area. Near Balgo Mission (LUCAS) and east of AQUITAINE Point Moody No. 1 (STANSMORE) the base of the Lightjack Formation is characterized by more than one concretionary bed.

Coal

Coal seams less than 10 cm thick are present in the basal part of the Condren Sandstone in extreme northwest MOUNT BANNERMAN, where they are interbedded with thinly bedded quartzose sandstone and plant-bearing siltstone.

Seams could also be present in the Poole Sandstone around the northern edge of its outcrop in BILLILUNA and MOUNT BANNERMAN. Shallow stratigraphic drilling in this region to date has only intersected carbonaceous shales from this unit. Elsewhere in the Gregory Sub-basin and Betty Terrace the Poole Sandstone appears to have been deposited in a marine (largely intertidal) environment and would be unprospective for coal.

Evaporites

Evaporite deposits consisting of gypsum, halite, and caliche are confined to some dry lakes in STANSMORE, WEBB, HELENA, and DUMMER and also to the margins of Lake Gregory (LUCAS and CORNISH).

In the subsurface, halite and gypsum occur in the Silurian Carribuddy Formation in the Crossland Platform.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance and cooperation extended to the field party by the staff of Balgo Mission, and "Billiluna", "Carranya", "Christmas Creek", and "Cherrabun" cattle stations.

Geologists of Mines Administration Ltd took part in valuable discussions of field problems while mapping part of the area in 1972 and 1973. In addition, they examined drill cores and selected surface samples submitted for palynological study.

Mrs Mary White identified floras collected.

The Basin Studies Group of BMR gave assistance with compilation of the subsurface data.

The Royal Flying Doctor Service, Derby, transmitted radio messages for the field party.

Drilling was carried out by a BMR drilling team. Cores cut usually had 100% recovery. The drilling has now enabled the setting up of a biostratigraphic sub-division of the Permian and Triassic in the area for the first time.

While under contract to BMR, staff of Jayrow Helicopters (in 1972) and Helicopter Operators (in 1973) provided efficient service while flying in remote parts of the area.

REFERENCES

ALLEN, J.R.L., 1963 - The classification of cross-stratified units with notes on their origin. Sedimentology, 1, 93-114.

ASSOCIATED AUSTRALIAN OILFIELDS N.L., 1972 - Billiluna-Helena aeromagnetic survey (unpubl. Co. Rep.).

ASSOCIATED AUSTRALIAN RESOURCES N.L., 1974 - Thornton seismic survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1966 - AQUITAINE Point Moody No. 1, well completion report. (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1968 - Dakota seismic and gravity survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969a - Terry Range magneto-telluric survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969b - Ryan seismic and gravity survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969c - AQUITAINE Wilson Cliffs No. 1, well completion report (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969d - Contention Heights seismic refraction survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1971 - Stretch Range seismic and gravity survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1972 - White Hills area high sensitivity aeromagnetic survey (unpubl. Co. Rep.).

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1974 - Contention Heights No. 1, well completion report (unpubl. Co. Rep.).

AUSTRALIAN CODE OF STRATIGRAPHIC NOMENCLATURE, 1973 - J. geol. Soc. Aust., 20(1), 105-12.

BALME, B.E., 1969 - The Permian-Triassic boundary in Australia. Spec. Publ. geol. Soc. Aust., 2, 19-112.

BALME, B.E., 1969 - The Triassic System in Western Australia. APEA, J. 1969(II), 67-78.

BEACH PETROLEUM N.L., 1965 - Stansmore Ranges gravity survey (unpubl. Co. Rep.).

BLAKE, D.H., HODGSON, I.M., & MUHLING, P.L., 1973 - Geology of the Granites and Precambrian parts of the Billiluna, Lucas, and Stansmore 1:250 000 Sheet areas, Northern Territory and Western Australia. Bur. Miner. Resour. Aust. Rec. 1973/71 (unpubl.).

BLAKE, D.H., & TOWNER, R.R., 1974 - Geology of the Webb 1:250 000 Sheet area, Western Australia. Bur. Miner. Resour. Aust. Rec. 1974/53 (unpubl.).

BORCHERT, H., 1960 - Genesis of marine sedimentary iron ores. Trans. Inst. Min. Metal., London, 69, 261-79.

BREMMER, C. St. J., 1940 - Aerial geological reconnaissance of the Fitzroy Desert Basin, Western Australia (unpubl. Co. Rep.). Caltex (Aust.) Oil Development Pty Ltd.

BREMMER, C. St. J., 1942 - Aerial reconnaissance of the south margin of the Fitzroy Basin, Western Australia (unpubl. Co. Rep.). Caltex (Aust.) Oil Development Pty Ltd.

BROWN, G.A., 1959 - Desert dune sands from the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1959/82 (unpubl.).

BRUNNSCHWEILER, R.O., 1954 - Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. J. geol. Soc. Aust., 1, 35-54.

BRUNNSCHWEILER, R.O., & DICKINS, J.M., 1954 - Pre-Permian, probably Devonian, plants from near Gregorys Salt Sea, Western Australia. Bur. Miner. Resour. Aust. Rec. 1954/27 (unpubl.).

CARNEGIE, D.W., 1898 - SPINIFEX AND SAND. London, Pearson.

CASEY, J.N., & NELLIGAN, P.F., 1956 - Land classification and new geographical names in the northeast part of the Canning Basin, W.A. Bur. Miner. Resour. Aust. Rec. 1956/106 (unpubl.).

CASEY, J.N., & WELLS, A.T., 1956 - Operational problems and conditions in the north-east Canning Basin, W.A. Bur. Miner. Resour. Aust. Rec. 1956/93 (unpubl.).

CASEY, J.N., & WELLS, A.T., 1960 - Regional geology of the north-east Canning Basin, Western Australia, Bur. Miner. Resour. Aust. Rec. 1960/110 (unpubl.).

CASEY, J.N., & WELLS, A.T., 1964 - The geology of the north-east Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 49.

COMPAGNIE GENERALE DE GEOPHYSIQUE, 1974 - Poole Range seismic survey. Bur. Miner. Resour. Aust. Rec. 1974/43 (unpubl.).

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1965a - St George's Range reconnaissance seismic project, (unpubl. Co. Rep.).

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1965b - Poole Range detail Vibroseis project (unpubl. Co. Rep.).

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1965c - Broome Swell area seismic survey (unpubl. Co. Rep.).

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1966a - Crossland area seismic survey (unpubl. Co. Rep.).

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1966b - Barbwire Range area seismic survey (unpubl. Co. Rep.).

CONYBEARE, C.E.B., & CROOK, K.A.W., 1968 - Manual of sedimentary structures. Bur. Miner. Resour. Aust. Bull. 102.

CROCKFORD, J., 1957 - Permian Bryozoa from the Fitzroy Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 34.

CROWE, R.W.A., 1973 - BMR Billiluna No. 1 stratigraphic test bore. Geol. Surv. W. Aust. Rec. 1973/13 (unpubl.).

DARBY, F., & FRASER, A.R., in press - Reconnaissance helicopter gravity survey, Canning Basin, W.A., 1968. Bur. Miner. Resour. Aust. Rec. 1969/37 (unpubl.).

DARBY, F., & VALE, K.R., 1969 - Progress of the reconnaissance gravity survey of Australia. Bur. Miner. Resour. Aust. Rec. 1969/110 (unpubl.).

DEPARTMENT OF MINERALS AND ENERGY, 1973 - ATLAS OF AUSTRALIAN RESOURCES, Second series. Canberra Division of National Mapping.

DICKINS, J.M., & JELL, P.A., 1974 - Permian fossils from the Canning Basin, 1971 and 1972. Bur. Miner. Resour. Aust. Rec. 1974/77 (unpubl.).

DICKINS, J.M. (in prep.) - Report on fossils collected in the northeast Canning Basin during 1973. Bur. Miner. Resour. Aust. Rec. (unpubl.).

DOW, D.B., & GEMUTS, I., 1967 - Dixon Range W.A. - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SE/52-6.

DOW, D.B., & GEMUTS, I., 1969 - Geology of the Kimberley region, Western Australia: the East Kimberley. Bur. Miner. Resour. Aust. Bull. 106.

DRUCE, E.C., RADKE, B.M., & NICOLL, R.S., (in prep.) - The Late Devonian and Early Carboniferous geology of the Lennard Shelf, Canning Basin, W.A. Bur. Miner. Resour. Aust. Bull.

DUNBAR, C.O., & RODGERS, J., 1963 - PRINCIPLES OF STRATIGRAPHY. N.Y., Wiley.

ELLIOTT, R.M.L., 1961 - New and amended formation names. Appendix 7, in WAPET 1961, Thangoo No. 1 and No. 1A Wells, Western Australia. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 14.

ELLIOTT, R.M.L., & ROBERTS, D.J., 1955 - Geology of the Crossland Sheet, Fitzroy Basin. Unpubl. Rep. for WAPET.

ELLIOTT, R.M., CASEY, J.N., & WELLS, A.T., 1958 - In McWhae et. al., 1958 - Stratigraphy of Western Australia. J. geol. Soc. Aust. 4(2), 1-161.

EVANS, G.R., & BROWN, L.N., 1974 - Report of the 1973 field mapping programme, Exploration Permits 58, 59 & 70 (W.A.) (unpubl. Co. Rep.). Mines Administration Ltd.

EVANS, H.J., 1948 - Memorandum on geological reconnaissance south and southwest of Pallotine Mission. Rep. for Frome-Broken Hill Pty Ltd. 2000 - G-20 (unpubl.).

FEEKEN, E.H.J., FEEKEN, G.E.E., & SPATE, O.H.K., 1970 - THE DISCOVERY AND EXPLORATION OF AUSTRALIA. Sydney, Nelson.

FERRAND, J., 1963 - Poole Range seismic survey 1962 - Discussion of the final report and analysis of some related problems (unpubl. Co. Rep.). Institut Francais du Petrole.

FLAVELLE, A.J., & GOODSPEED, M.J., 1962 - Fitzroy and Canning Basins, reconnaissance gravity surveys, Western Australia 1952-60. Bur. Miner. Resour. Aust. Rec. 1962/105 (unpubl.).

FOLK, R.L., 1971 - Longitudinal dunes of the northwestern edge of the Simpson Desert, Northern Territory, Australia: Part 1, Geomorphology and grain size relationships. Sedimentology, 16(1/2), 5-54.

FORMAN, D.J., WYBORN, L., KURYLOWICZ, L.E., PASSMORE, V.L., & MAYNE, S.J., 1973 - Summary of sedimentary basins in Australia and Papua New Guinea, 1973. Bur. Miner. Resour. Aust. Rec. 1973/98 (unpubl.).

GENTILLI, J., & FAIRBRIDGE, R.W., 1951 - PHYSIOGRAPHIC DIVISIONS OF AUSTRALIA. N.Y., Geographical Press, Columbia University.

GEWERKSCHAFT ELWERATH INC. 1968 - Yullero No. 1, well completion report (unpubl. Co. Rep.).

GLENNIE, K.W., 1970 - DESERT SEDIMENTARY ENVIRONMENTS, DEVELOPMENTS IN SEDIMENTOLOGY, No. 14. Amsterdam, Elsevier.

GOUDIE, A.S., 1972 - On the definition of calcrete deposits. Z. Geomorph., 14(4), 464-8.

GOUDIE, A., 1973 - DURICRUSTS IN TROPICAL AND SUBTROPICAL LANDSCAPES. Oxford, Clarendon Press.

GREGORY, A.C., 1857 - Papers relating to an expedition recently undertaken for the purpose of exploring the northern portion of Australia. Brit. parl. Pap., London.

GREGORY, A.C., 1898 - Appendix M, in Report by the Surveyor General for the year 1897, W. Aust. parl. Pap. II.

GROSS, W., 1971 - Unterdevonishe Thelodontier - und Acanthedin Schippen aus Westaustralien. Palaont. Z., 45(3/4), 97-106.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1952 - The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. XIX ieme Cong. geol. int. (Gondwana Symposium) Alger, 1952.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1958 - The geology of the Fitzroy Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 36.

HACKATHORN NEW ZEALAND OILS LTD & AUSTRALIAN OIL CORPORATION, 1963 - Stansmore Range aeromagnetic survey (unpubl. Co. Rep.).

HENDERSON, S.D., CONDON, M.A., & BASTIAN, L.V., 1963 - Stratigraphic drilling, Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 60.

JENNINGS, J.N., & MABBUTT, J.A., 1967 - LANDFORM STUDIES FROM AUSTRALIA AND NEW GUINEA. Canberra, ANU Press.

JONES, L.J., 1922 - A geological reconnaissance of Locke Oil Co. Lease 21H, Canning Basin W.A. Geol. Surv. W. Aust. File 121/22 (unpubl.).

KIDSON, E., 1921 - General magnetic survey of Australia and on an expedition over the Canning Stock Route, W.A., 1914. Carneg. Inst. Wash., Dep. terrest. Mag., 4, 164.

KOOP, W.J., 1966a - Sahara No. 1 well, stratigraphic nomenclature. Appendix 1 in WAPET 1966, Sahara No. 1 Well. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 80.

KOOP, W.J., 1966b - Recent contributions to Palaeozoic geology in the south Canning Basin, Western Australia. APEA. J., 105-9.

KRAUS, P.S., 1941 - Geologic and stratigraphic reconnaissance, northwest portion Caltex Concession 7-H, Kimberley Division, Western Australia. Rep. for Caltex (Aust.) Oil Development Pty Ltd (unpubl.).

KREIG, G.W., JACKSON, M.J., & VAN DE GRAAFF, W.J.E., (in press) - Officer Basin in Aust. Inst. Min. Met., The Geology of Australia and Papua and New Guinea, Petroleum Volume.

LONSDALE, G.F., & FLAVELLE, A.J., 1968 - Amadeus and south Canning Basins gravity survey, Northern Territory and Western Australia, 1962. Bur. Miner. Resour. Aust. Rep. 133.

McCOY, F., 1874 - Prodromus of the palaeontology of Victoria. Geol. Surv. Vic., 1(37).

MACKAY, D.F., 1934 - The Mackay aerial survey expedition, Central Australia, May - June. Geogr. J., 84(6), 511-14.

McTAVISH, R.A., In PLAYFORD et al., in press - Geology of Western Australia. Geol. Surv. W. Aust. Mem. 2.

McWHAE, J.R.H., PLAYFORD, P.E., LINDNER, A.W., GLENISTER, B.F., & BALME, B.E., 1958 - The stratigraphy of Western Australia. J. geol. Soc. Aust., 4(2).

MADDOX, W.H., 1941 - A geological reconnaissance of the north-eastern part of the Fitzroy Basin, Western Australia. Rep. for Caltex (Aust.) Oil Development Co. Pty Ltd (unpubl.).

PATEN, R.J., McDONAGH, G.P., BROWN, L.N., & EVANS, G.R., 1972a - Tenement review and report of the 1971 field mapping programme, E.P. 58 and 59, W.A. (unpubl. Co. Rep.) Mines Administration Pty Ltd Rep. WA/EP 58, 59/491.

PATEN, R.J., EVANS, G.R., & BROWN, L.N., 1972b - Exploration Permits E.P. 58 and 59 (W.A.) Report on the 1972 field mapping programme. (unpubl. Co. Rep.) Mines Administration Pty Ltd.

PETTIJOHN, F.J., 1957 - SEDIMENTARY ROCKS, 2nd edition. N.Y. Harper & Row.

PLAYFORD, P.E., 1971 - Petroleum exploration in Western Australia, past, present and future. J. Roy. Soc. W. Aust. 54(1), 1-13.

PLAYFORD, P.E., COPE, R.N., LOW, C.H., COCKBAIN, A.E., & LOWRY, D.C., in press - Geology of Western Australia. Geol. Surv. W. Aust. Mem. 2.

PLUMB, K.A., & DERRICK, G.M., 1973 - Geology of the Proterozoic Rocks of Northern Australia. Bur. Miner. Resour. Aust. Rec. 1973/207 (unpubl.).

PLUMB, K.A., & VEEVERS, J.J., 1971 - Cambridge Gulf - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes. SD/52-14.

QUILTY, J.H., 1960 - Canning Basin aeromagnetic reconnaissance survey, W.A. 1954 - Bur. Miner. Resour. Aust. Rec. 1960/11 (unpubl.).

RATTIGAN, J.H., 1967 - Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia. Australas. Inst. Min. Metall. Proc., 223, 17-22.

REEVES, F., 1949 - Geology and oil prospects of the Desert Basin W.A. (unpubl. Co. Rep.) Vacuum Oil Company.

REEVES, F., 1951 - Australian oil possibilities. Am. Assoc. Petrol. Geol. Bull., 35(12), 1479.

RETALLACK, G.J., 1974 - Report on plant fossils from Culvida Soak: Appendix 1(c). In Evans, G.R. & Brown, L.N., 1974 - Report on the 1973 field mapping program Exploration Permits 58, 59 & 70 (W.A.) Unpubl. Rep. for Mines Administration Ltd.

ROBERTS, H.G., HALLIGAN, R., & PLAYFORD, P.E., 1968 - Mount Ramsay, Western Australia - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SE/52-9.

SMITH, J.G., 1968 - Tectonics of the Fitzroy wrench trough. W.A. Am. J. Sci., 266, 766-76.

STANTON, R.L., 1972 - ORE PETROLOGY. N.Y. McGraw-Hill.

TALBOT, H.W.B., 1910 - Geological observations in the country between Wiluna, Halls Creek, and Tanami. Geol. Surv. W. Aust. Bull., 39, 1-88.

TALBOT, H.W.B., 1927 - in Blatchford, T., - The geology of portions of the Kimberley District, with special reference to the Fitzroy Basin and the possibilities of the occurrences of mineral oil. Geol. Surv. W. Aust. Bull. 93.

TANNER, W.F., 1967 - Ripple mark indicies and their uses. Sedimentology, 9, 89-104.

TAYLOR, J.K., 1966 - Soils. In The Australian Environment. CSIRO, Melbourne Univ. Press., 29-44.

TERRY, M., 1925 - ACROSS UNKNOWN AUSTRALIA. London, Jenkins.

TERRY, M., 1927 - THROUGH A LAND OF PROMISE. London, Jenkins.

TERRY, M., 1934 - Explorations near the border of Western Australia. Geogr. J., 84(6), 498-510.

TERRY, M., 1937 - SAND AND SUN. London, Michael Joseph.

TERRY, M., 1957 - The Canning Basin of Western Australia. Geogr. J., 123(2), 157-66.

THOMAS, G.A., 1958 - Permian Orthotetacea from Western Australia. Bur. Miner. Resour. Aust. Bull. 39.

THOMAS, G.A., & DICKINS, J.M., 1954 - Correlation and age of the marine Permian formations of Western Australia. Aust. J. Sci., 16(6), 219-23.

TOMLINSON, Joyce G., 1968 - A new record of Bothriolepis in the Northern Territory of Australia. In Palaeontological Papers, 1965. Bur. Miner. Resour. Aust. Bull. 80.

TOTAL EXPLORATION PTY LTD, 1968 - McLarty No. 1, well completion report. (unpubl. Co. Rep.).

TRAVES, D.M., CASEY, J.N., & WELLS, A.T., 1956 - The geology of the south-western Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 29.

VEEVERS, J.J., 1957 - Operation of the 1957 Canning Basin party. Bur. Miner. Resour. Aust. Rec. 1957/90 (unpubl.).

VEEVERS, J.J., 1962 - Rhizocorallium in the Lower Cretaceous rocks of Australia. In Bur. Miner. Resour. Aust. Bull. 62.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 60.

VEEVERS, J.J., ROBERTS, J., WHITE, Mary, E., & GEMUTS, I., 1967 - Sandstone of probable Lower Carboniferous age in the north-eastern Canning Basin, W.A. Aust. J. Sci., 299, 330-1.

WADE, A., 1924 - Petroleum prospects, Kimberley district, Western Australia and Northern Territory. Aust. parl. Pap.

WADE, A., 1936 - The geology of the West Kimberley district of Western Australia. Final Rep. by Freney Kimberley Oil Co. Perth (unpubl.).

WARBURTON, P.E., 1875 - JOURNEY ACROSS THE WESTERN INTERIOR OF AUSTRALIA. London, Sampson Low.

WELLS, A.T., 1960 - Mount Bannerman, W.A. - 4-Mile Geological Series. Bur. Miner. Resour. Aust. explan. Notes SE52-14.

WELLS, A.T., 1962a - Billiluna, W.A. - 4-Mile Geological Series. Bur. Miner. Resour. Aust. explan. Notes SE52-14.

WELLS, A.T., 1962b - Lucas, W.A. - 4-Mile Geological Series. Bur. Miner. Resour. Aust. explan. Notes. SF52-2.

WELLS, A.T., 1962c - Stansmore, W.A. - 4-Mile Geological Series. Bur. Miner. Resour. Aust. explan. Notes SF52-6.

WELLS, A.T., 1962d - Cornish, W.A. - 4-Mile Geological Series. Bur. Miner. Resour. Aust. explan. Notes. SF52-1.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1961 - Thangoo No. 1 and No. 1A wells, Western Australia. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 14.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1962 - Meda No. 1, well completion report. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. No. 7.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1963 - South Canning Basin aeromagnetic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1964a - Lake Betty reconnaissance gravity survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1964b - Johanna Spring gravity survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1964c - Balgo-Lake Betty seismograph survey. (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966a - South Canning Basin aeromagnetic survey, Western Australia, 1962-1963. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 72.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966a - Sahara No. 1, well completion report. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 80.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966b - Betty detail seismic project (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966c - Kidson No. 1, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1967 - May River No. 1, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1968 - Blackstone No. 1, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1970a - Helena (267) reconnaissance seismic project (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1970b - Lake Betty (269) detail/reconnaissance seismic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1971a - Crossland (268) reconnaissance seismic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1971b - Crossland Platform (304) seismic project (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1971c - Crossland Nos 1, 2 and 3, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1972a - Lake Betty No. 1, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1972b - Barbwire No. 1, well completion report (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1972c - Dampier Downs (331) - Collins (336) seismic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1972d - East Canning seismic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1973 - Crosslands 3 (358) seismic survey (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1974a - Jones Range (364) and Hall Range (370) seismic project (unpubl. Co. Rep.).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1974b - Barbwire 2 (361) seismic survey (unpubl. Co. Rep.).

WHITE, Mary E., 1957 - Report on plant fossils from the northeast Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1957/74 (unpubl.).

WHITE, Mary E., & YEATES, A.N., in prep. - Report on 1972 and 1973 collections of plant fossils from the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec.

WHITWORTH, R., 1970 - Reconnaissance gravity survey of parts of Northern Territory and Western Australia, 1967. Bur. Miner. Resour. Aust. Rec. 1970/15 (unpubl.).

WOOLNOUGH, W.G., 1927 - Presidential address. Part 1 - The chemical criteria of peneplanation; Part 2 - The duricrust of Australia. J. Roy. Soc. NSW, 61, 17-53.

WOOLNOUGH, W.G., 1933 - Report on aerial survey operations in Australia during 1932. Canberra, Aer. geol. geophys. surv. N. Aust.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, Lesley, A.I., & PASSMORE, Virginia, L., in press - New and revised stratigraphic nomenclature, northeast Canning Basin, Western Australia. Geol. Surv. W. Aust. Ann. Rep. for 1974.

YOUNG, G.C., (in press) - Stratigraphic occurrence of some Placoderm fishes in the Middle and Late Devonian. Newsletters on Stratigraphy.

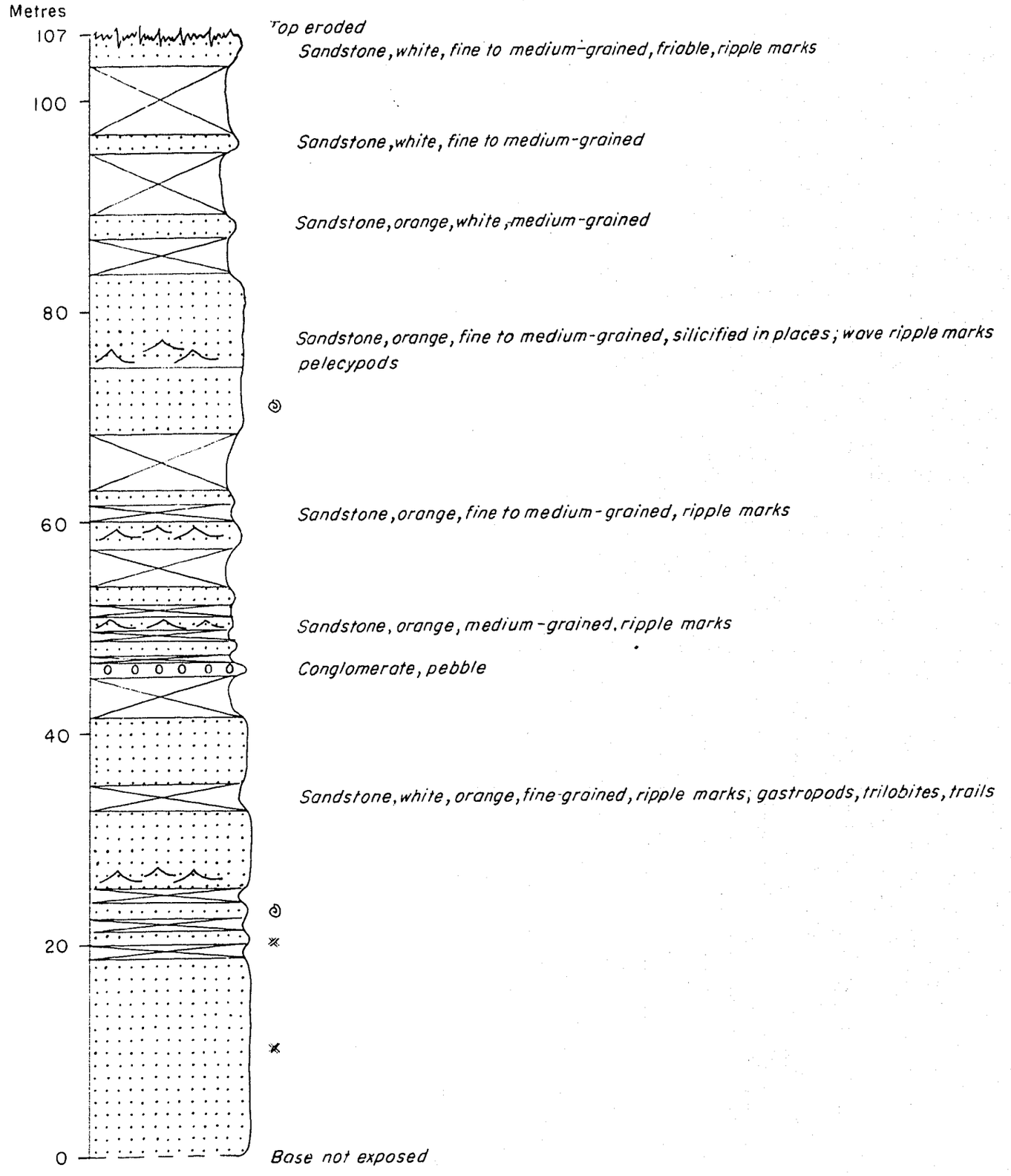


Fig.A1. Type Section of the Carranya Beds

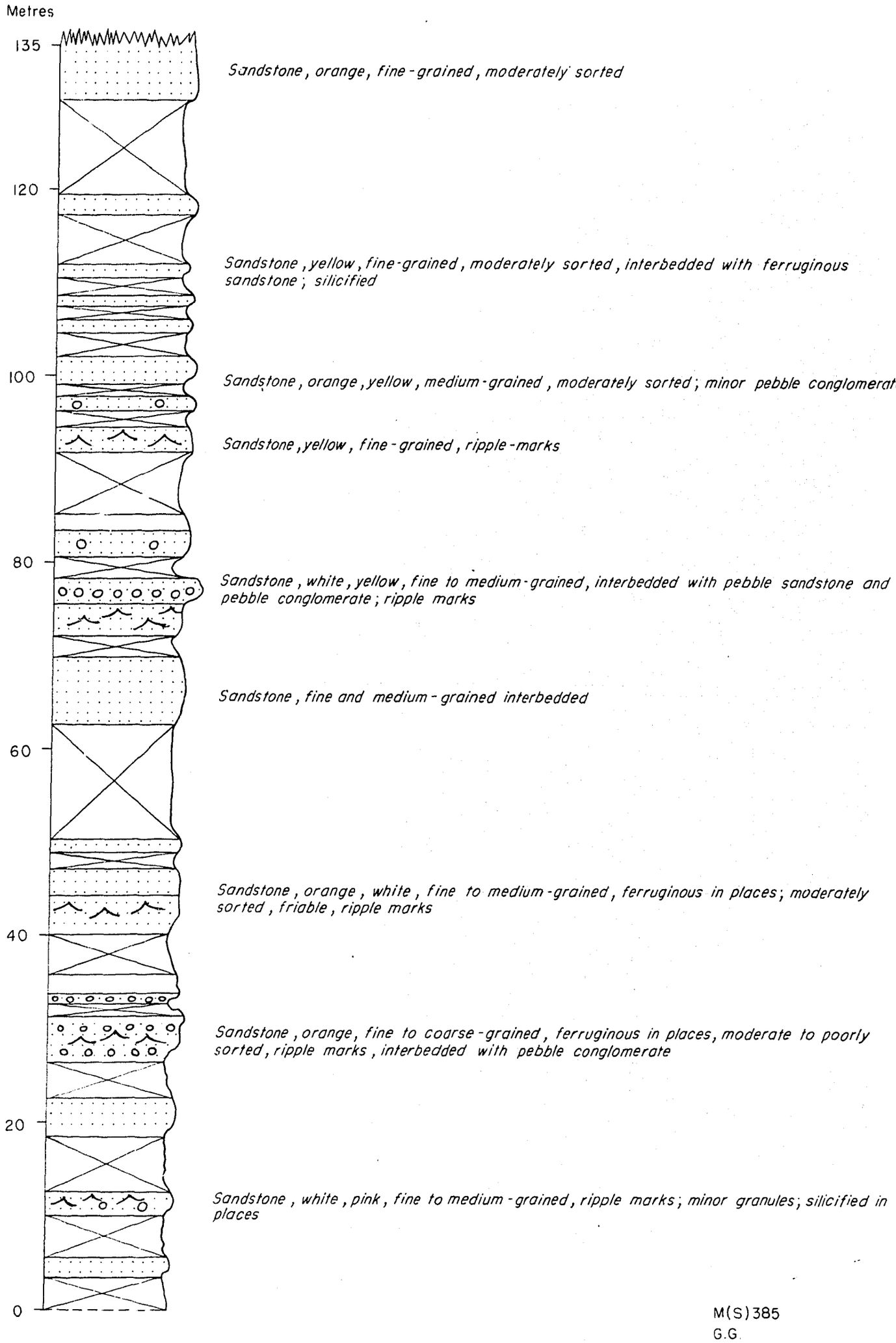
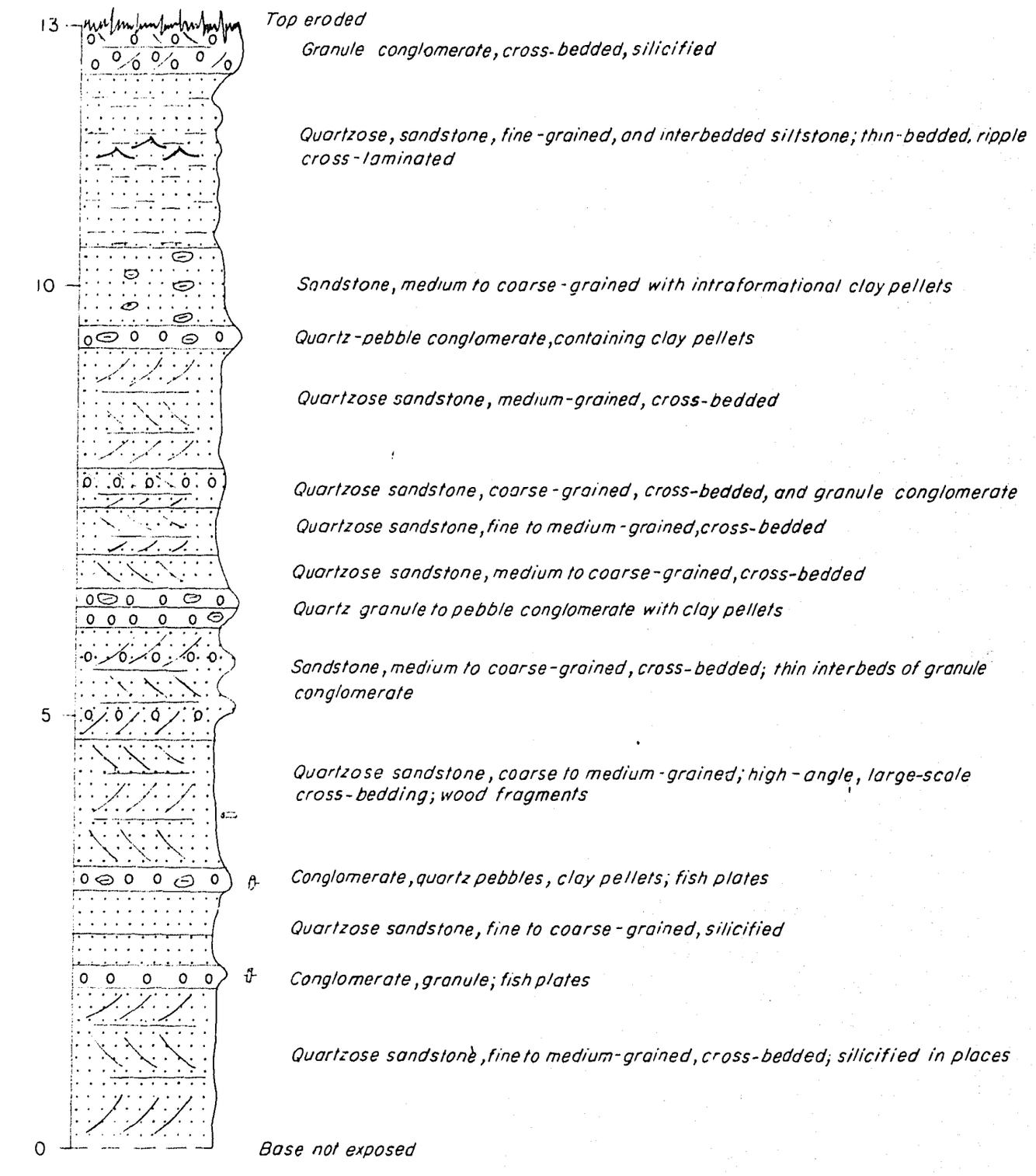


Fig. A2. Measured section of the Carranya Beds, 15km. west of type section.



M(S) 383
P.D.

Fig. A3. Type section of the Knobby Sandstone

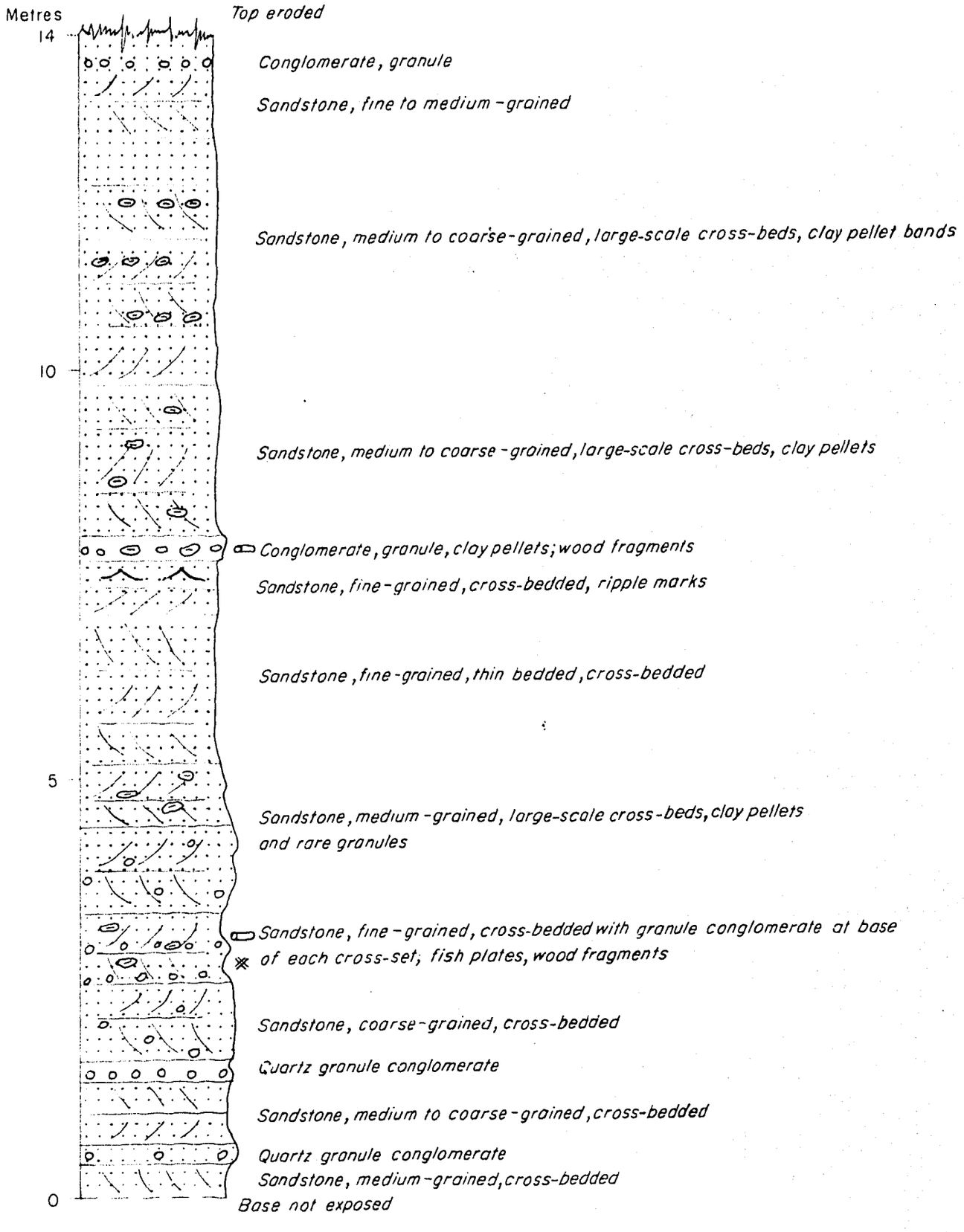


Fig.A4. Measured section of the Knobby Sandstone at Falconer Hills, BILLILUNA, 1:250000 Sheet area.

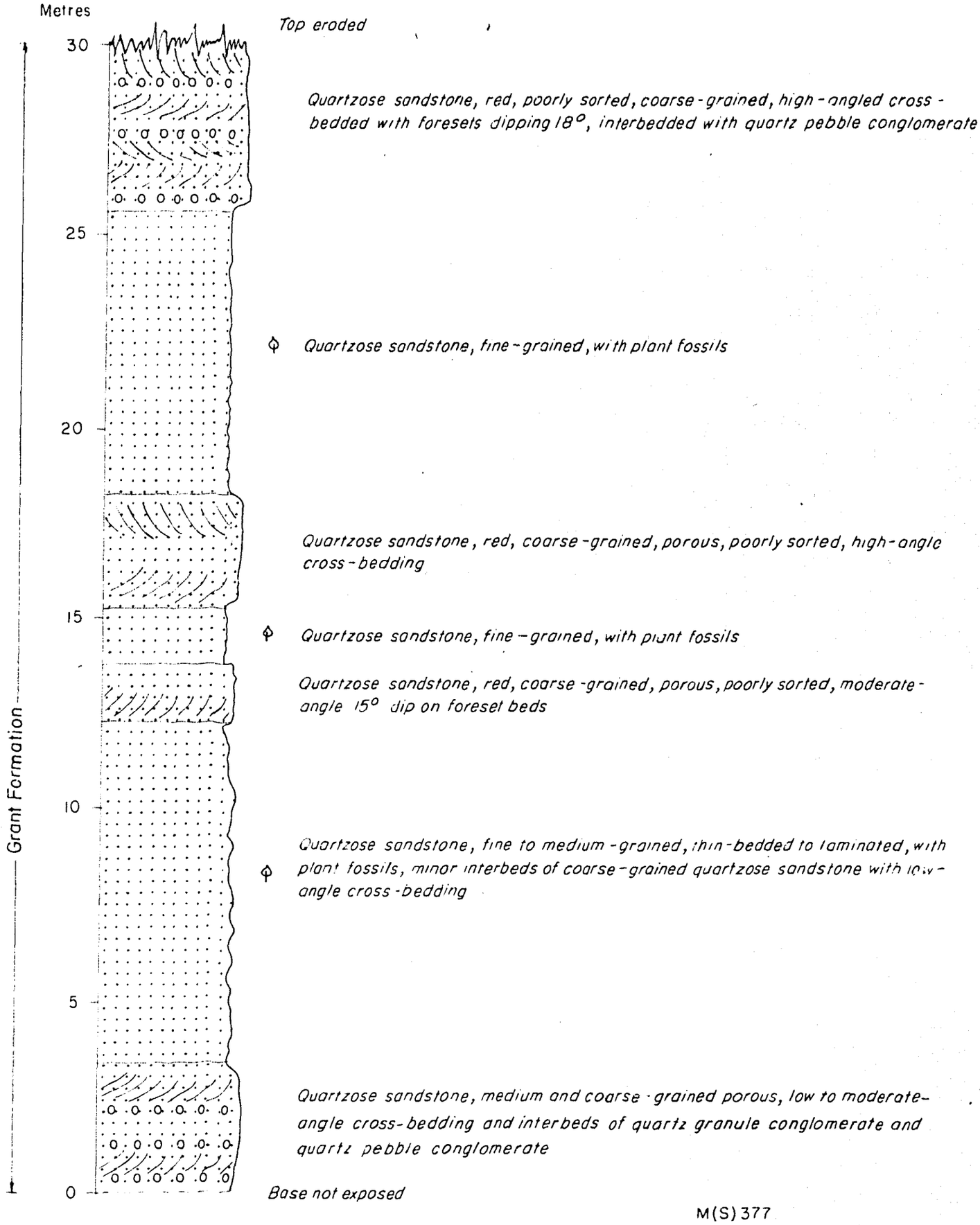
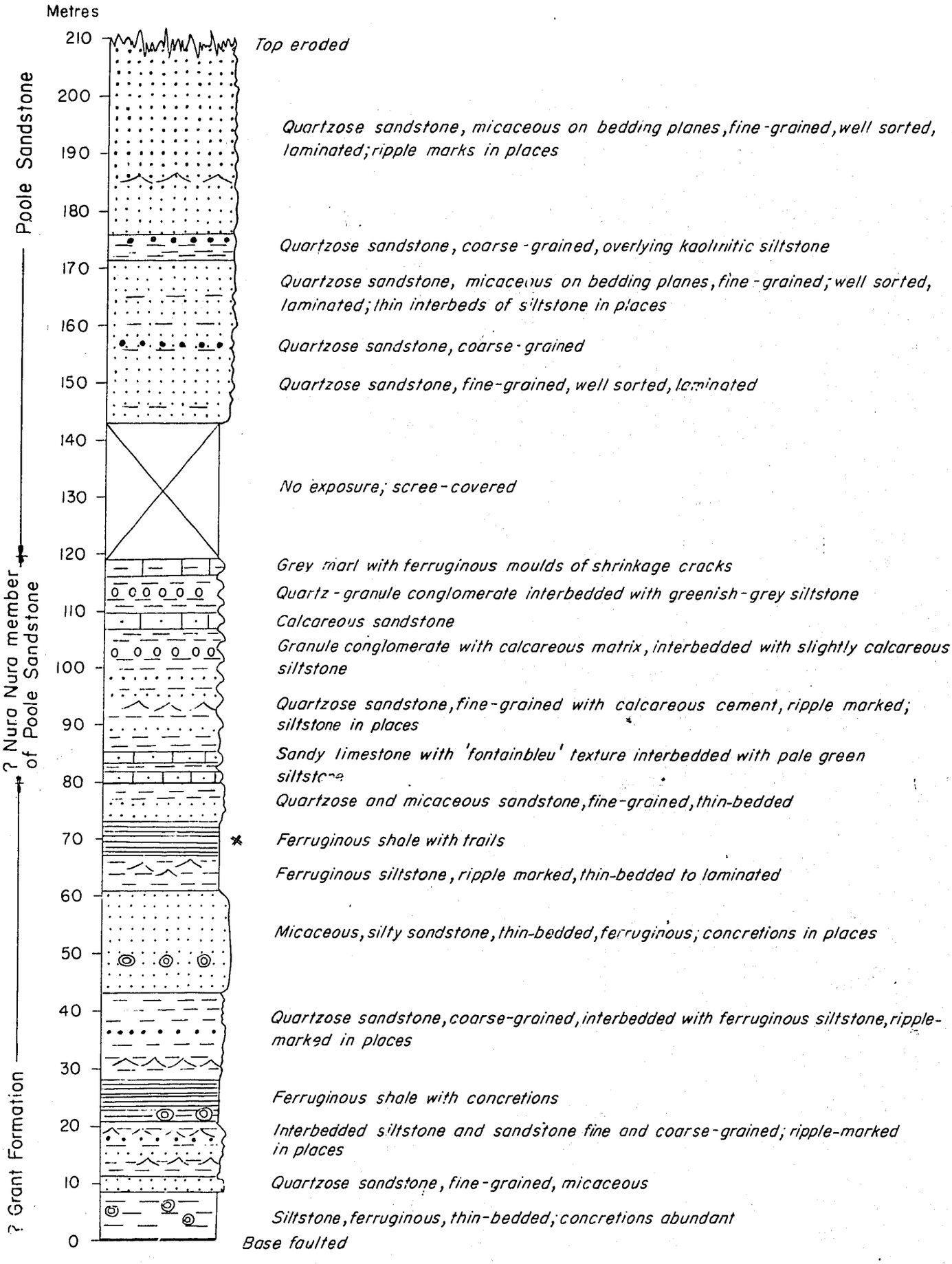


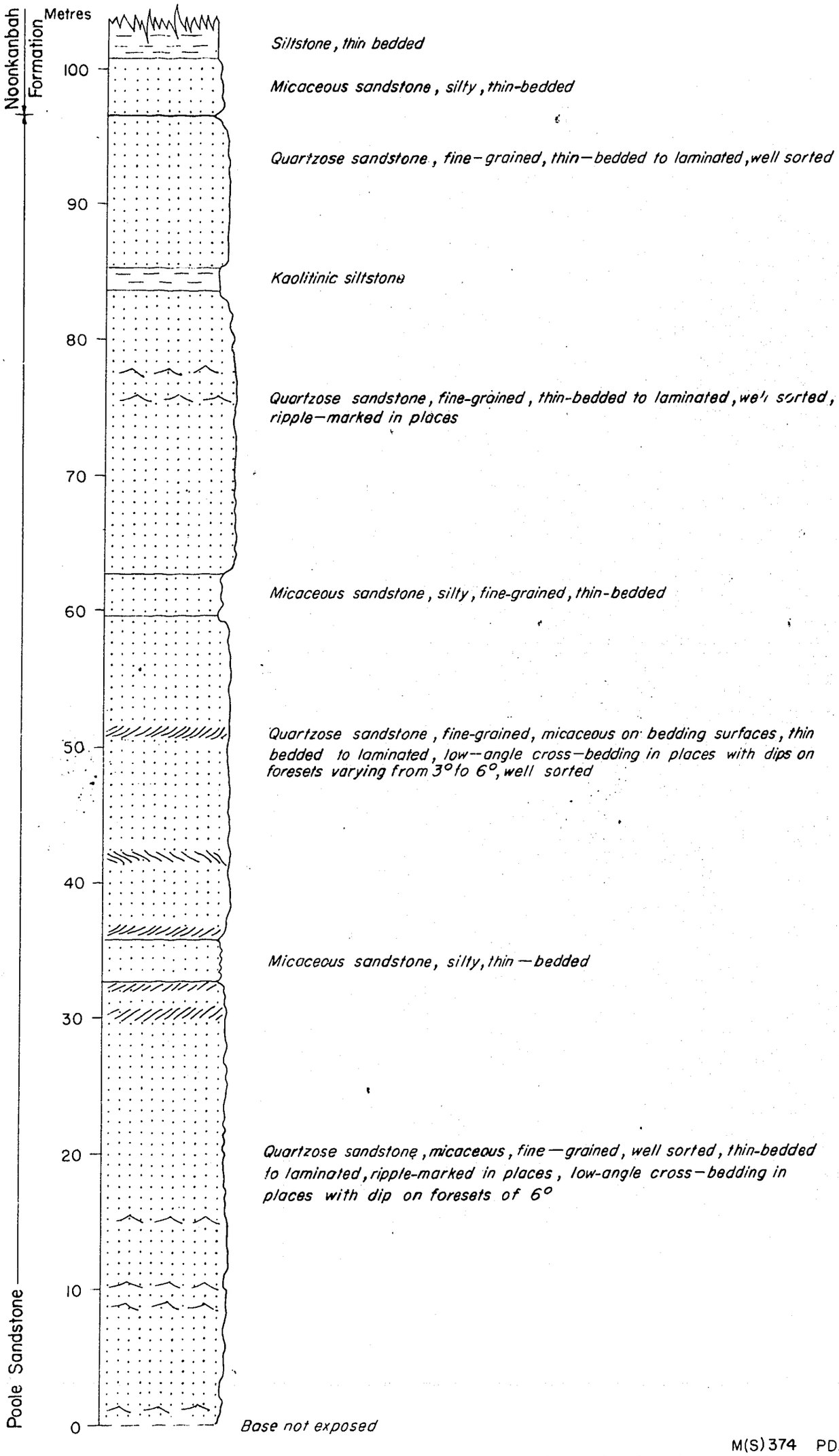
Fig.A5. Measured section of part of Grant Formation adjacent to Mt Bannerman, 19°27'45"S, 127°11'00"E, MOUNT BANNERMAN. 1:250 000 Sheet area.

Record
1975/77



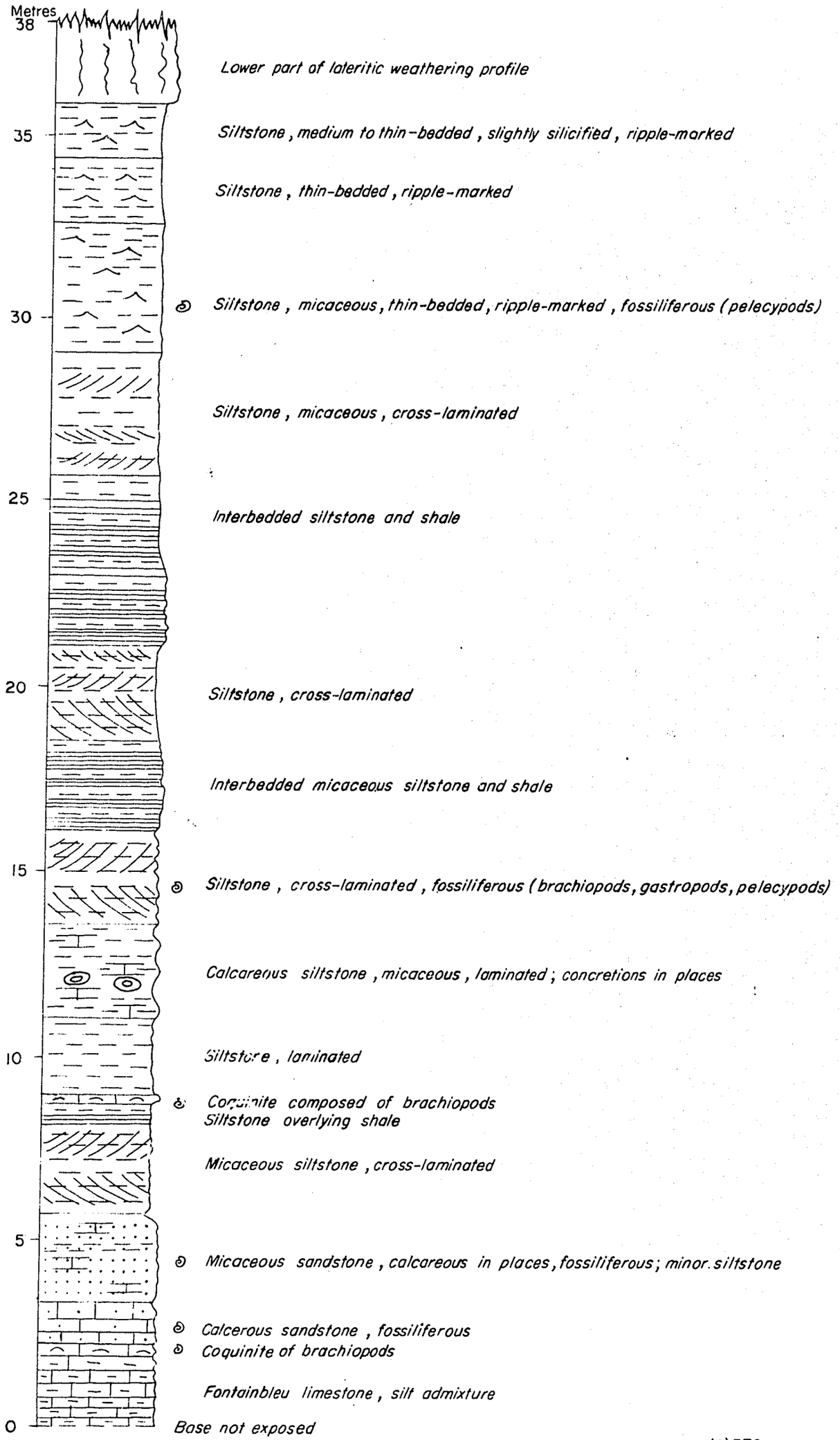
M(S)396
P.D.

Fig.A6. Measured section of base of Poole Sandstone and top of Grant Formation near southern end of Stansmore Range, 21°30'00"S, 128°08'00"E, STANSMORE. 1:250 000 Sheet area.



M(S)374 PD.

Fig. A7. Measured section of upper part of Poole Sandstone, Stansmore Range, 21°13'38" S, 128°00'20"E, STANSMORE. 1:250 000 Sheet area.



M(S) 370
P.D.

Fig. A8. Measured section of Noonkanbah Formation 4km. north of Narelli Rockhole, 20°06'30"S, 127°55'10"E, LUCAS. 1:250 000 Sheet area.

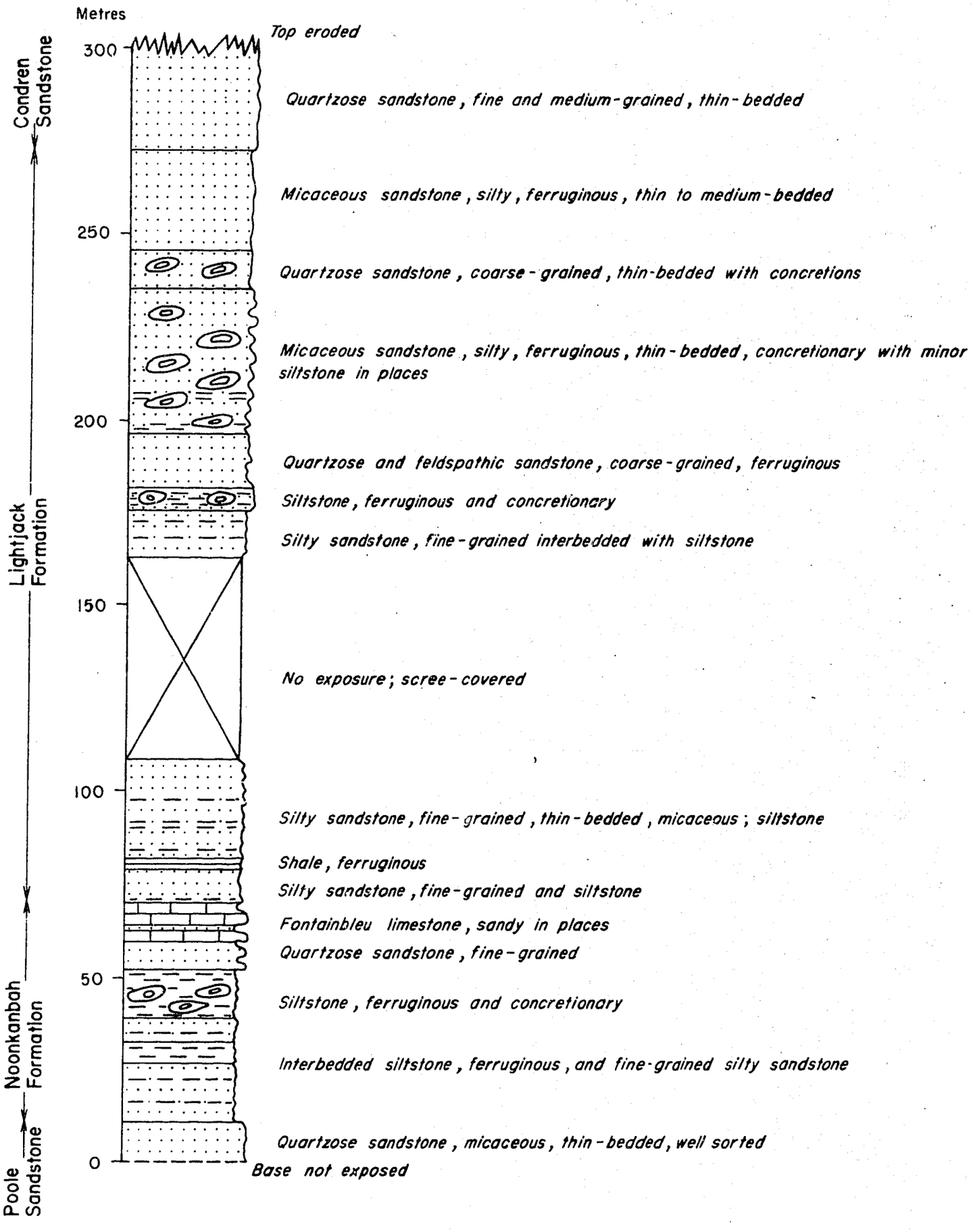
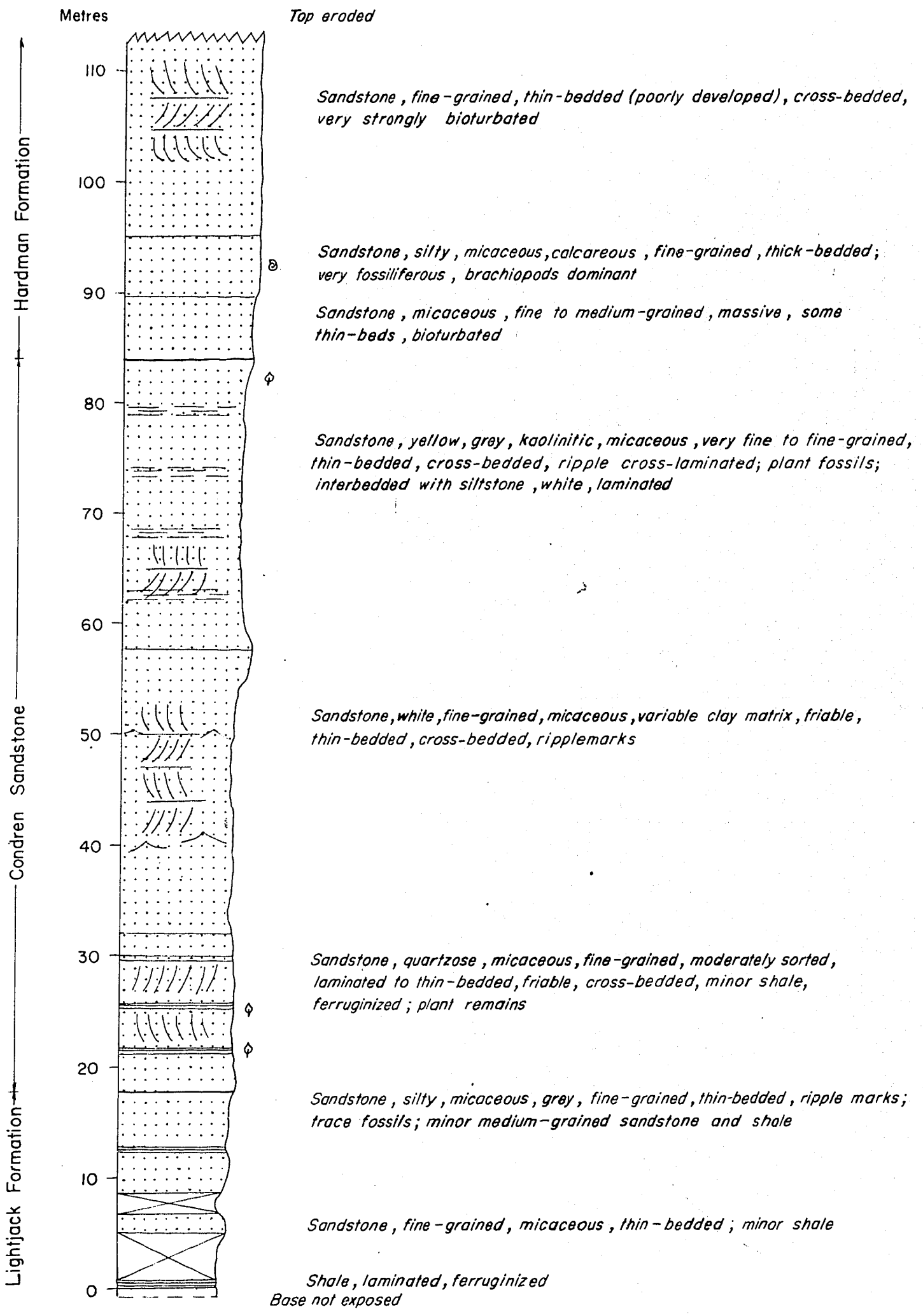
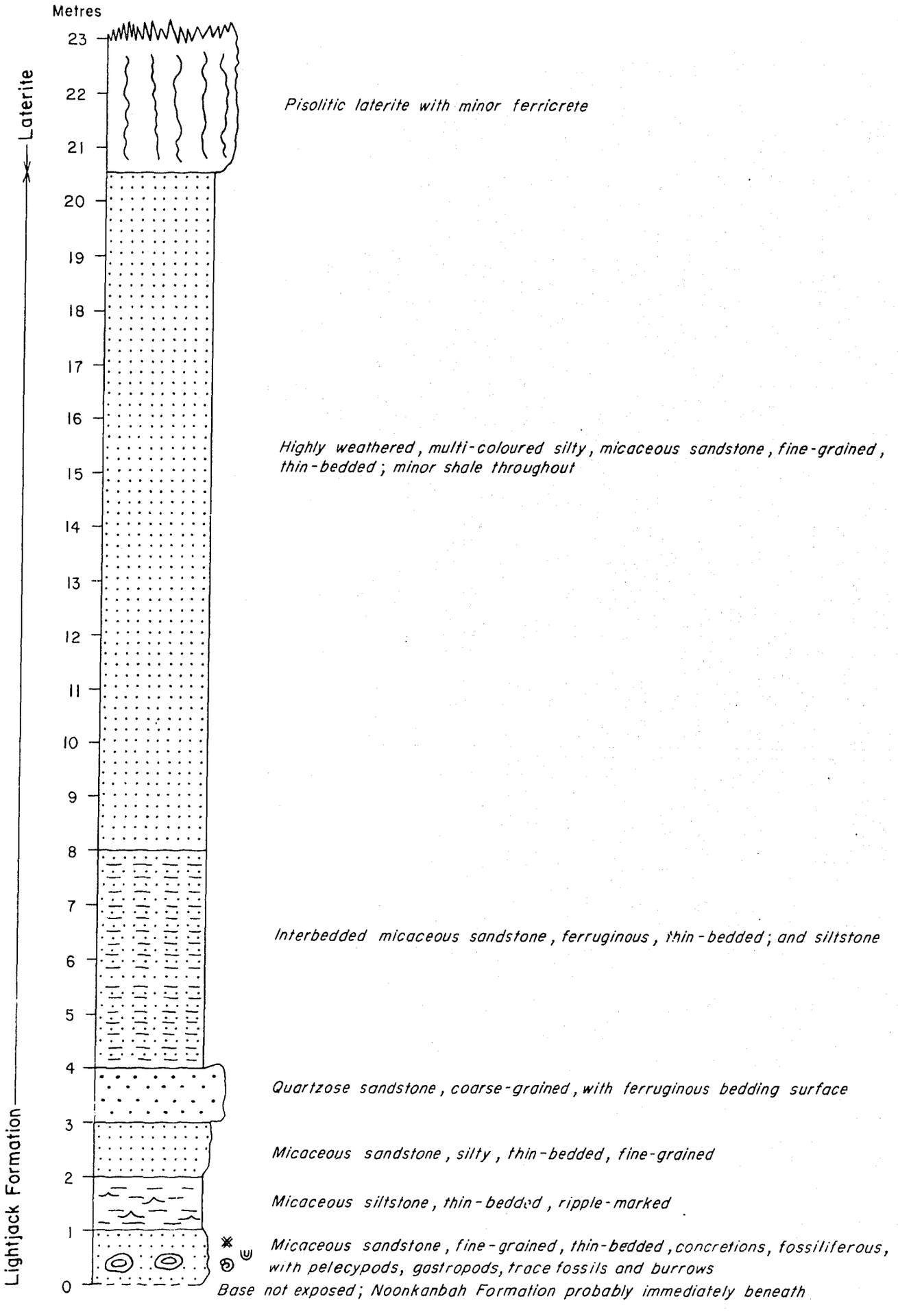


Fig.A9. Measured section from top of Poole Sandstone to base of Condren Sandstone in Stansmore Range, 28°14'00"S, 128°00'00"E, STANSMORE. 1:250 000 Sheet area.



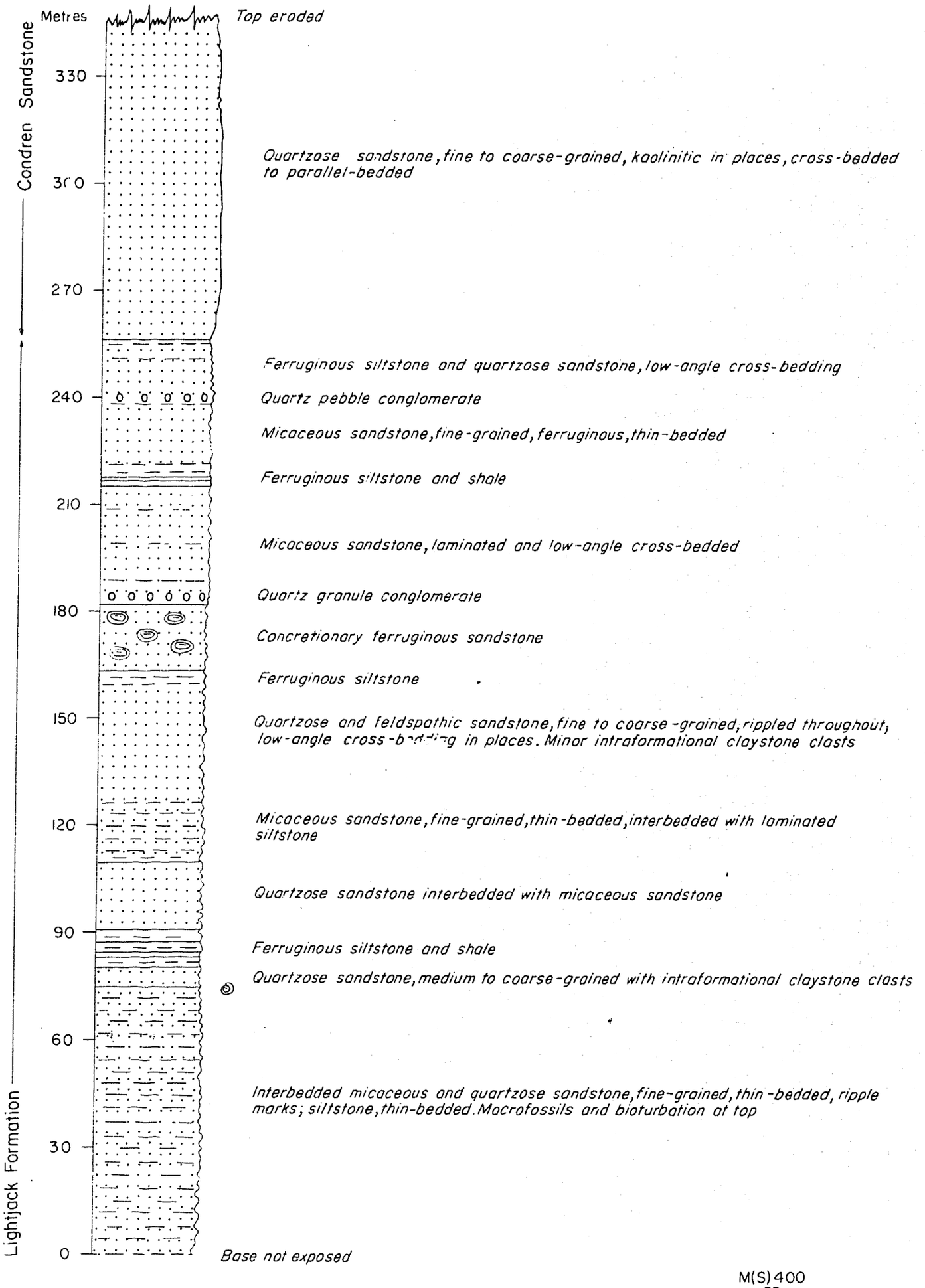
M(S)371
PD.

Fig.A10. Measured section from top of Lightjack Formation to base of Hardman Formation in Millyit Range, 19°12'10"S, 125°28'42" E, CROSSLAND, 1:250 000 Sheet area.



M(S)404
G.G.

Fig.All. Measured section of Lightjack Formation at Carnegie Bluff, 21°48'30" S, 127°57'20"E STANSMORE 1:250 000 Sheet area.
This section is the type section of the discarded term "Balgo Member" of Casey & Wells (1964).



M(S) 400
P.D.

Fig. A12. Measured section of part of Lightjack Formation and Condren Sandstone, Stansmore Range, 21°15'S, 128°01'30"E, STANSMORE 1:250 000 Sheet area.

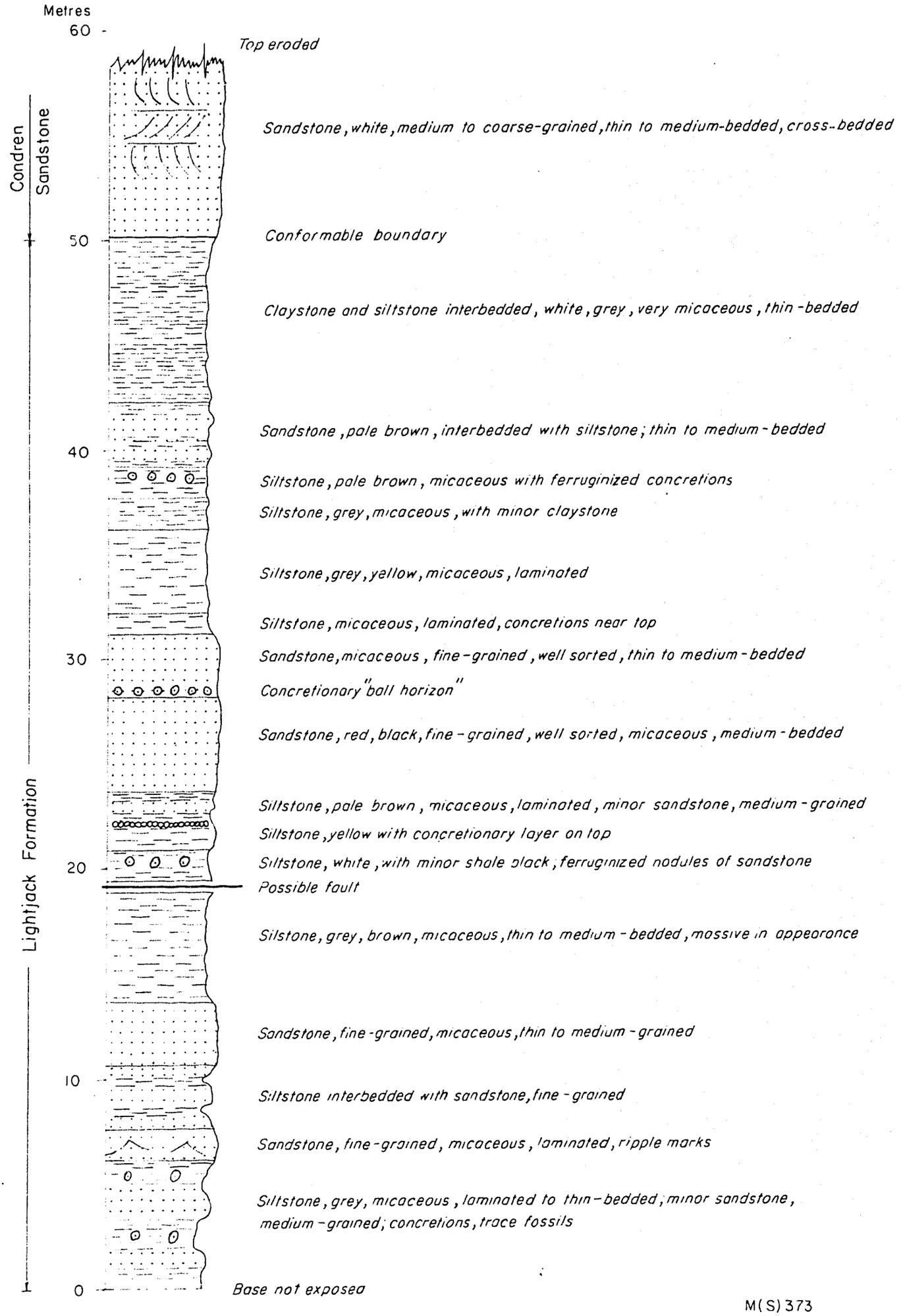
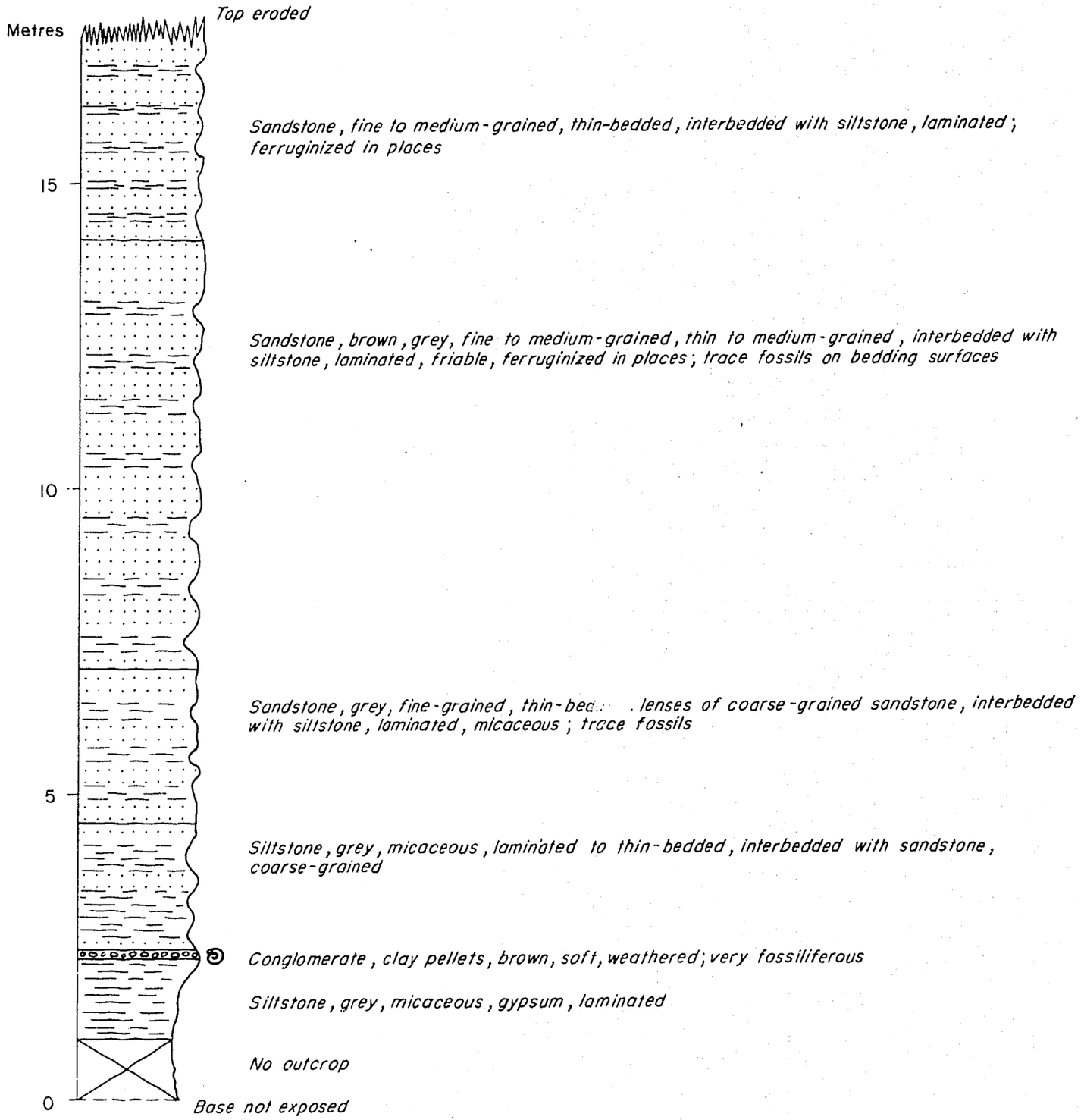


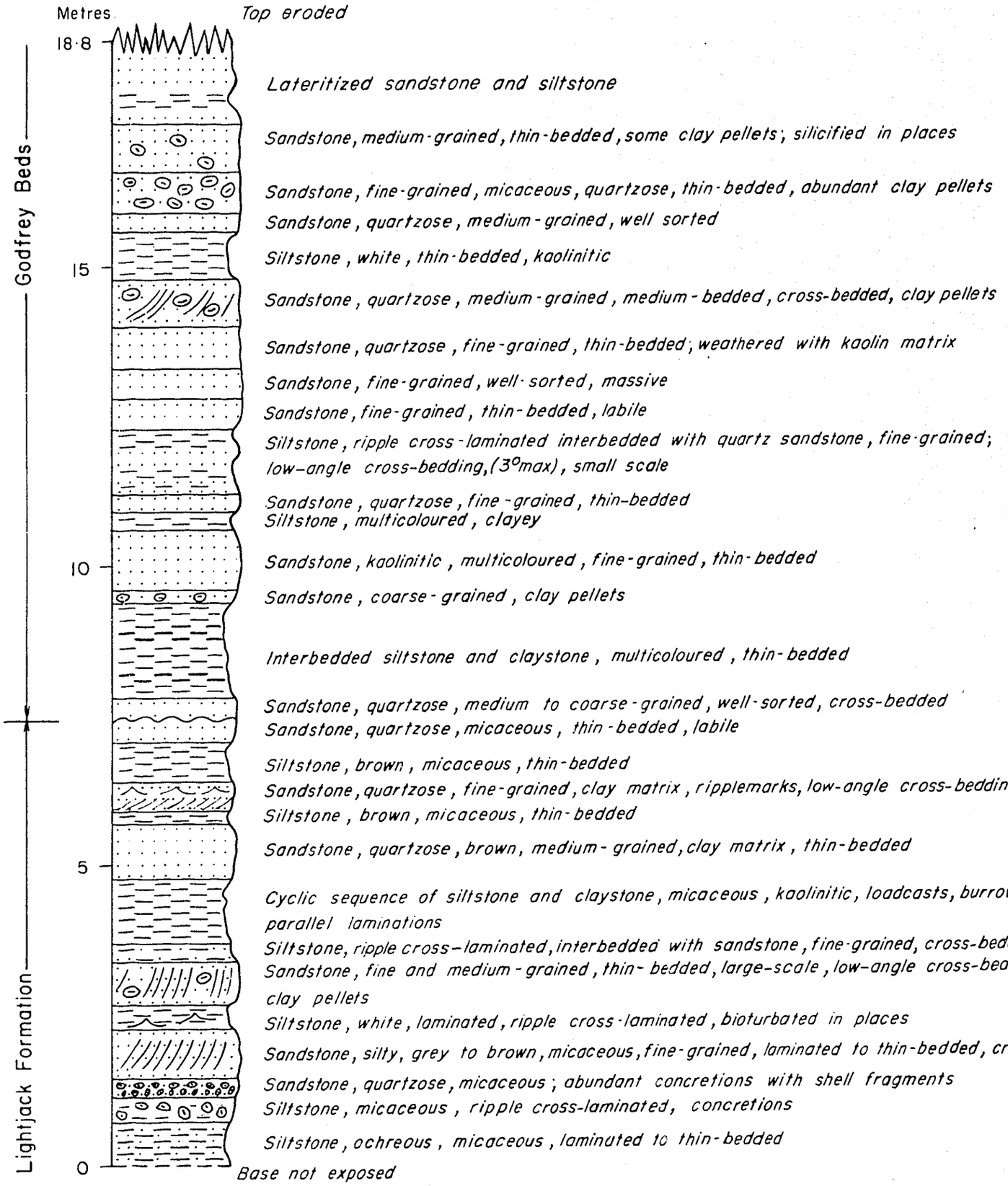
Fig. A13. Measured section of Lightjack Formation and Condren Sandstone in the Stretch Range, LUCAS, 1:250 000 Sheet area.



M(S) 393
G.G.

Fig. A14. Measured section of Lightjack Formation at Gumbo Point, LUCAS, 1:250 000 Sheet area.

Record
1975-77



M(S) 372
G.G.

Fig.AI5. Measured section of part of the Lightjack Formation and Godfrey Beds 2·5 km. east southeast of Micha Bore, LUCAS 1:250 000 Sheet area.

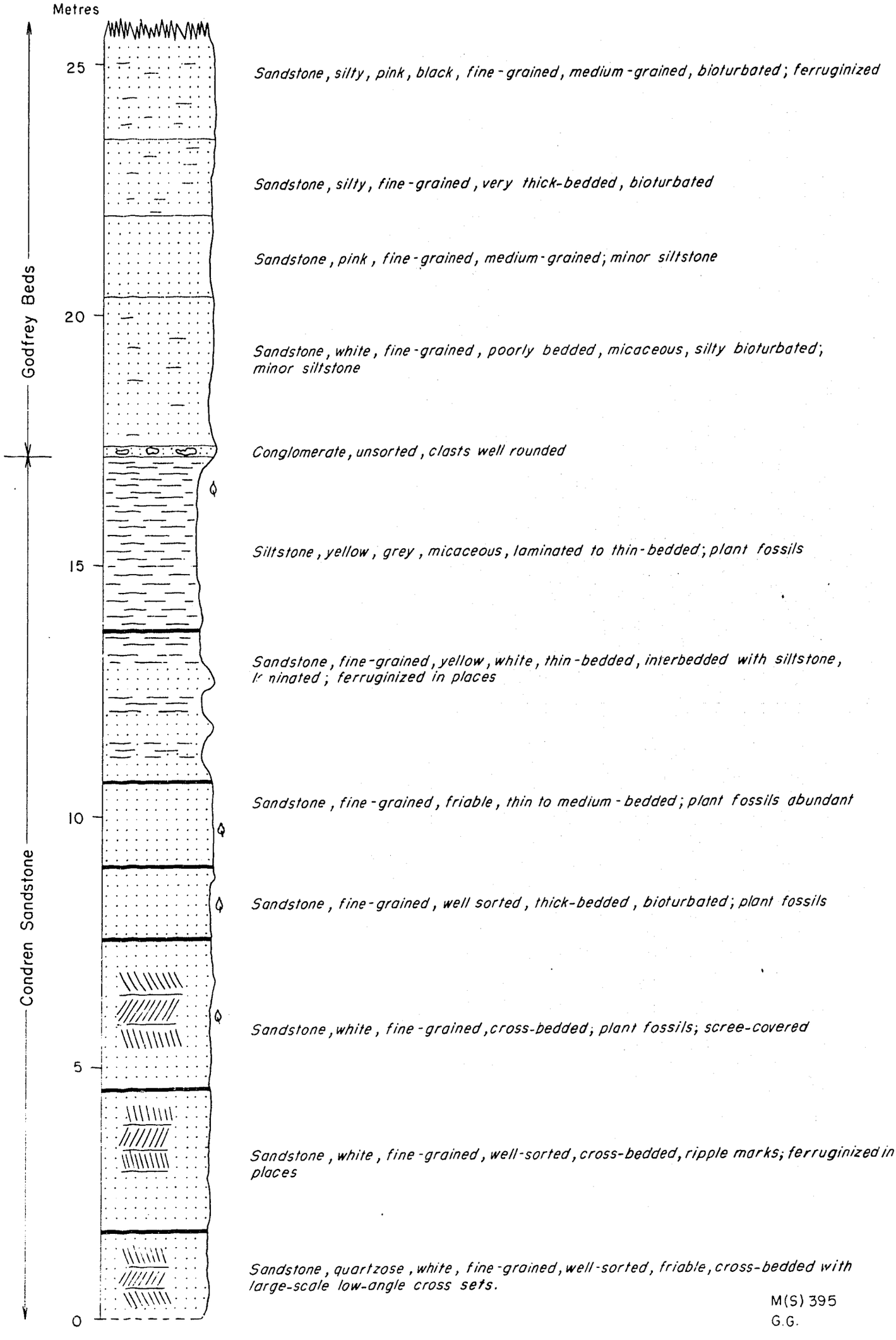
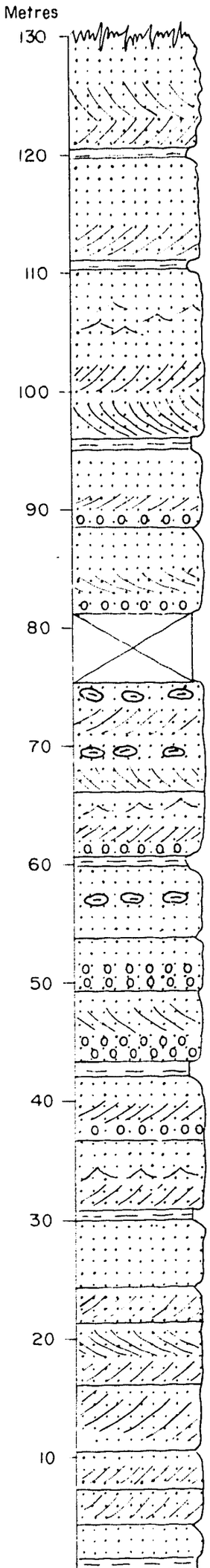


Fig. A16. Measured section at Condren Pinnacles, LUCAS 1:250 000 Sheet area.



Quartzose sandstone, medium to coarse-grained; cross-bedded, dip on foresets 18°

Kaolitinic siltstone

Quartzose sandstone, cross-bedded at base, fining upwards

Kaolitinic siltstone

Quartzose sandstone, medium-grained, cross-bedded, ripple-marked in places

Kaolitinic siltstone

Quartz granule conglomerate and cross-bedded, quartzose sandstone, fining upwards

Quartzose sandstone, fine-grained, thin-bedded

Quartzose sandstone, medium and coarse-grained, cross-bedded

Quartz-pebble conglomerate

No exposure; scree-covered

Quartzose sandstone, coarse-grained, intraformational claystone clasts; cross-bedded, dip on foresets up to 23°

Quartz-granule conglomerate and cross-bedded, quartzose sandstone

Kaolitinic siltstone

Quartzose sandstone, coarse-grained, with intraformational claystone clasts

Quartz-pebble conglomerate overlain by quartzose sandstone, medium-grained, fining upwards

Quartz-granule conglomerate overlain by quartzose sandstone

Kaolitinic siltstone

Quartzose sandstone, pebbly at base, fining upwards; cross-bedded, dip on foresets 21°

Quartzose sandstone, medium-grained, cross-bedded firing upwards and becoming ripple cross-laminated

Kaolinitic siltstone

Quartzose sandstone, fine-grained, thinly bedded

Quartzose sandstone, medium and coarse-grained; cross-bedded, dip on foresets 19°

Quartzose sandstone, coarse-grained, fining upwards, cross-bedded, dip on foresets 16°

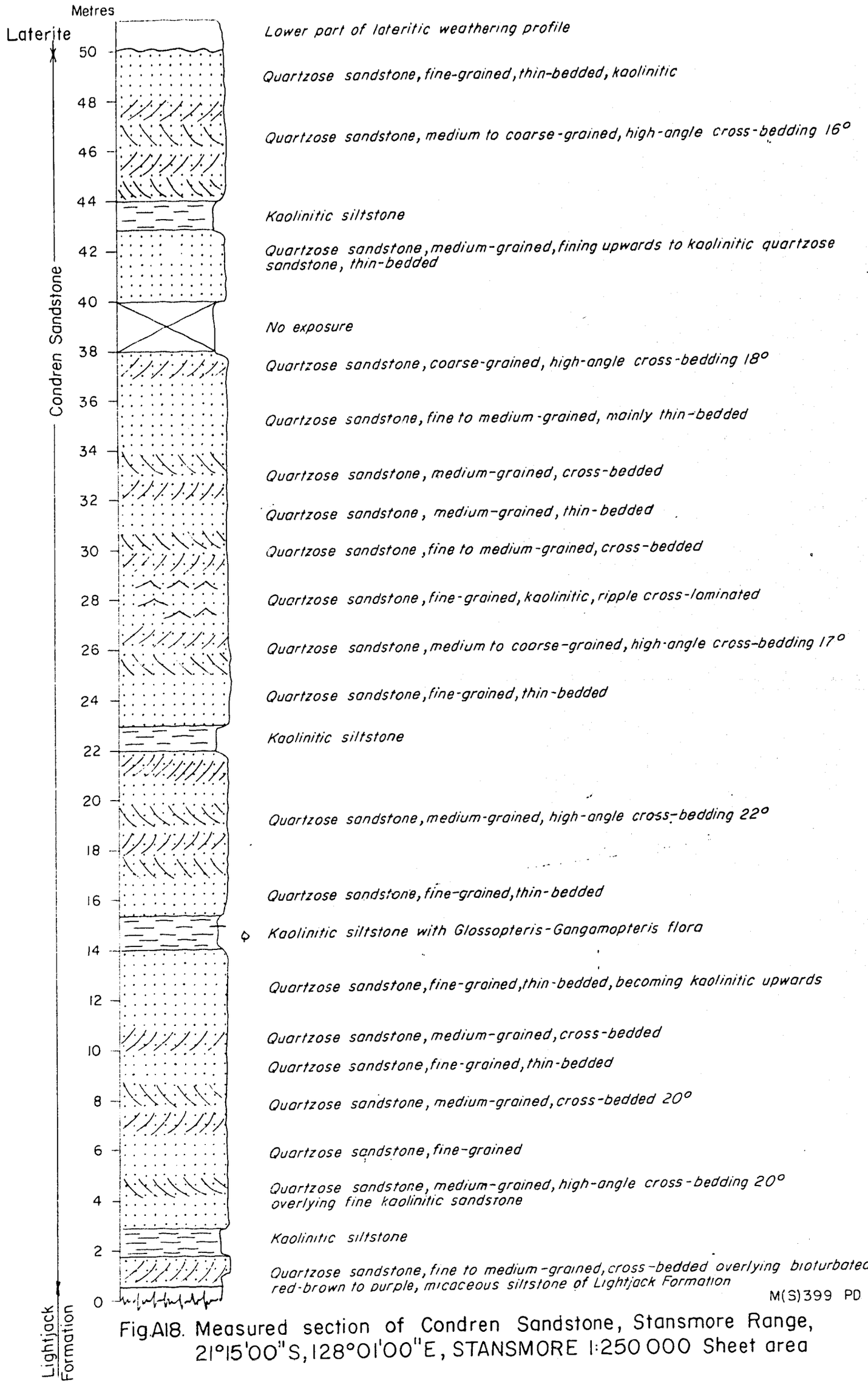
Quartzose sandstone, medium-grained; thinly bedded

Kaolitinic siltstone

Quartzose sandstone, overlying ferruginous, micaceous siltstone with trails of Lightjack Formation

M(S)392 P.D.

Fig. A17. Measured section of Condren Sandstone, 2km. north of Warri Peak, Stansmore Range, 21°27'40"S, 128°05'30"E, STANSMORE 1:250 000 Sheet area



M(S)399 PD

Fig.A18. Measured section of Condren Sandstone, Stansmore Range, 21°15'00"S, 128°01'00"E, STANSMORE 1:250 000 Sheet area

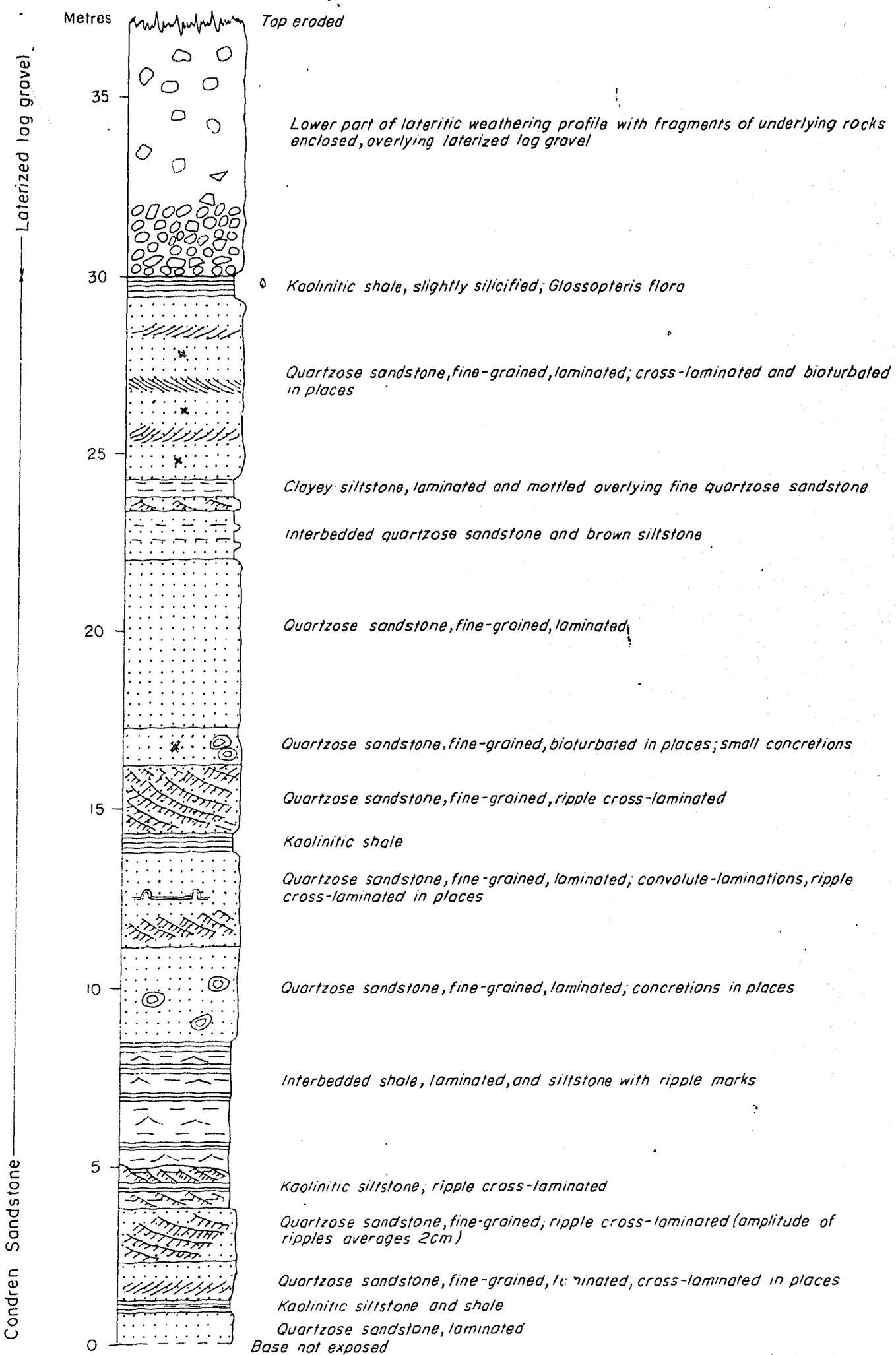
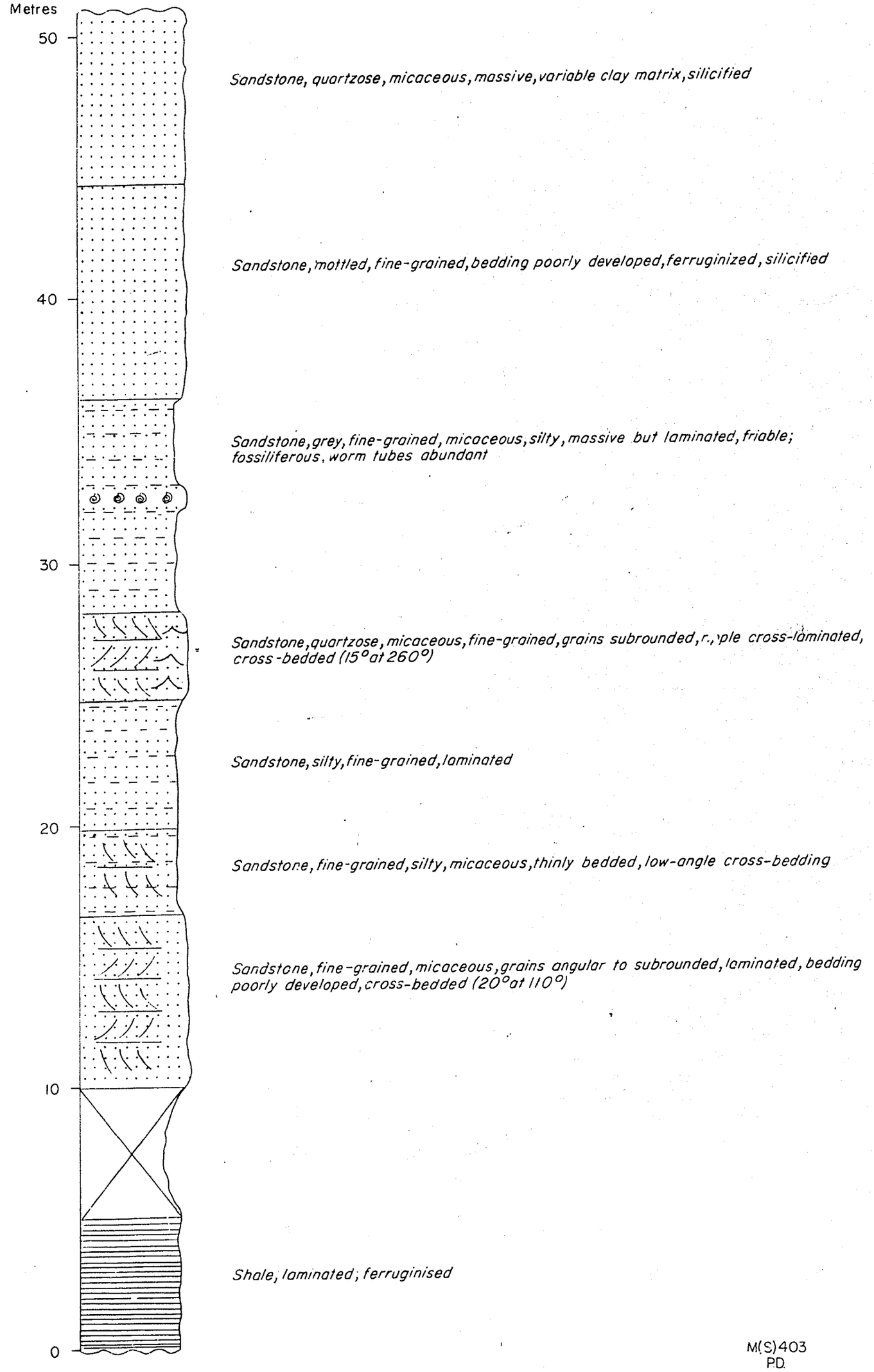


Fig.A19. Measured section of Condren Sandstone approximately 8km south of Chudla Bore, 19°04'00"S, 126°09'30"E, MOUNT BANNERMAN 1:250 000 Sheet area



M(S)403
P.D.

Fig.A20. Type section of Kirby Range Member

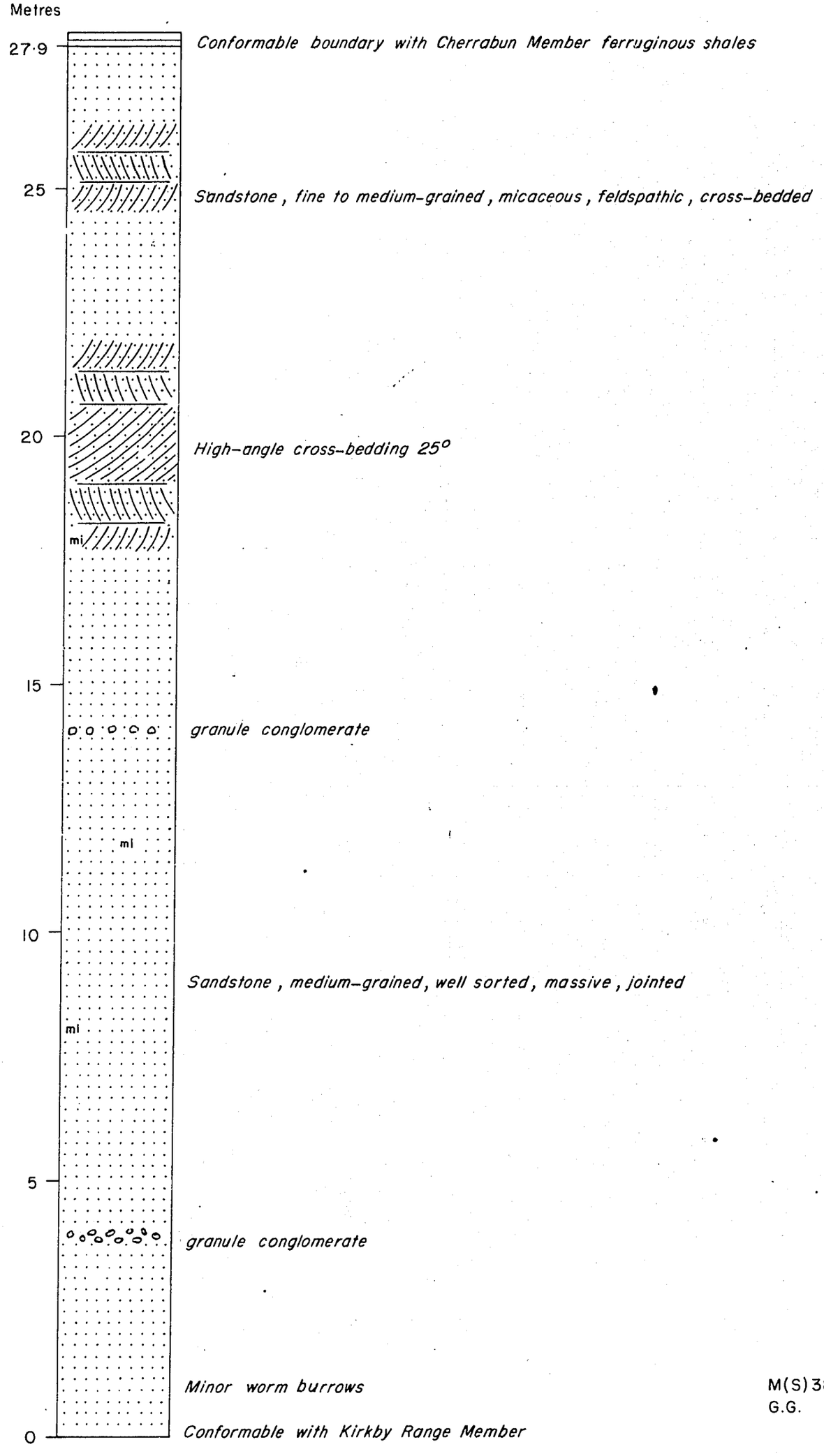
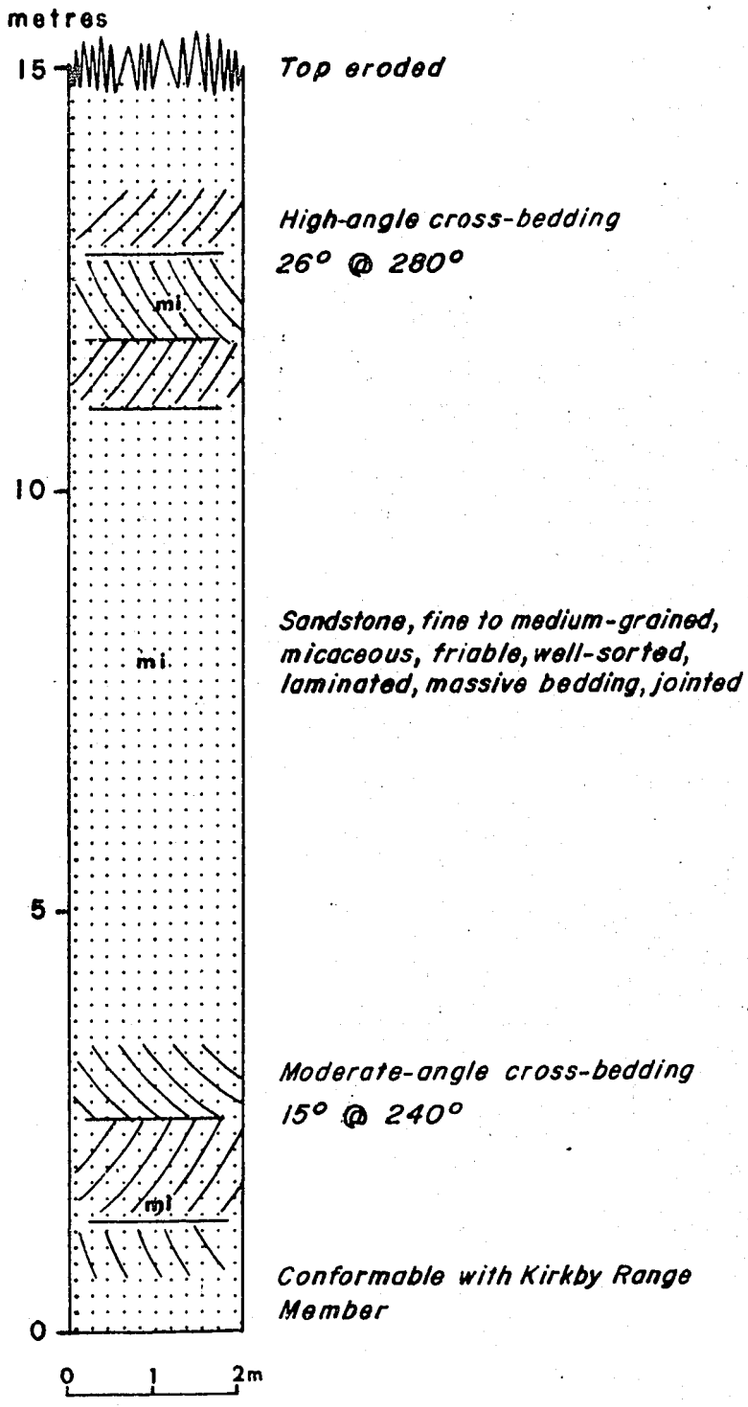
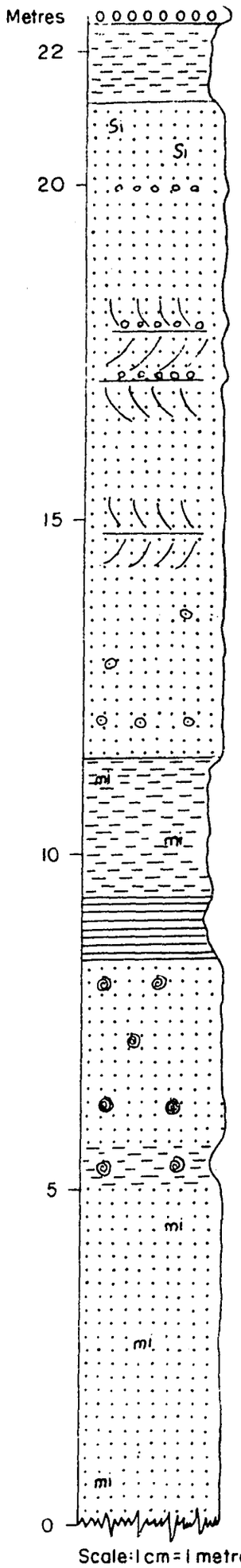


Fig.A21. Type section of Hicks Range Sandstone Member in Millyit Range, CROSSLAND 1:250 000 Sheet area.



M(S) 365

Fig.A22. Measured section of Hicks Range Sandstone Member in Millyit Range, CROSSLAND 1:250 000 Sheet area.



Quartz pebble conglomerate (Millyit Sandstone)

Siltstone, dark grey to black, laminated; palynolomorphs

Sandstone, fine-grained, thin-bedded, clay pellets, low-angle cross-bedding, friable; lenses of conglomerate

Siltstone, grey, micaceous, laminated, ferruginized in parts

Shale, laminated

Sandstone, very fine-grained, silty, thin-bedded, micaceous; fossiliferous

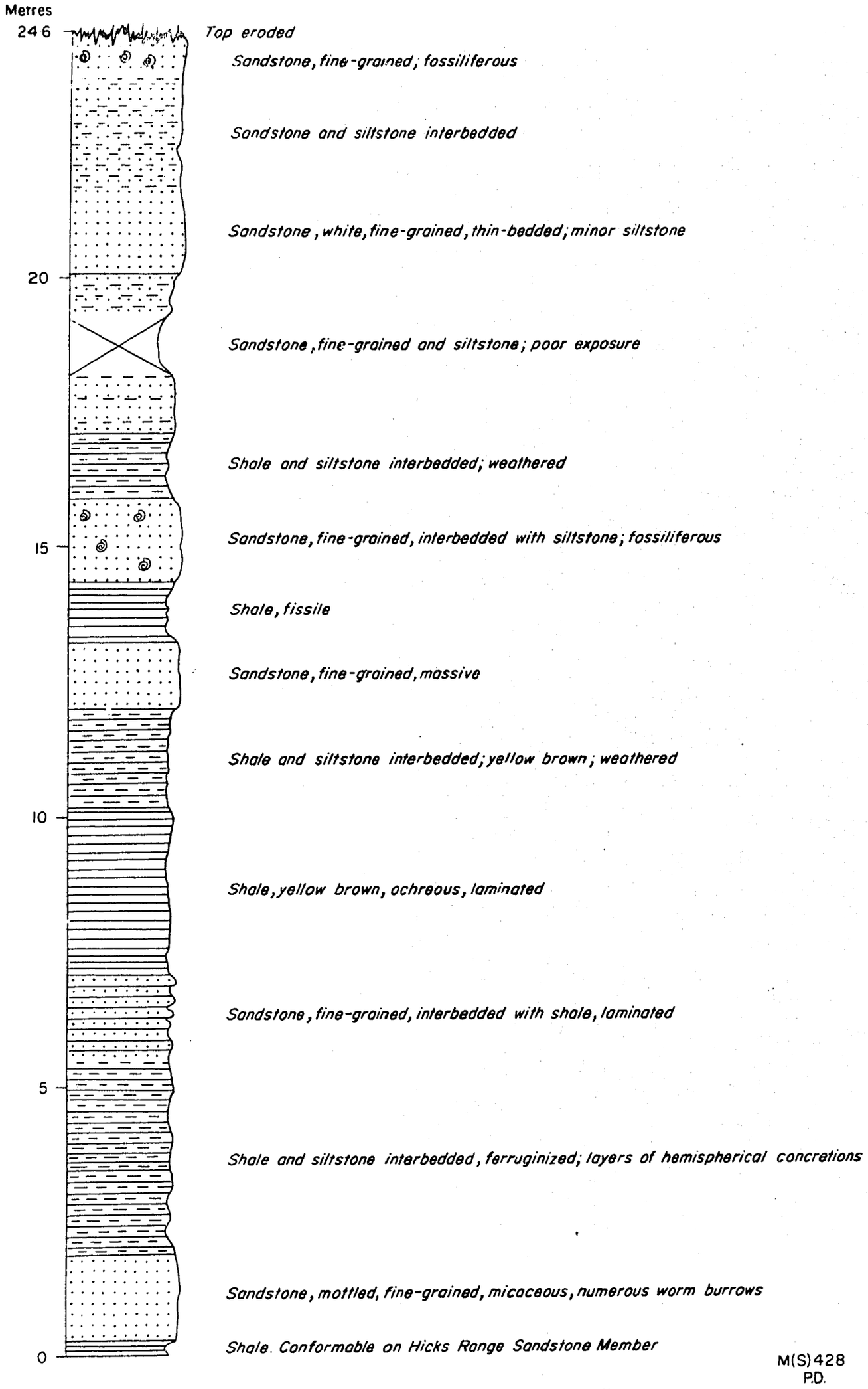
Siltstone, laminated; fossiliferous

Sandstone, light brown, very fine-grained, poorly sorted, silty, micaceous, thin-bedded

M(S)405
P.D.

Fig.A23. Type section of Cherrabun Member

Record
1975-77



M(S)428
P.D.

Fig.A24. Measured section of Cherrabun Member, Hicks Range, CROSSLAND 1:250 000 Sheet area

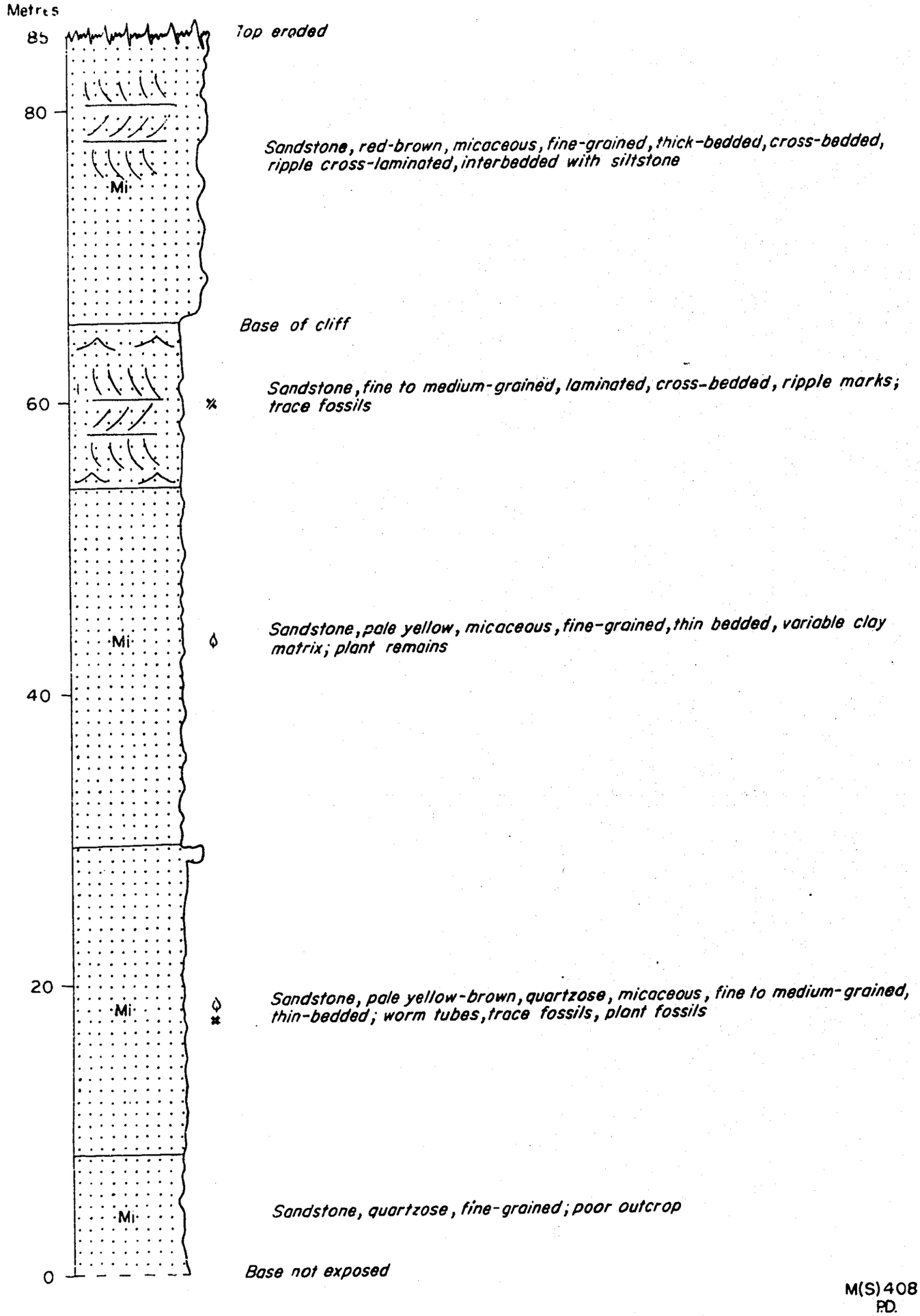


Fig.A25. Measured section of Godfrey Beds in vicinity of Crown Head, CORNISH 1:250 000 Sheet area

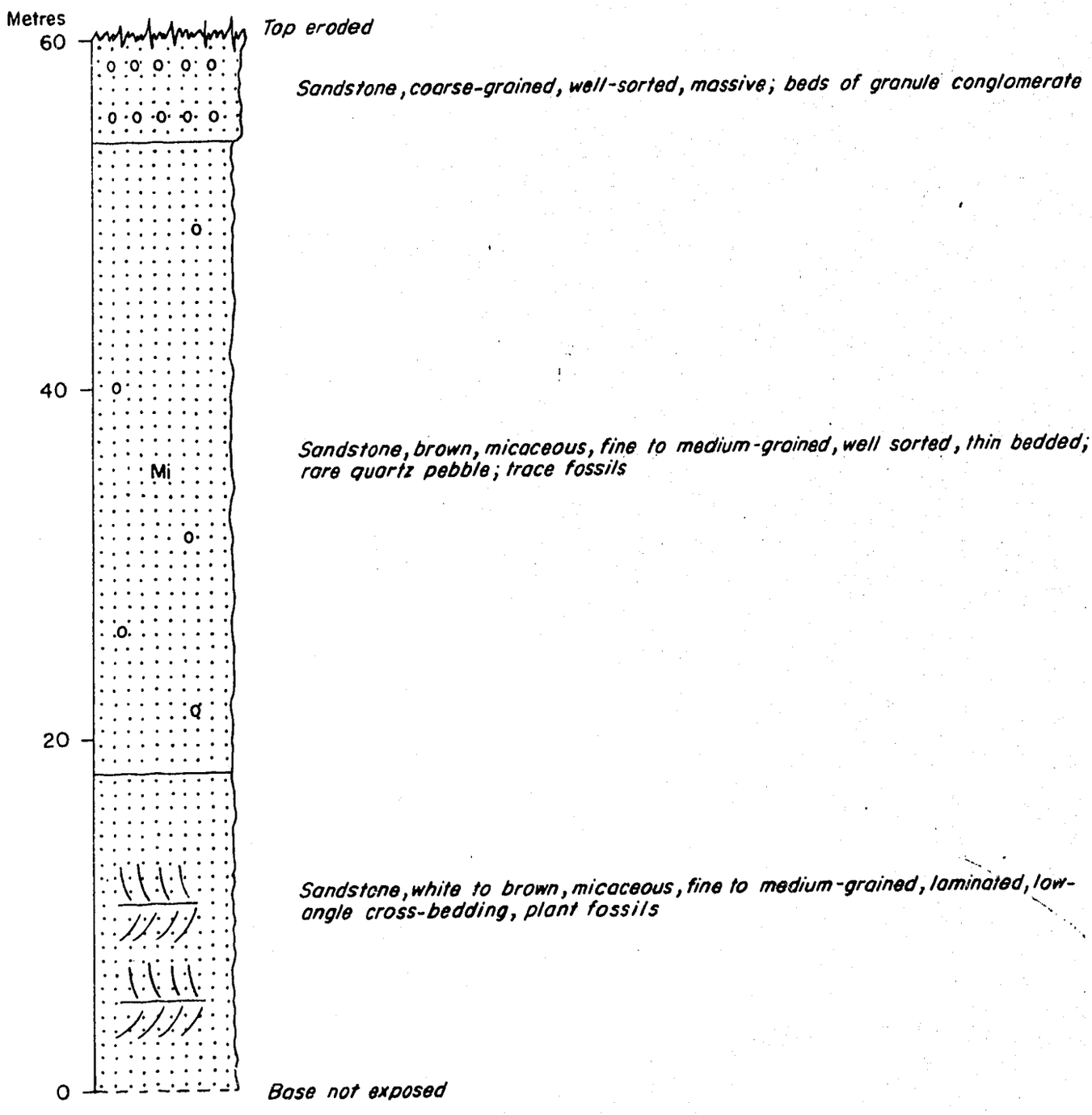


Fig.A26. Meosured section of Godfrey Beds in vicinity of Crown Head, CORNISH 1:250 000 Sheet area.

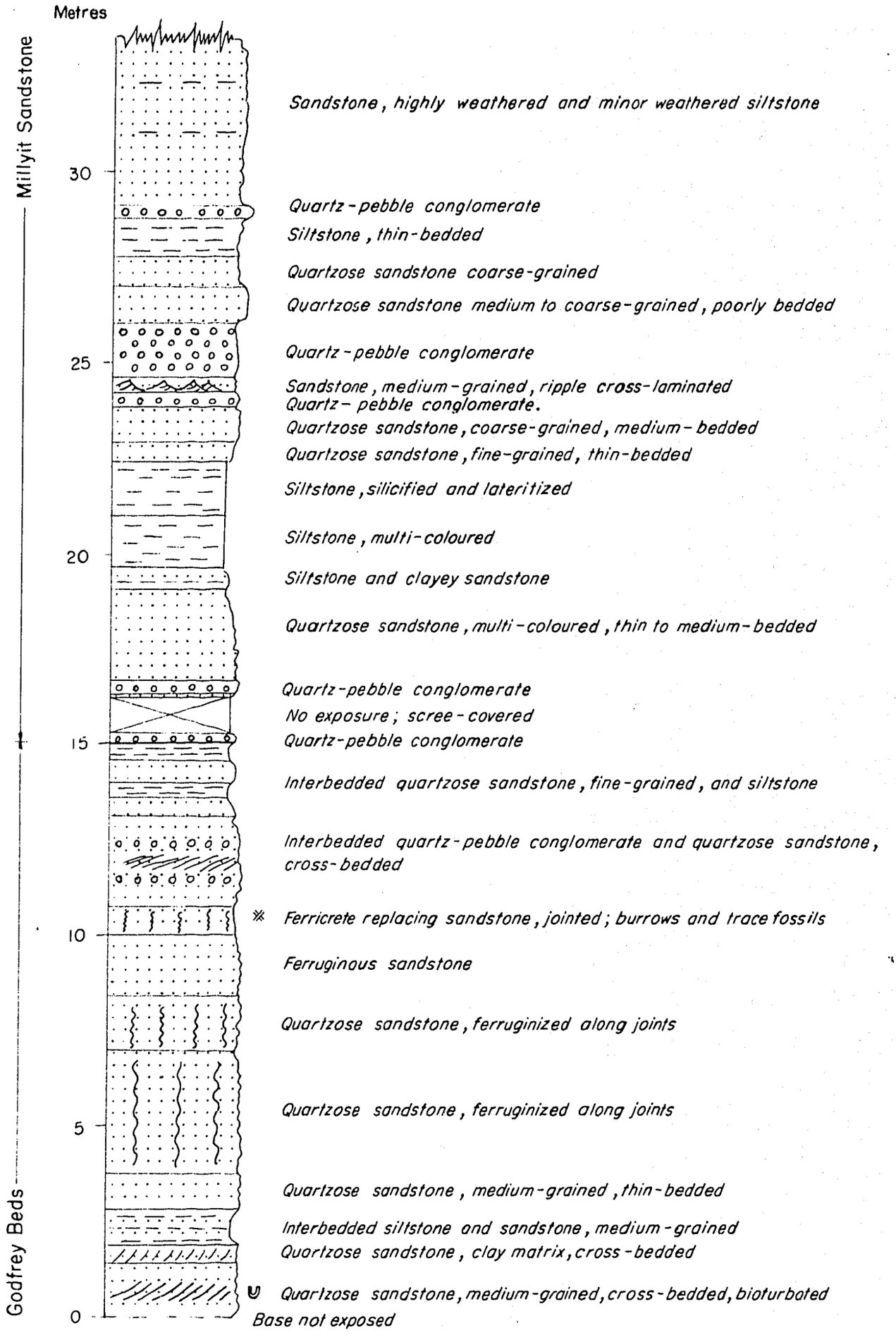


Fig.A27. Measured section of top part of Godfrey Beds and base of Millyit Sandstone 6km. west of Micha Bore, 20°16'30"S, 127°40'00"E, LUCAS 1:250 000 Sheet area.

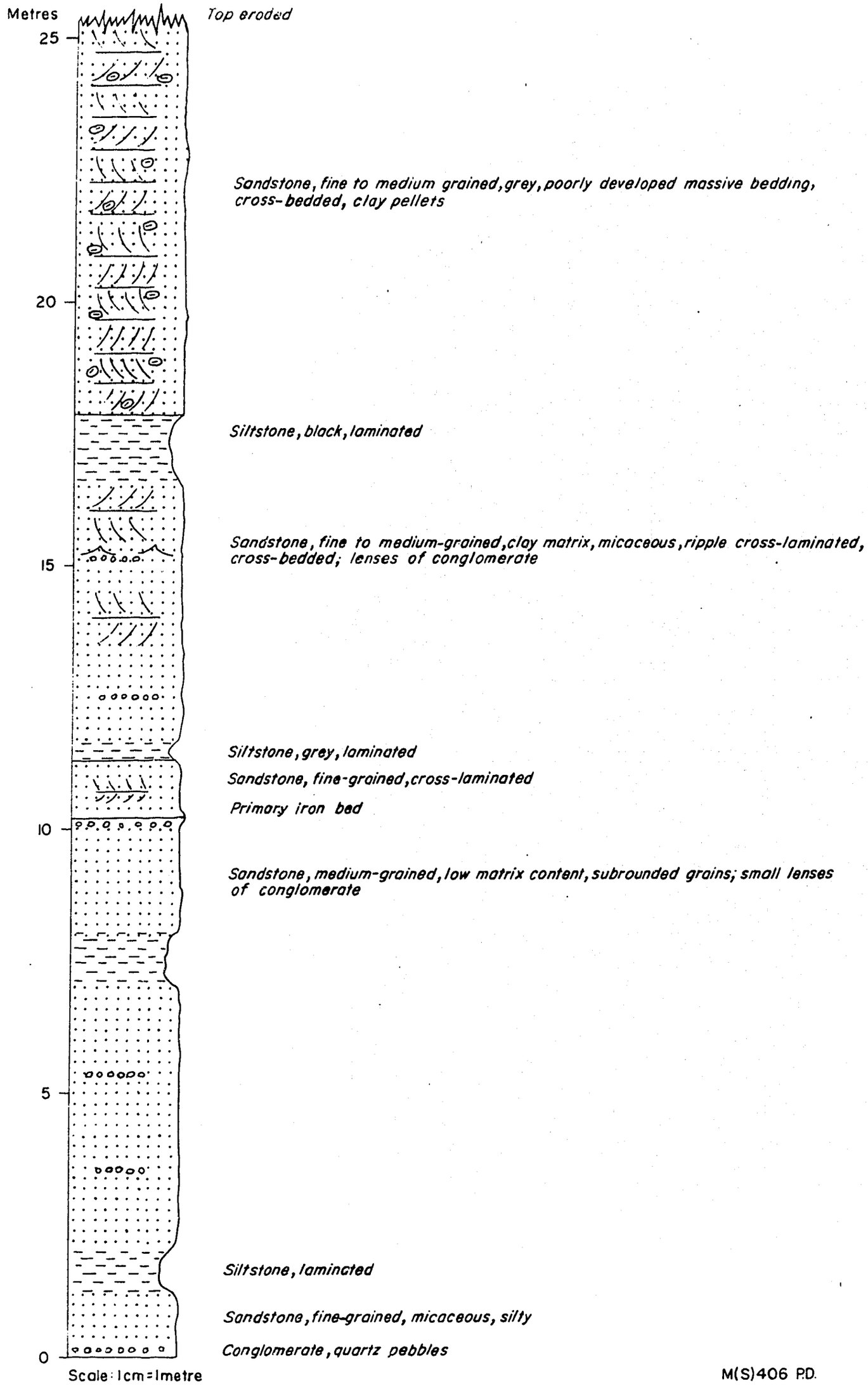


Fig.A28.Type section of Millyit Sandstone

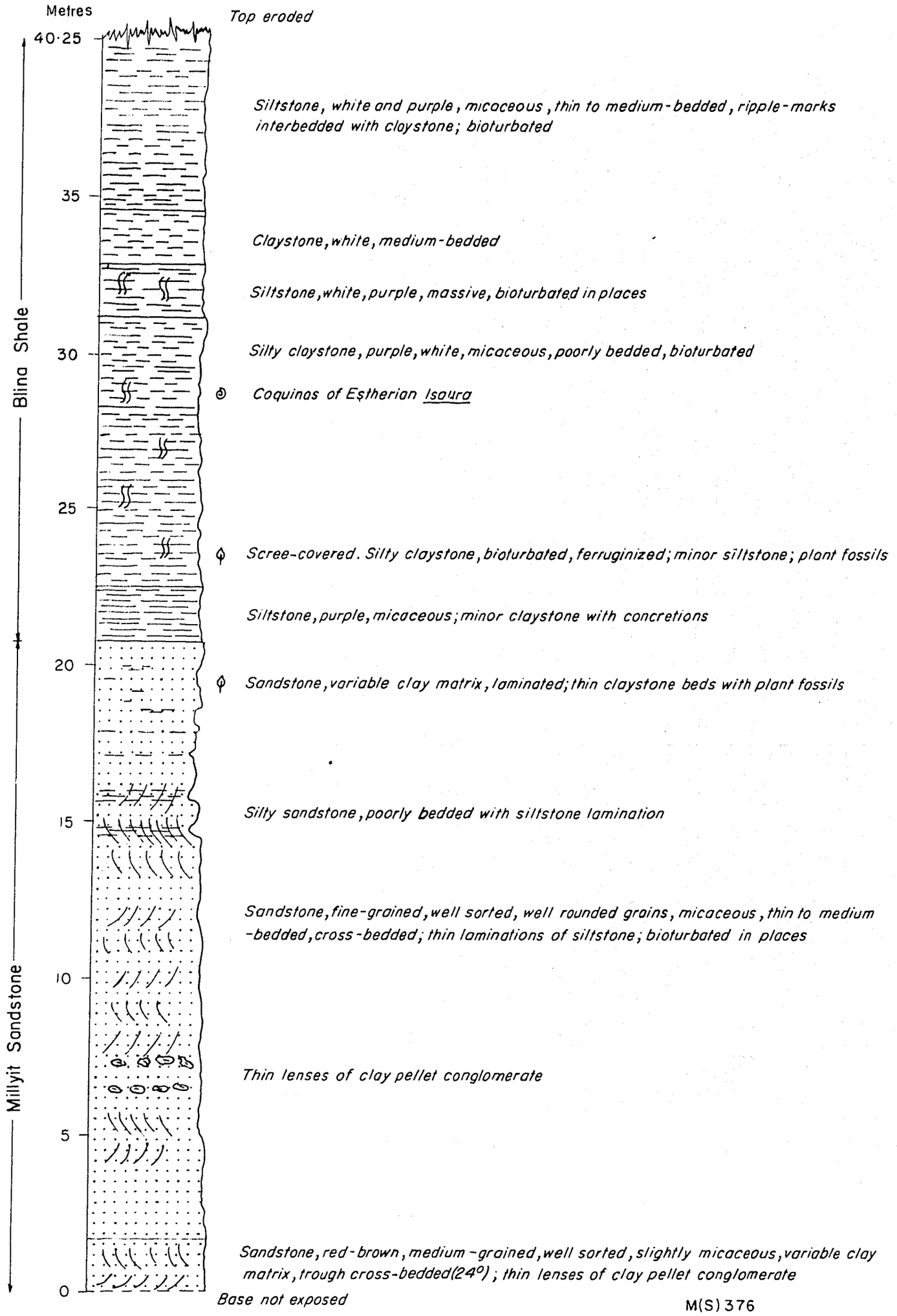


Fig.A29. Measured section of Millyit Sandstone and Blina Shale at Chilpada Chara, CORNISH 1:250 000 Sheet area.

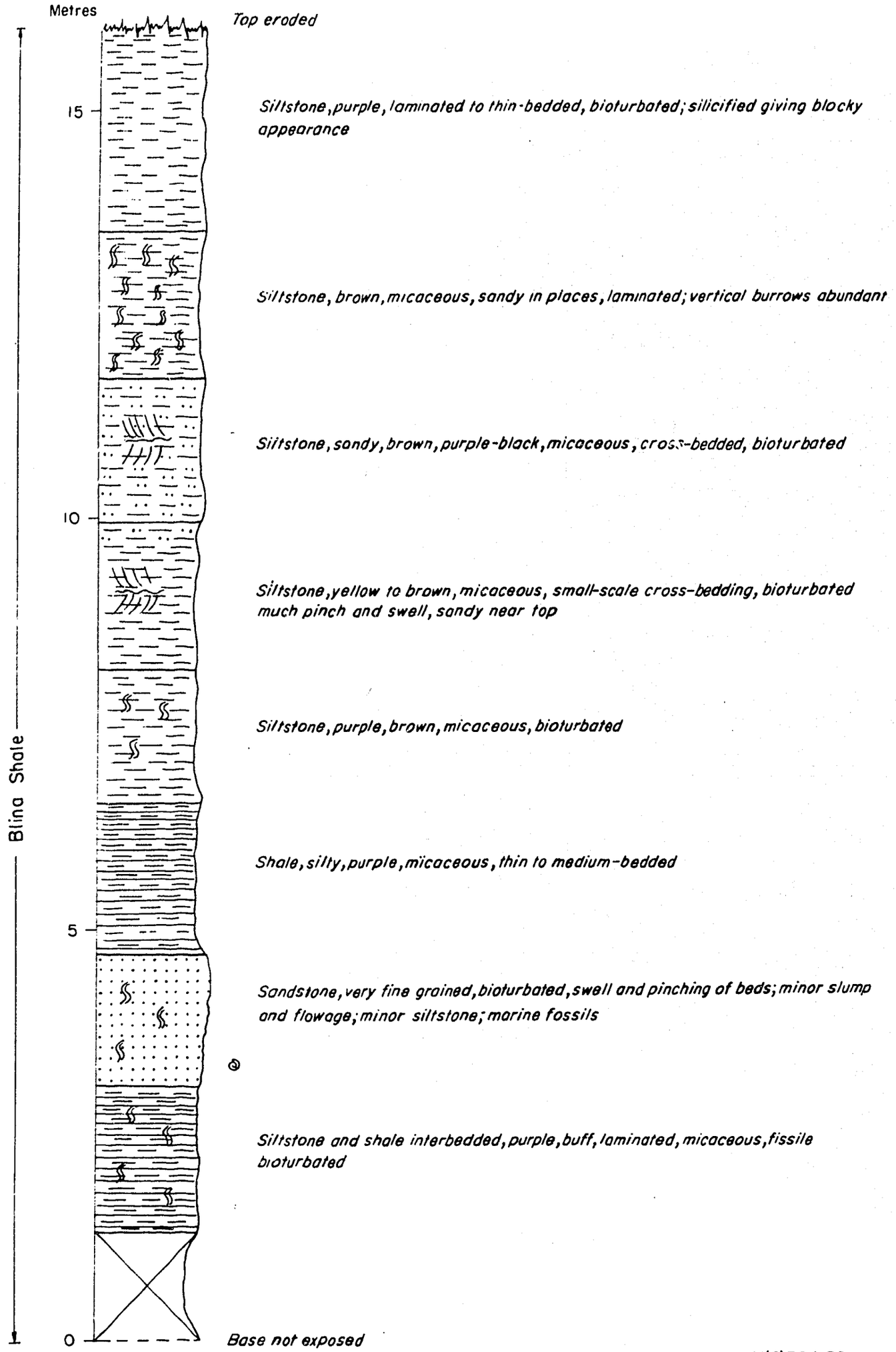
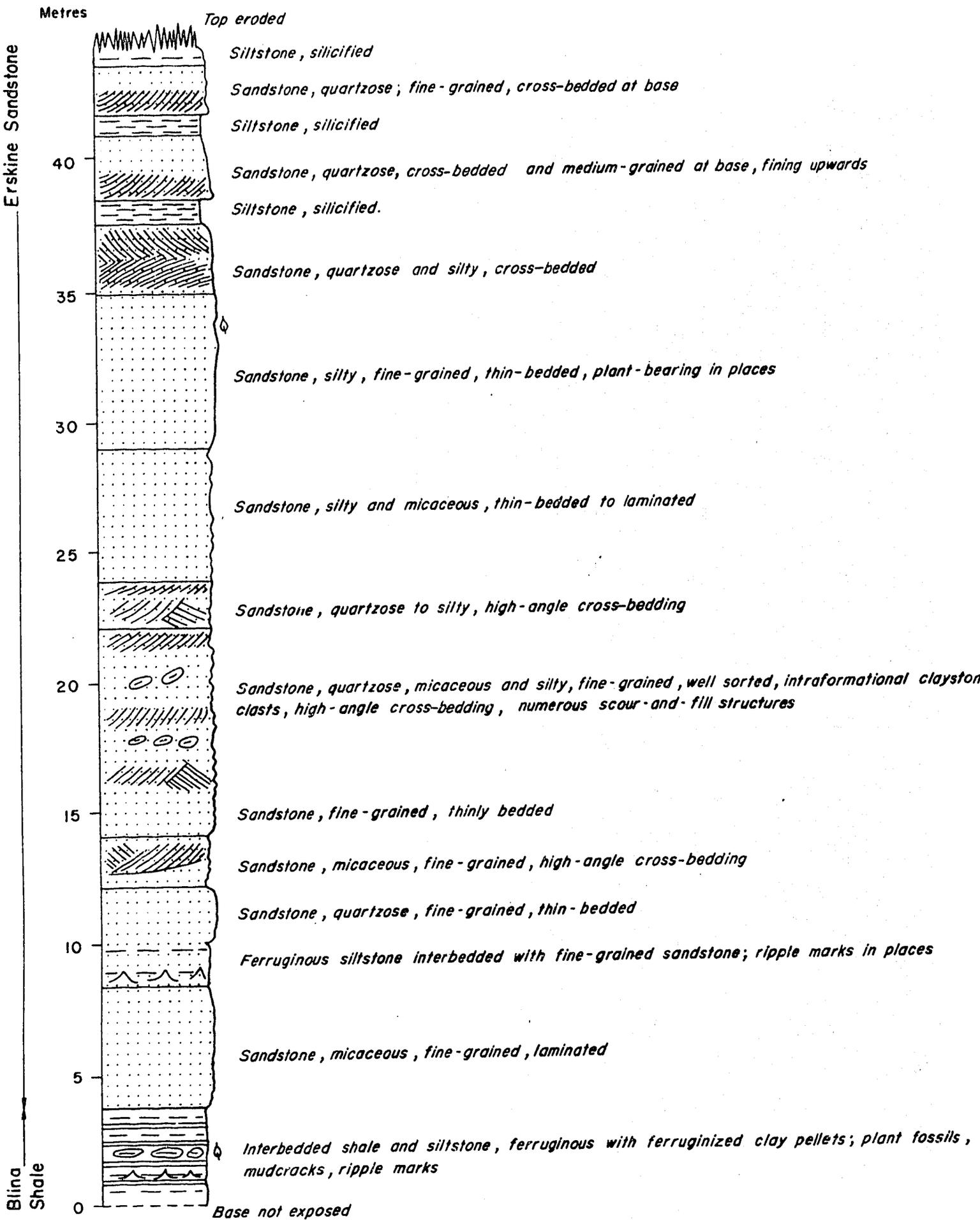


Fig.A30. Measured section of Blina Shale about 9 km. south of Lake Betty, MOUNT BANNERMAN 1:250 000 Sheet area



M(S)379
G.G.

Fig.A31. Measured section of Erskine Sandstone at Point Alphonse, 20°23'30" S, 127°36'30" E, LUCAS 1:250 000 Sheet area.

Record
1575·77

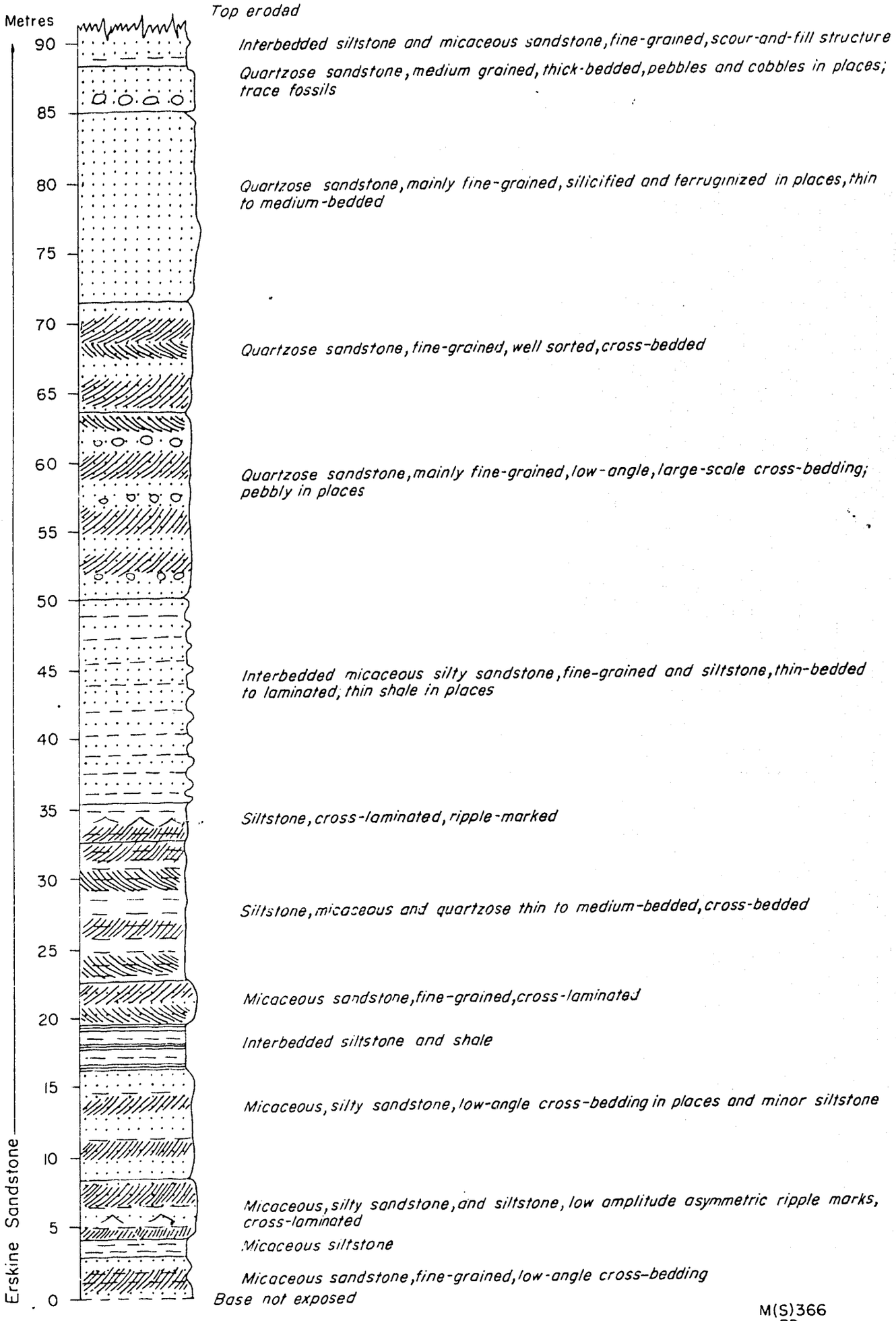


Fig.A32. Measured section of Erskine Sandstone in Stretch Range LUCAS 1:250 000 Sheet area

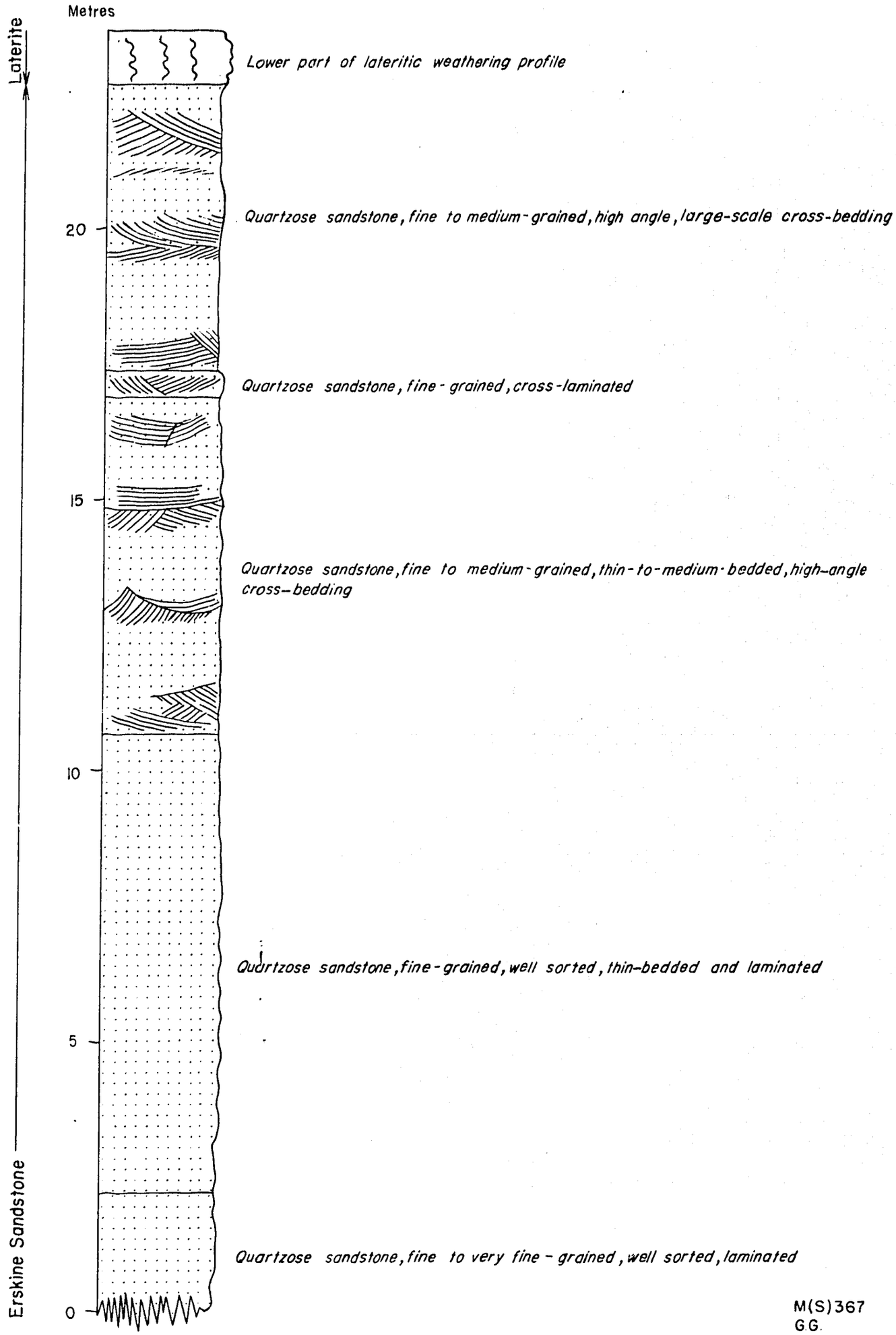


Fig. A33. Measured section of Erskine Sandstone 6 km. east-southeast of Point Alphonse, 20°25'30"S, 127°40'05"E, LUCAS 1:250 000 Sheet area.

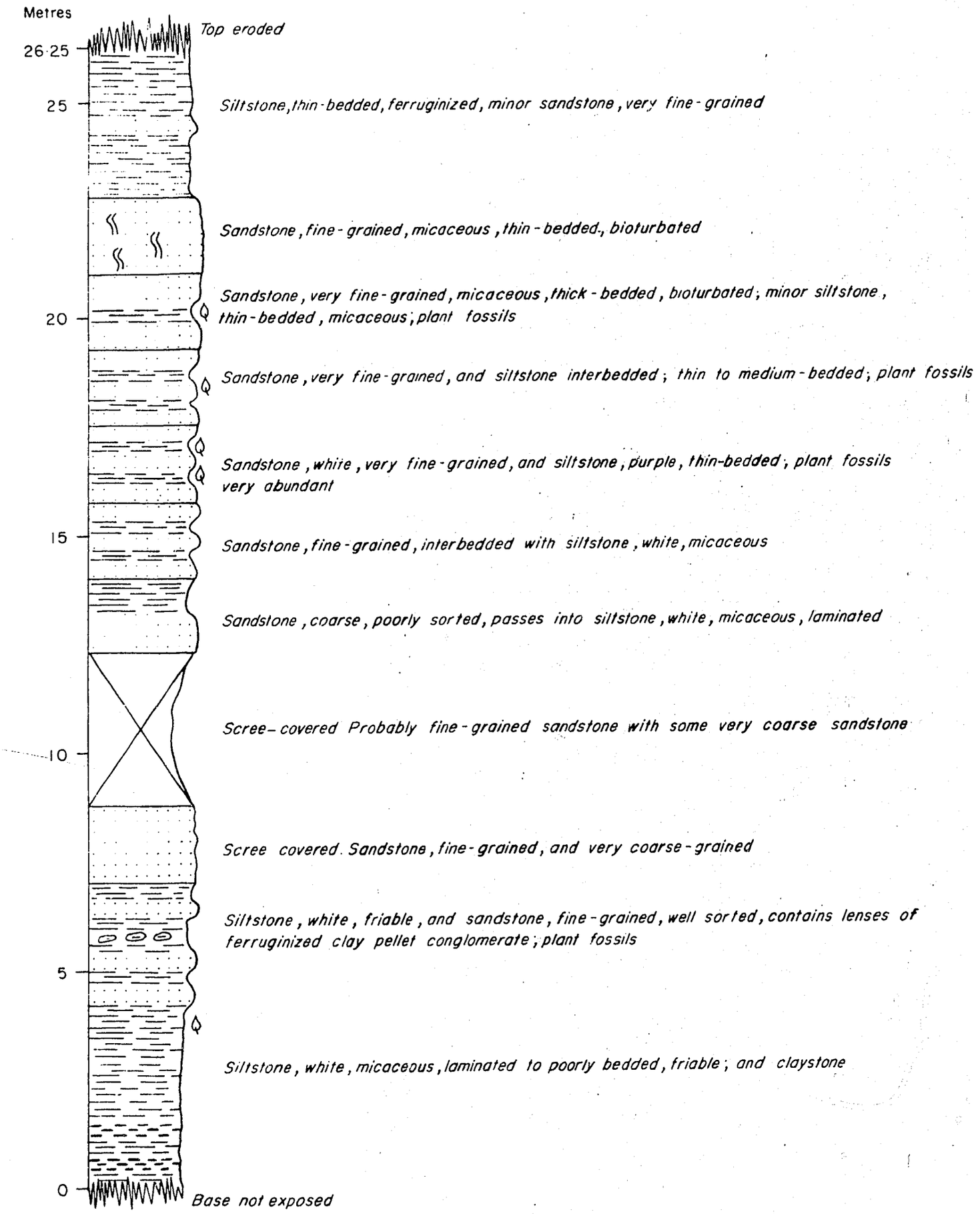


Fig.A34. Measured section of Culvida Sandstone, at 20°18'10" S, 126°51'45" E, CORNISH 1:250 000 Sheet area.

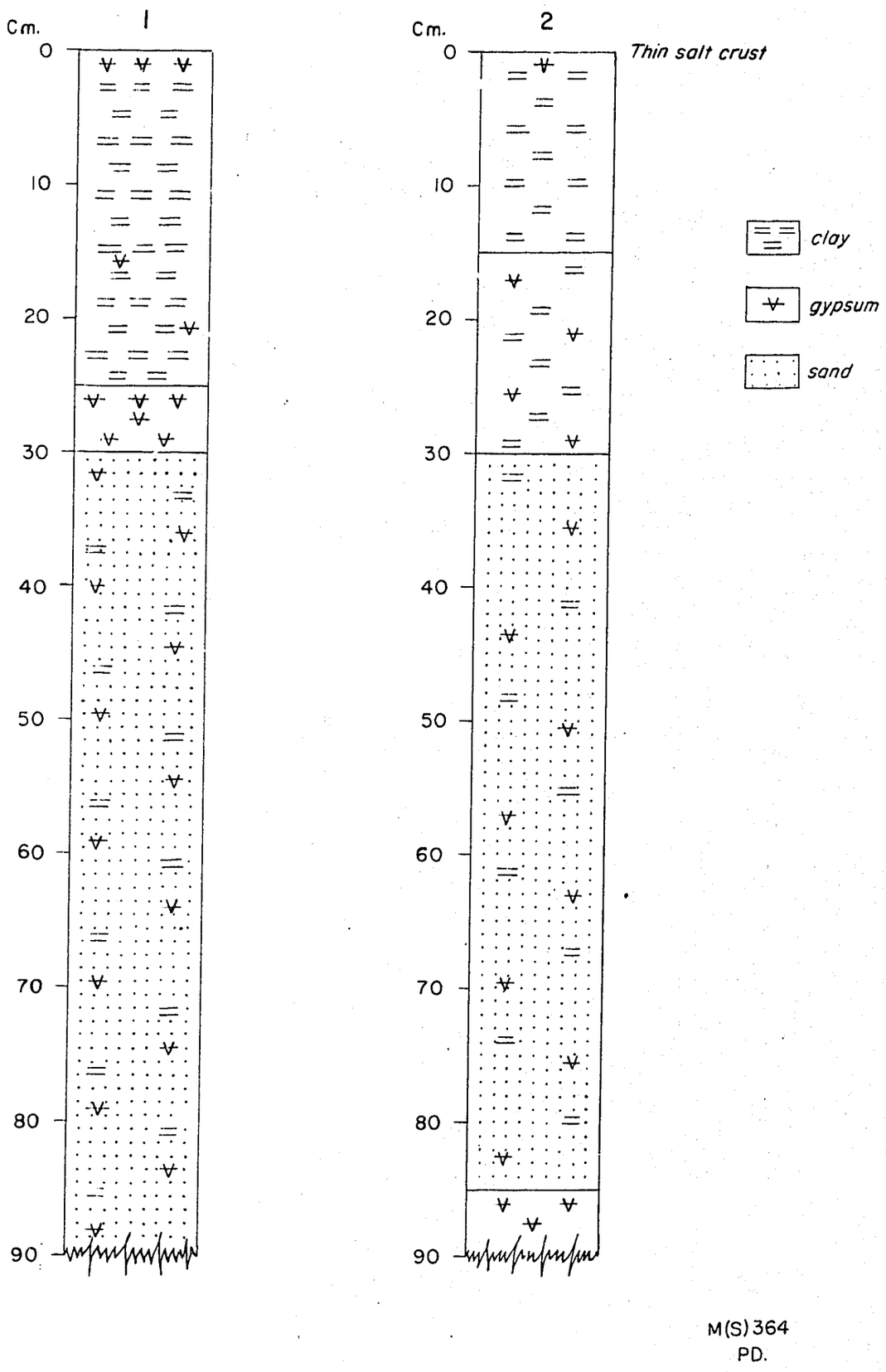
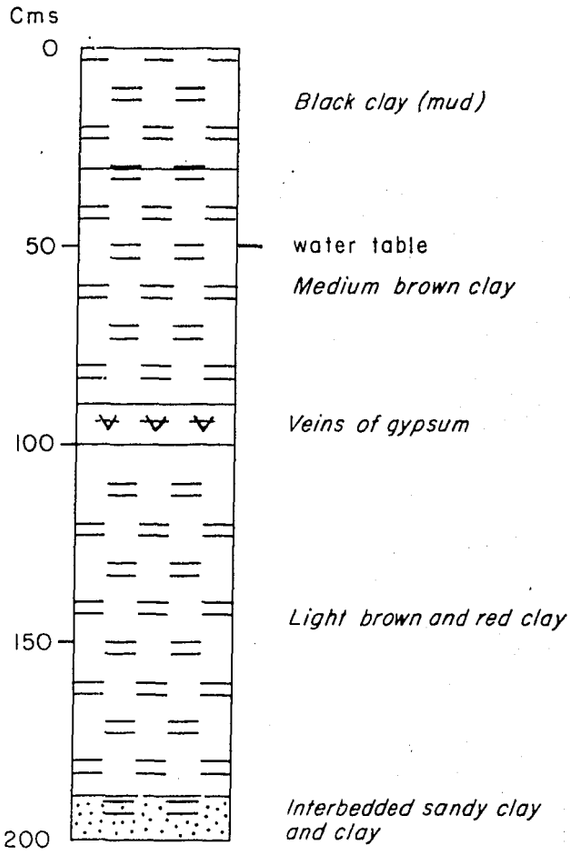
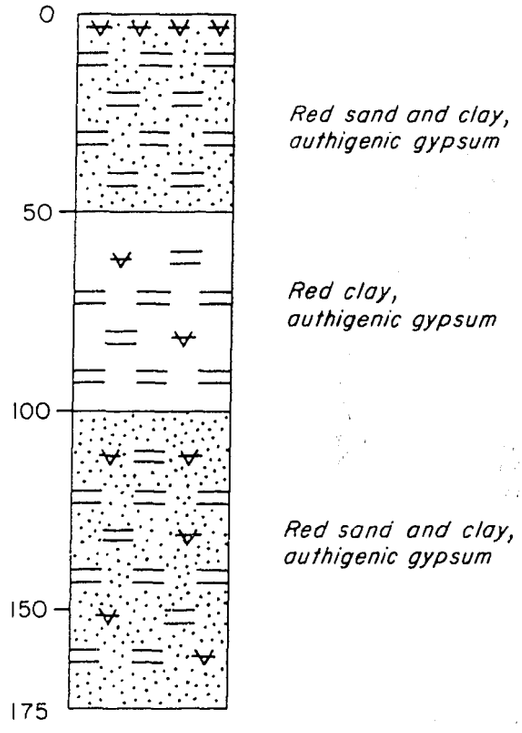


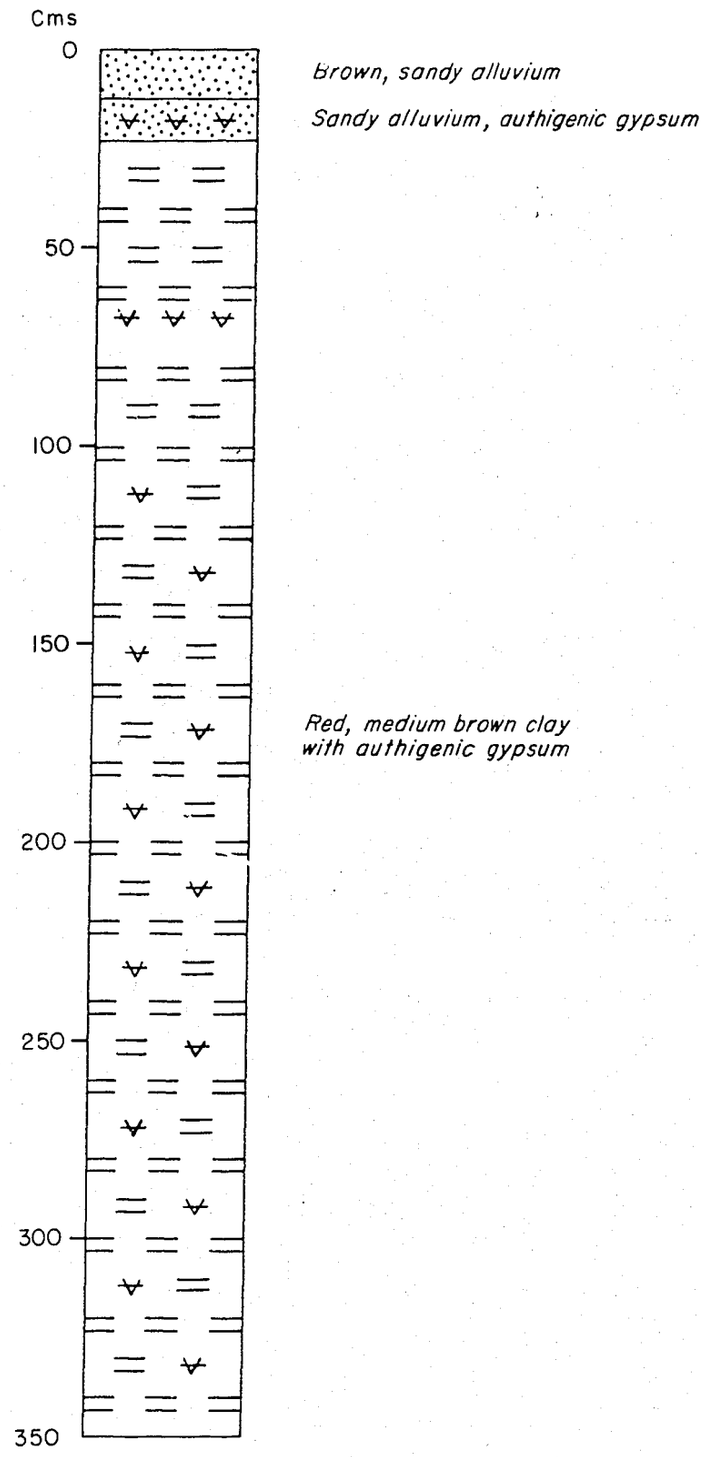
Fig. A 35 Sections encountered in hand-augered holes in salt lakes
1. Salt lake in far southwest HELENA 21°50'00"S, 126°04'00"E.
2. Salt lake in southwest HELENA 21°42'00"S, 126°21'30"E.



Auger hole in Lake Mackay
at 22° 32' S, 128° 33' E



Auger hole in Lake Mackay
at 22° 26' S, 128° 21' E



Auger hole in Lake Mackay
at 22° 35' S, 128° 21' E

Fig. A 36 Auger hole sections in Lake Mackay, WEBB 1:250000 Sheet area

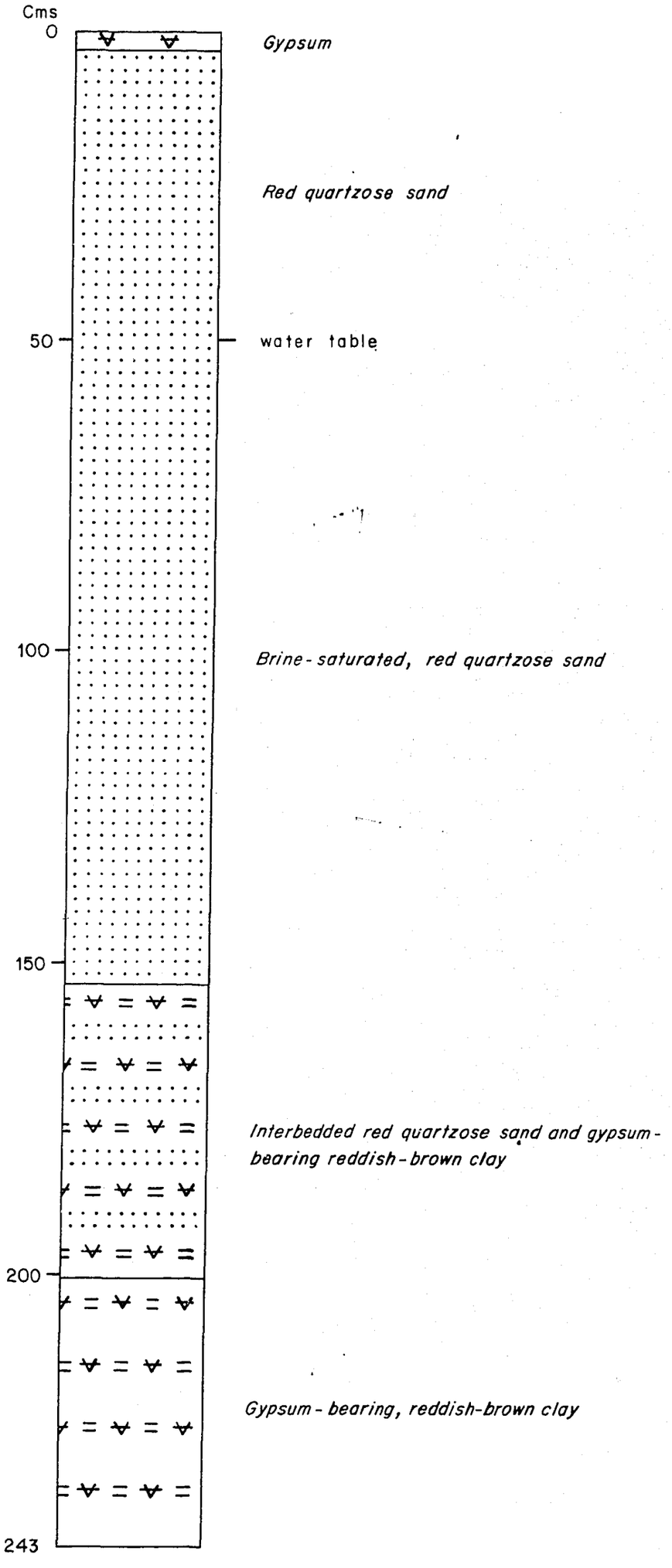
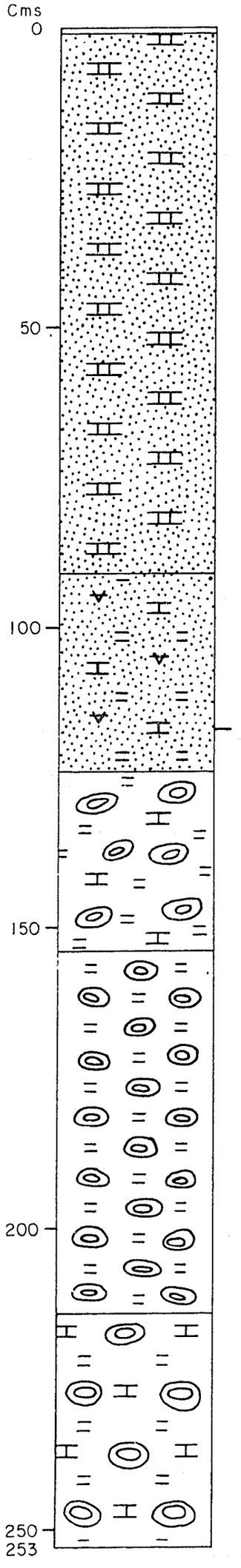


Fig. A 37 Auger hole section in salt lake, 22° 20' 30" S 127° 45' 52" E
WEBB 1:250 000 Sheet area



Thin gypsum crust

Caliche, powdery, interbedded with poorly consolidated calcareous sandstone

Gypsum-bearing, pale green to reddish-brown clayey calcareous sandstone

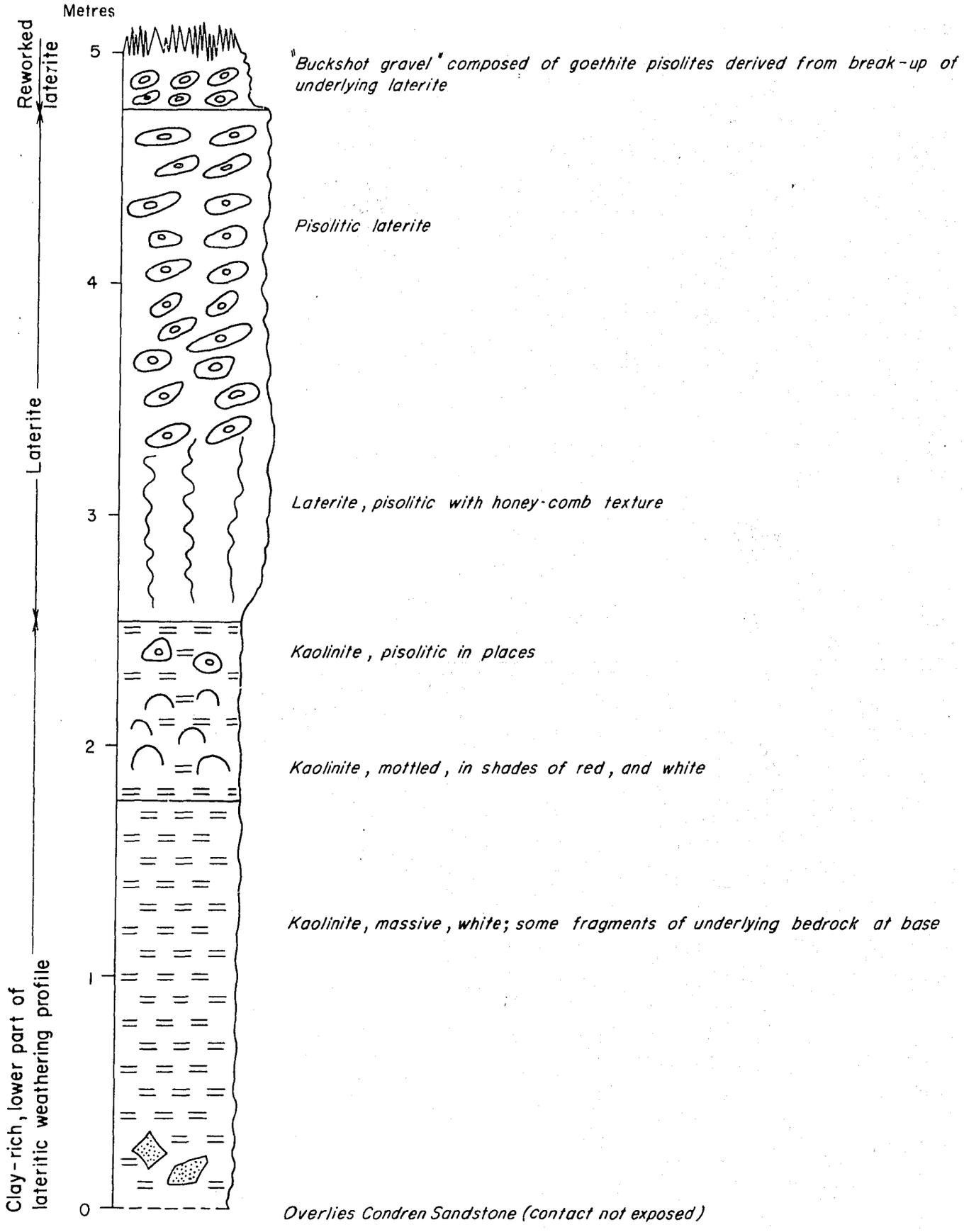
water table

Clayey caliche with ferruginous pisolites

Goethite pisolites in matrix of (?) chamosite and reddish-brown sandy clay

Goethite pisolites in (?) chamosite-bearing, clayey caliche

Fig. A 38 Auger hole section in one of Gwenneth Lakes, southwest DUMMER 1:250000 Sheet area



M(S) 369
G.G.

Fig. A39. Measured section of a lateritic weathering profile, Stansmore Range, 21°15'42" S, 128°01'00" E, STANSMORE 1:250 000 Sheet area

Record
1975-77

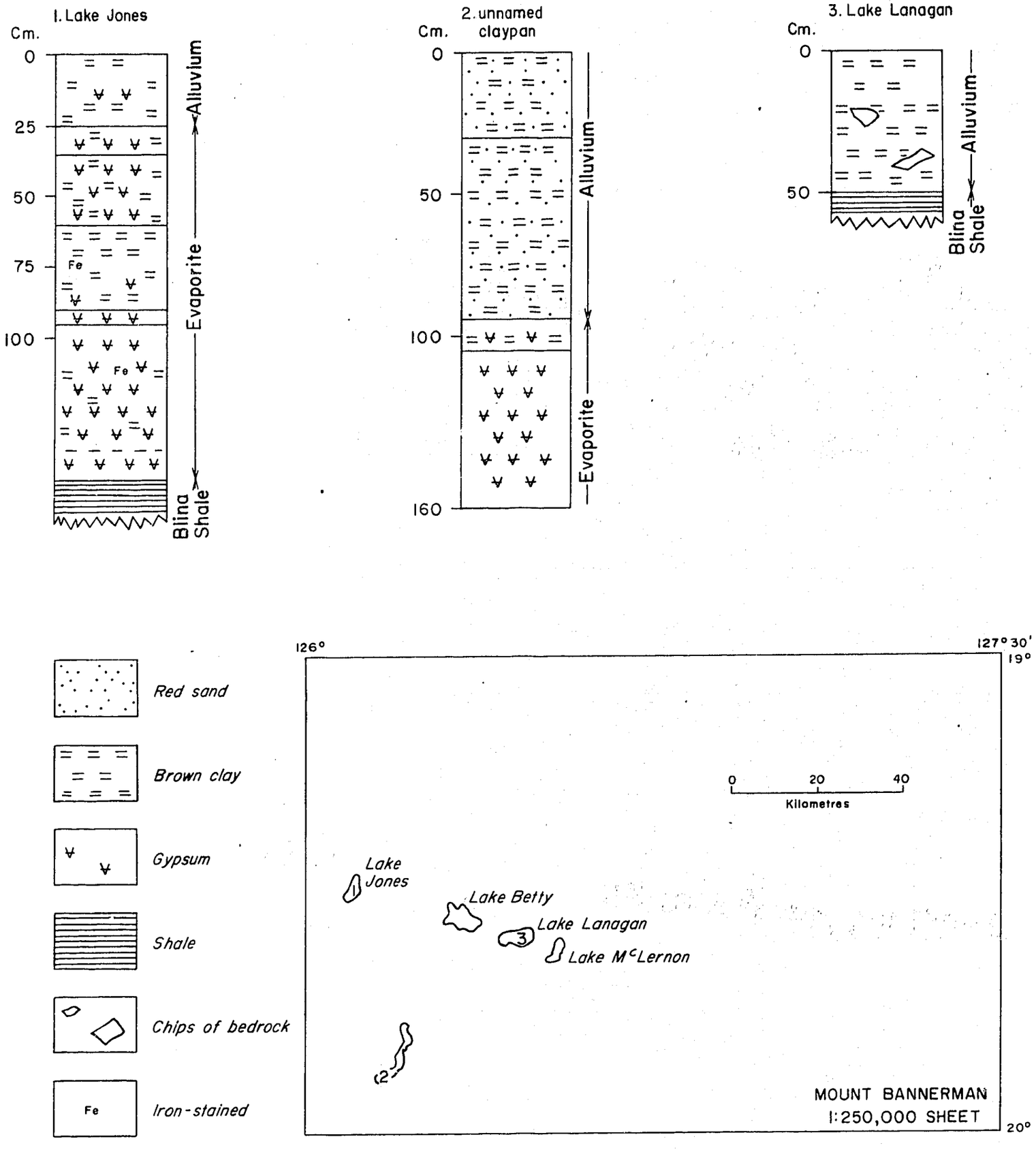


Fig.A40. Sections encountered in hand-augered holes on claypans in MOUNT BANNERMAN 1:250 000 Sheet area.

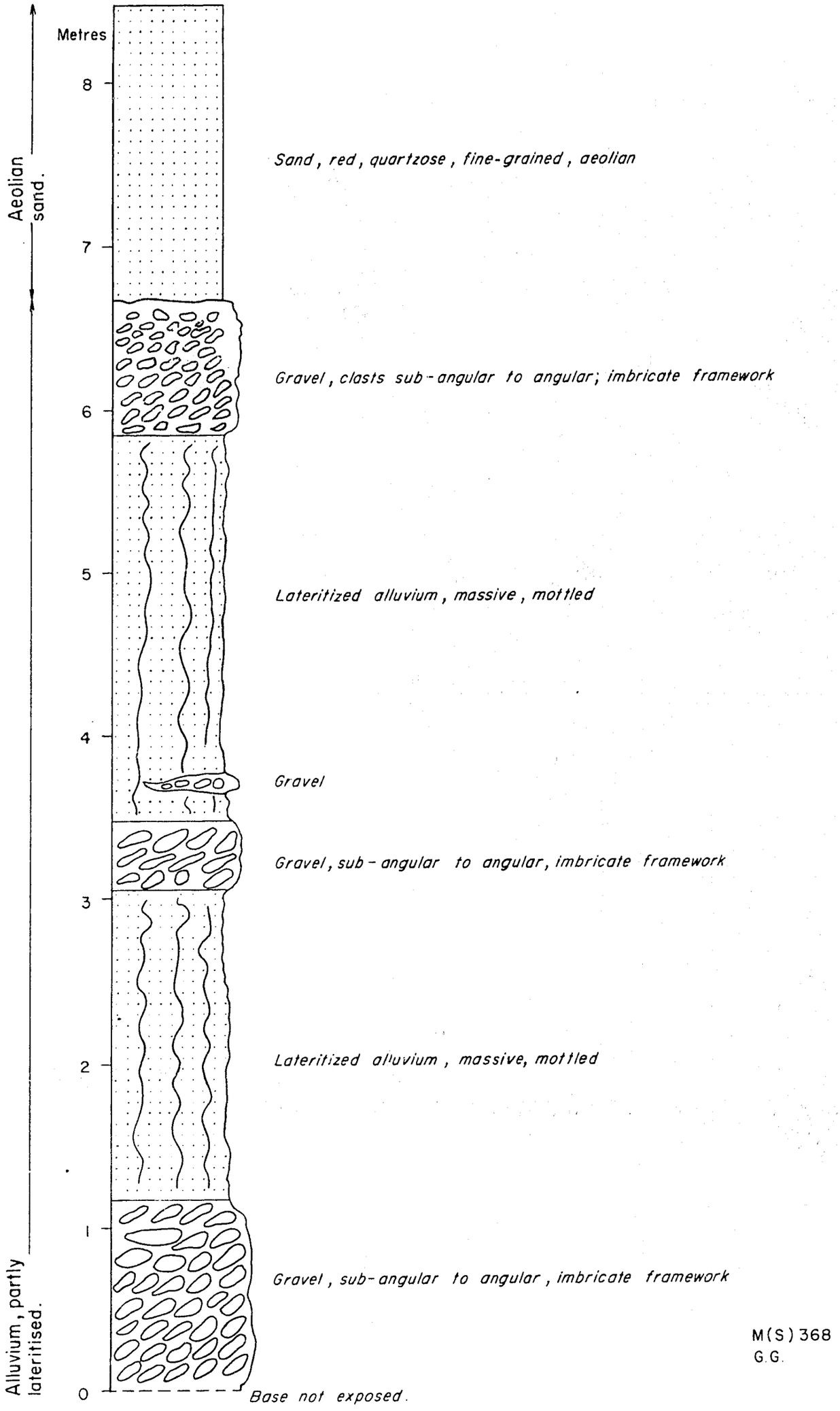
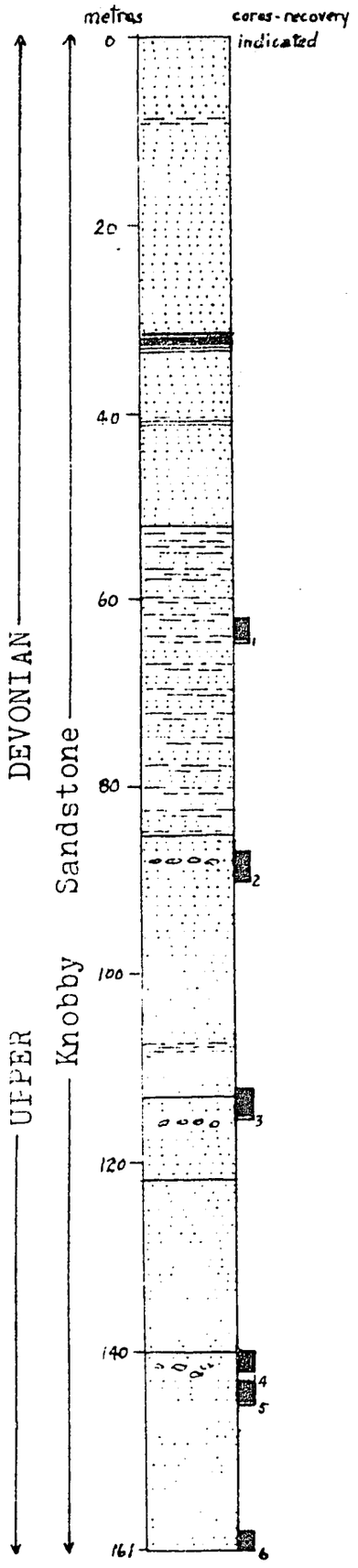


Fig.A41. Measured section of alluvial deposits which have been partly lateritised in gully adjacent to eastern scarp of Stansmore Range, 21°15'42"S, 128°03'30"E STANSMORE 1:250,000 Sheet area

BMR BILLILUNA No 3



0 - 31 Sandstone, quartzose, fine to medium-grained, moderate sorting, subangular to subrounded grains; minor siltstone and granule conglomerate

31 - 33 Shale, red-brown

33 - 52 Sandstone, quartzose, fine to medium-grained; minor shale

52 - 85 Sandstone, quartzose, micaceous, fine-grained, low-angle cross-bedding, clay pellets abundant; interbedded with siltstone, pink, white, clayey

85 - 113 Sandstone, quartzose, fine medium-grained, grains subrounded with low sphericity; minor granule conglomerate with clay pellets; and minor siltstone

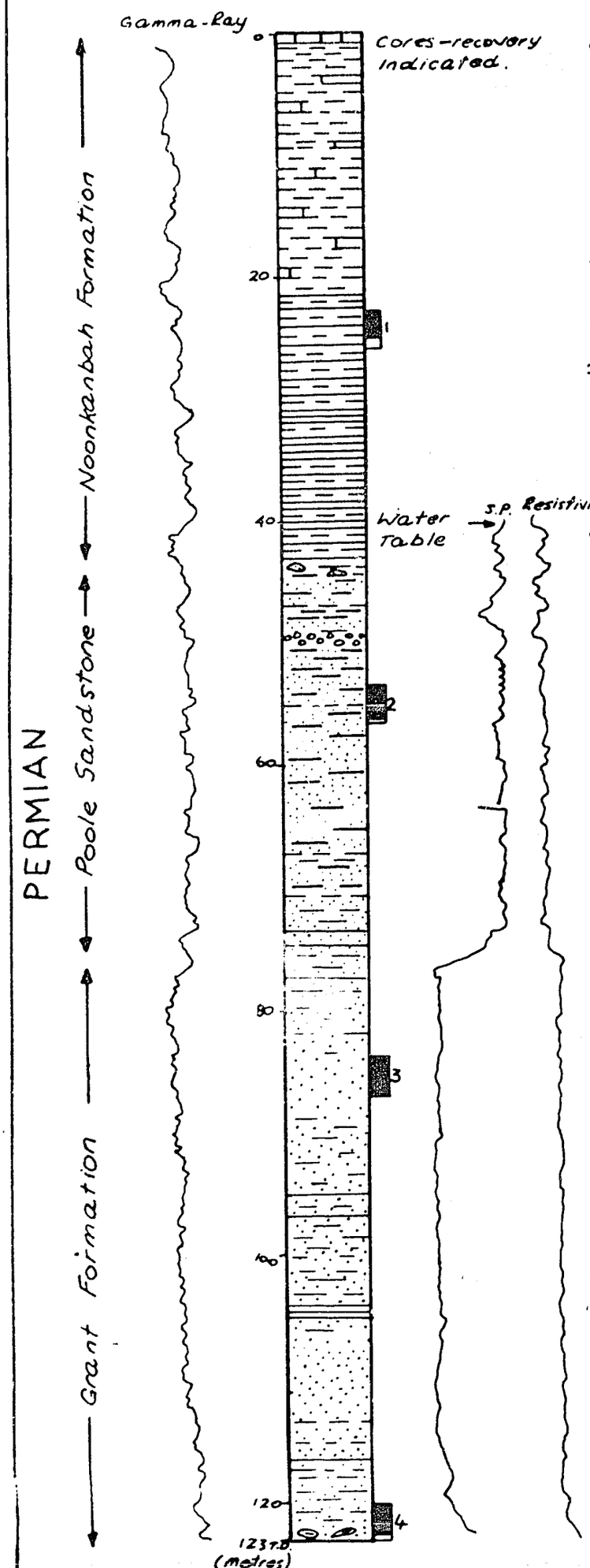
113 - 122 Sandstone, white, medium to coarse-grained; and granule-conglomerate with minor clay pellets

122 - 140 Sandstone, white, fine to medium-grained, rare granules of quartz

140 - 161 Sandstone, white, medium to coarse-grained; minor granule conglomerate with clay pellets

Fig. 81 Knobby Sandstone

BMR BILLILUNA No 1



0-21 M. Siltstone; variegated, light grey, red and brown, purple, micaceous, calcareous, fissile limonitic and minor shale, purple, micaceous

21-32 M. Siltstone; grey, brown, limonitic, micaceous, interbedded with carbonaceous mudstone, dark-grey to black

32-43 M. Mudstone; black and brown, carbonaceous, with minor siltstone; brown, grey, micaceous, ferruginied

43-70 M. Sandstone; fine to very fine-grained, grey and yellow, pebbly

70-76 M. Sandstone; fine to medium-grained, variegated, multicoloured, poorly sorted, angular grains, arkosic and claystone; micaceous, white

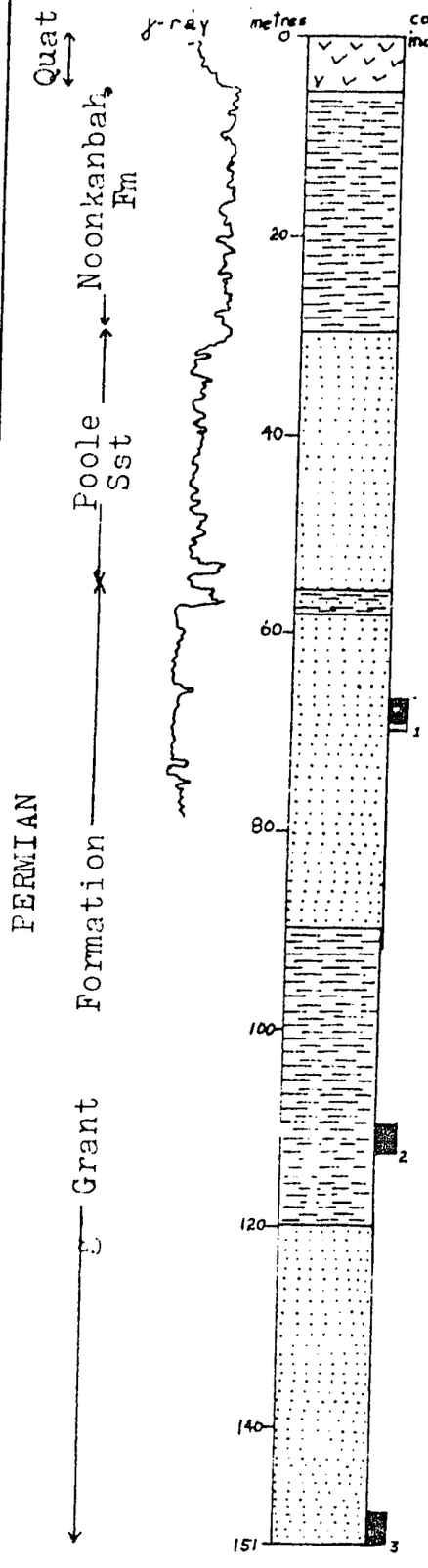
76-80 M. Sandstone; fine to medium-grained, clay matrix, ferruginied and siltstone; micaceous, laminated, stained with hematite

80-104 M. Sandstone; medium-grained, ferruginised at top, moderate sphericity, subrounded, arkosic, clay matrix and interbedded minor siltstone; red, micaceous, fissile

104-123 M. Sandstone; medium-grained, mostly clean, iron-stained in places and interbedded with siltstone; red, micaceous, pyritic, minor shale and claystone, white at top and at base- sandstone; coarse-grained, yellow and red, with intra-formational clay pellets

Fig. B2 Grant Formation, Pool Sandstone and Noonkanbah Formation

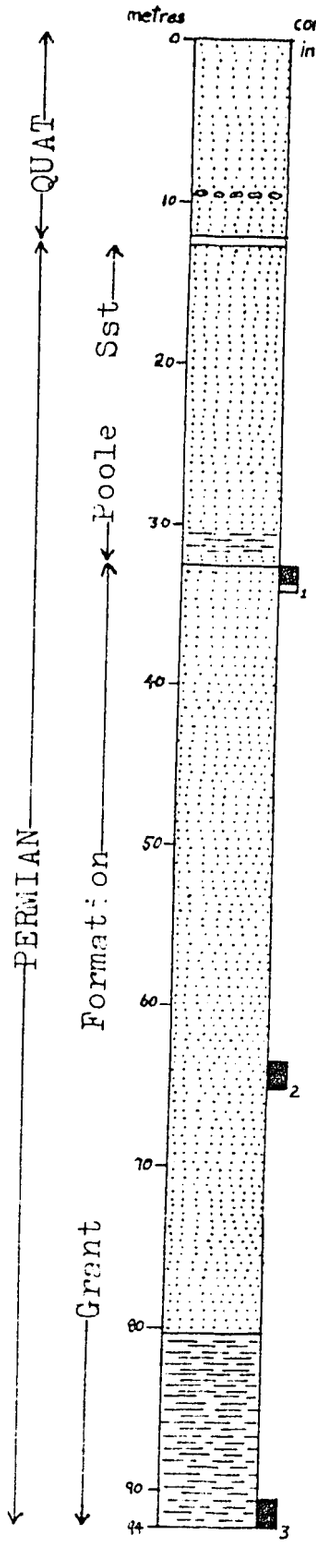
BMR MT BANNERMAN No 4



0-5.5	Alluvium, red sandy soil
5.5-29	Siltstone, multicoloured, black, micaceous; weathered
29-55	Sandstone, white, quartzose, micaceous, very fine-grained, thin-bedded; minor siltstone
55-58	Sandstone, fine-grained, micaceous, interbedded with siltstone and black shale
58-90	Sandstone, white, fine-grained, micaceous, cross-bedded; minor siltstone and claystone
90-120	Siltstone, black, micaceous, carbonaceous, pyritic, laminated
120-151	Sandstone, quartzose, white to brown, fine to medium-grained, laminated, low-angle cross-bedding; minor shale

Fig. B3 Grant Formation, Poole Sandstone and Noonkanbah Formation

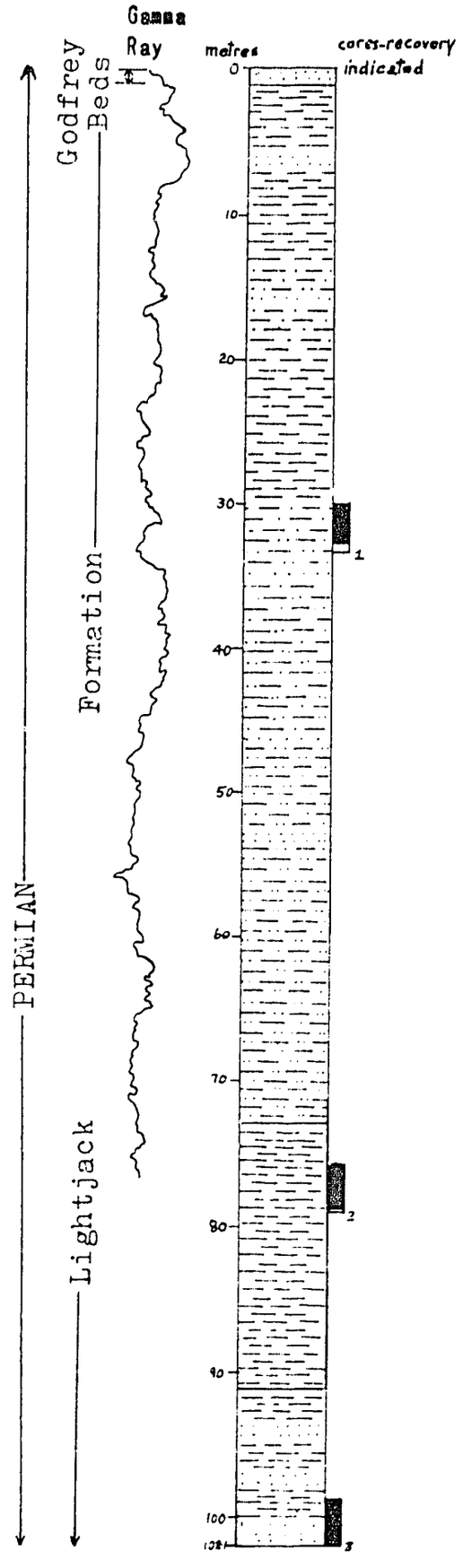
MT
BMR BANNERMAN No 3



0-14.5	Sand, quartzose, red, coarse-grained; and minor quartz gravel
14.5-15	Laterite
15-35	Sandstone, quartzose, white, fine to medium-grained, micaceous
35-80	Sandstone, quartzose, red-brown, white, medium to coarse-grained, high-angle cross-bedding, clay pellets abundant; minor siltstone, white, laminated; and minor granule-conglomerate; wood fragments
80-94	Siltstone, black, grey, micaceous, laminated, low-angle cross-bedding, pyritic; plant fragments

Fig. B4 Grant Formation and Poole Sandstone

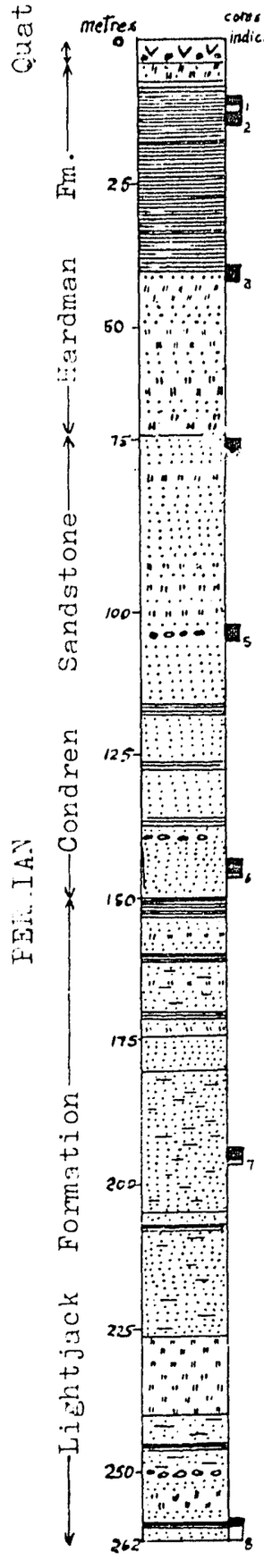
BMR LUCAS No 14



0-1.3	Sandstone, fine to medium-grained, micaceous; silicified
1.3-33.5	Siltstone, brown, grey, laminated; interbedded with sandstone, silty, very fine-grained; weathered
33.5-73.0	Sandstone, silty, grey, very fine to fine-grained, laminated
73.0-91.5	Siltstone, grey and black, micaceous, laminated, low-angle cross-bedding; carbonaceous, pyritic in parts; minor sandstone, silty
91.5-102.1	Siltstone, black, grey, carbonaceous, interbedded with sandstone, grey, fine-grained, low-angle cross-bedding.

Fig. 85 Lightjack Formation

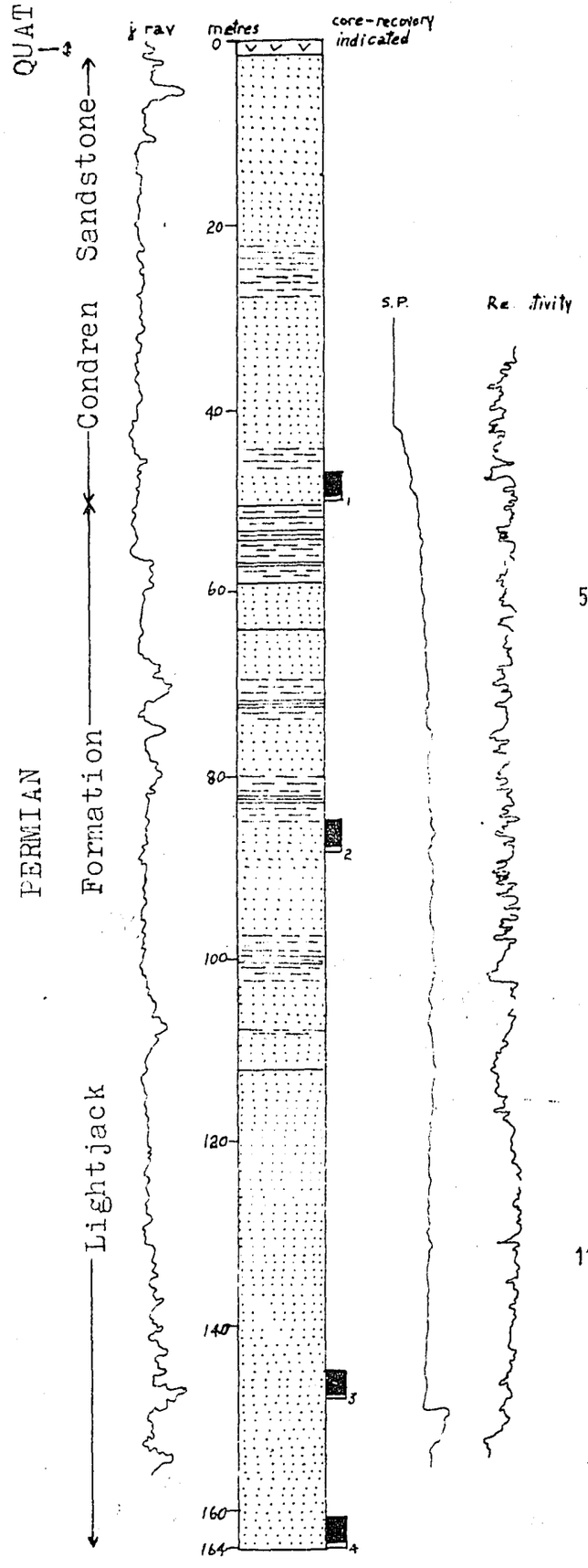
BMR CROSSLAND No1



0–3	Alluvium, white, fine; minor gravel
3–6	Siltstone, white, pink, micaceous; minor sandstone, fine-grained; weathered
6–41	Shale, black, carbonaceous, laminated
41–70	Sandstone, grey, very fine to fine-grained; interbedded with siltstone, light grey, calcareous and shale, black, carbonaceous, laminated
70–103	Sandstone, quartz, fine-grained; interlaminated with siltstone, grey and shale, black, carbonaceous. Small-scale, low-angle, cross-bedding; ripple x-laminated.
103–150	Sandstone, quartz, micaceous, fine to medium-grained, laminated to thin-bedded, cross-bedded; calcareous in places; minor shale, black, carbonaceous.
103	Thin bed of quartz-granule conglomerate
150–175	Shale, black, carbonaceous, pyritic; interbedded with sandstone, clayey, fine-grained, and siltstone
175–178	Sandstone, light green, quartzose, fine-grained, carbonaceous; minor shale
178–209	Sandstone, grey, fine-grained, micaceous, variable clay matrix; pyritic
209–227	Sandstone, green-grey, clayey and micaceous; minor shale, black, carbonaceous
227–240	Siltstone, grey, clayey, calcareous, carbonaceous; laminated.
240–250	Sandstone, grey, fine-grained, variable clay matrix; interbedded with shale, black, carbonaceous
250–262	Shale, black, carbonaceous; and sandstone, grey, fine-grained, micaceous; laminated

Fig. 86 Lightjack Formation, Condren Sandstone and Hardman Formation

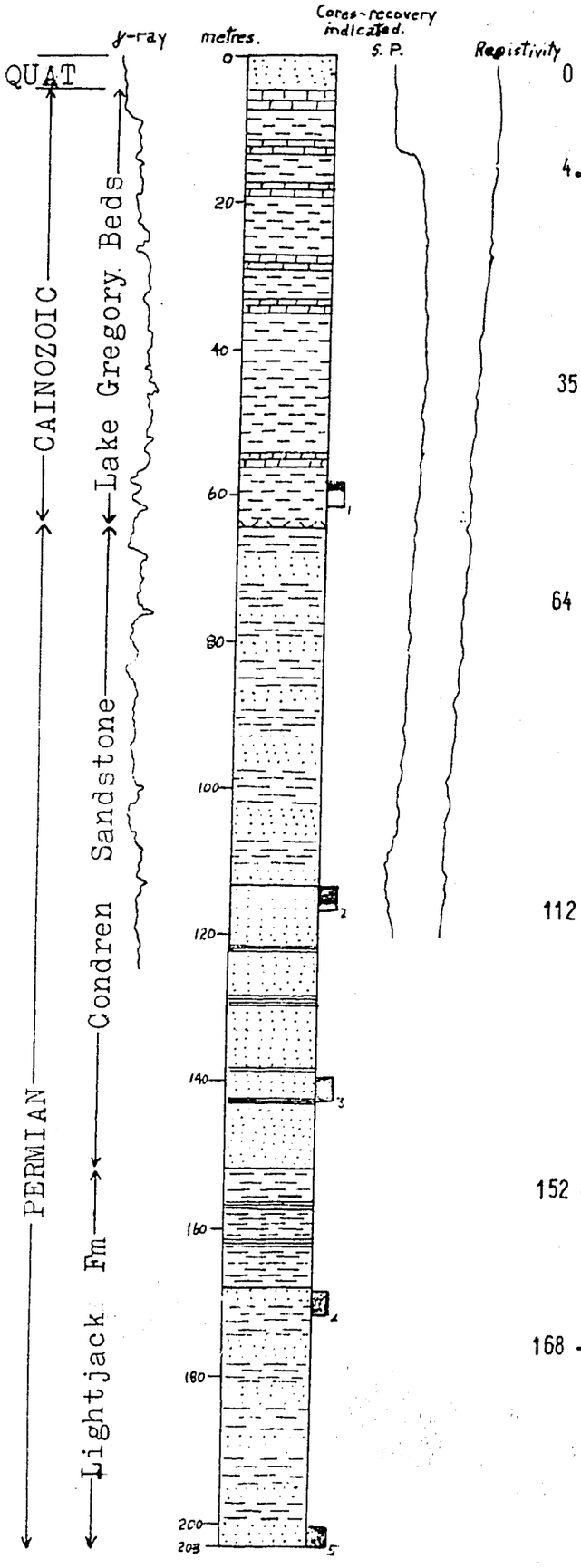
BMR CORNISH No 1



0 - 1.5	Alluvium, red, yellow
1.5 - 51	Sandstone, quartzose, micaceous, fine-grained, well-sorted, variable clay matrix, minor calcareous cement; and siltstone, grey, brown, carbonaceous
51 - 59	Siltstone, pale grey and shale, black, carbonaceous, interbedded
59 - 63	Sandstone, quartzose, fine to medium-grained, well sorted
63 - 112	Sandstone, quartzose, fine-grained, well sorted, interbedded with siltstone, grey and shale, black, carbonaceous, laminated
112 - 164	Sandstone, quartzose, blue-grey, micaceous, fine-grained, well sorted, laminated

Fig. 87 Lightjack Formation and Condren Sandstone

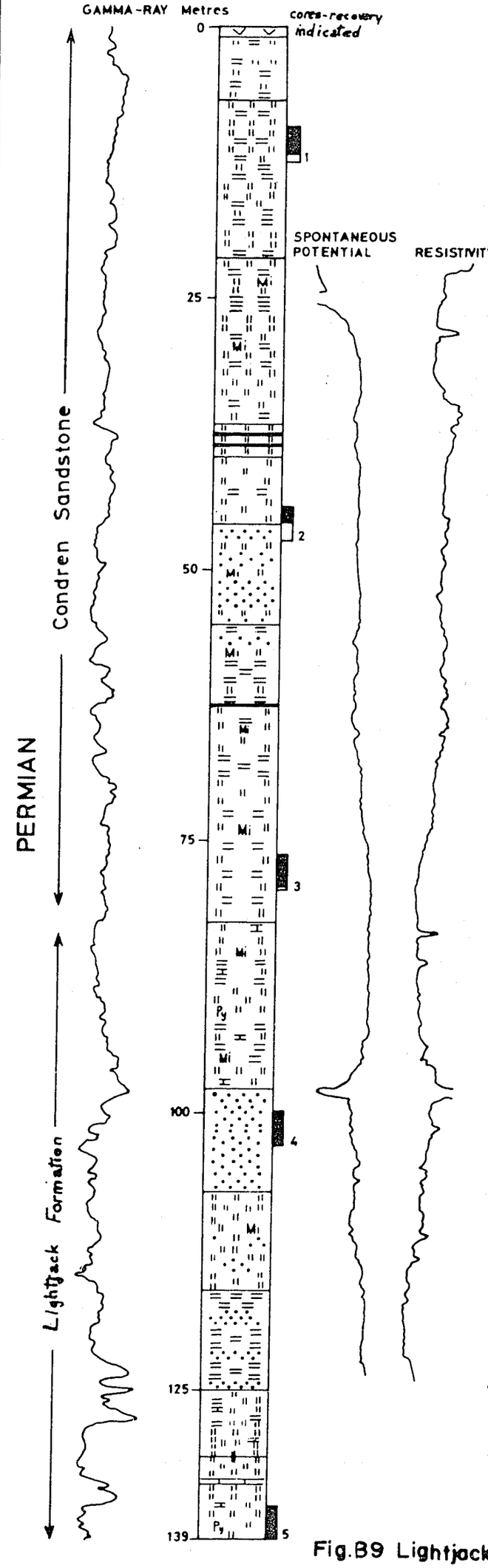
BMR MT BANNERMAN No. 1



0 - 4.6	Alluvium, sand, quartz, red, fine to medium-grained
4.6 - 35	Calcrete, white interbedded with clay, green and brown, calcareous; minor sand, calcareous
35 - 64	Clay, pale green, pale brown; minor marl, chalcedony and rare moss agate
64 - 112	Sandstone, quartzose, clayey, white, fine-grained, interbedded with siltstone, multicoloured, laminated; minor chalcedony and clay; weathered
112 - 152	Sandstone, quartzose, fine to very fine-grained, well sorted, thin-bedded, ripple cross-laminated, low-angle cross-bedding, interbedded with shale, black, carbonaceous, laminated, and pale grey siltstone
152 - 168	Siltstone, grey interbedded with shale, black, carbonaceous; minor sandstone
168 - 203	Sandstone, grey, quartzose, micaceous, fine-grained, well-sorted, interbedded with siltstone, black, carbonaceous, micaceous

Fig. 88 Lightjack Formation, Condren Sandstone and Lake Gregory Beds

BMR MT. BANNERMAN No.2



0-1 Alluvium, white, fine, micaceous

1-6·7 Siltstone, red and light grey, micaceous; and claystone, red, grey, yellow, weathered

6·7-21 Siltstone, grey, micaceous; interlaminated with mudstone, black, very carbonaceous, slump and flowage structures

21 Water table

21-37 Siltstone, grey, micaceous; interlaminated with mudstone, black, carbonaceous; and claystone, white

37-40 Siltstone; thin beds of coal

40-46 Siltstone, grey; interlaminated with mudstone; carbonaceous; and claystone, white

46-55 Sandstone, white, grey, very fine-grained, well sorted; interbedded with siltstone, grey, micaceous; and mudstone, black, carbonaceous

55-62 Siltstone, white, dark grey and black, micaceous; interbedded with sandstone, fine-grained

62·5 Thin beds of coal

82-98 Siltstone, white and black, micaceous, slightly calcareous; interbedded with mudstone, black, carbonaceous; thin lens of pyrite at 90 m

98-107 Sandstone, grey, fine-grained, well sorte-d variable amount of clay matrix, low angle cross-bedding

107-116 Sandy siltstone, black and white, micaceous, carbonaceous specks

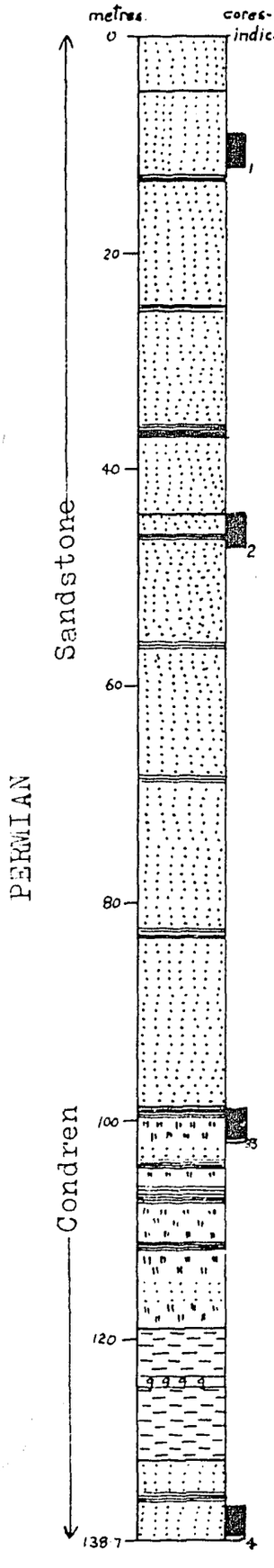
116-125 Mudstone, black, very carbonaceous; and sandstone; thin beds

125-131 Siltstone, grey and white, thin carbonaceous and calcareous laminae

131-139 Siltstone, white, grey and black, sandy in parts, carbonaceous, pyritic, calcareous; interbedded with mudstone, black, carbonaceous

Fig.B9 Lightjack Formation and Condren Sandstone

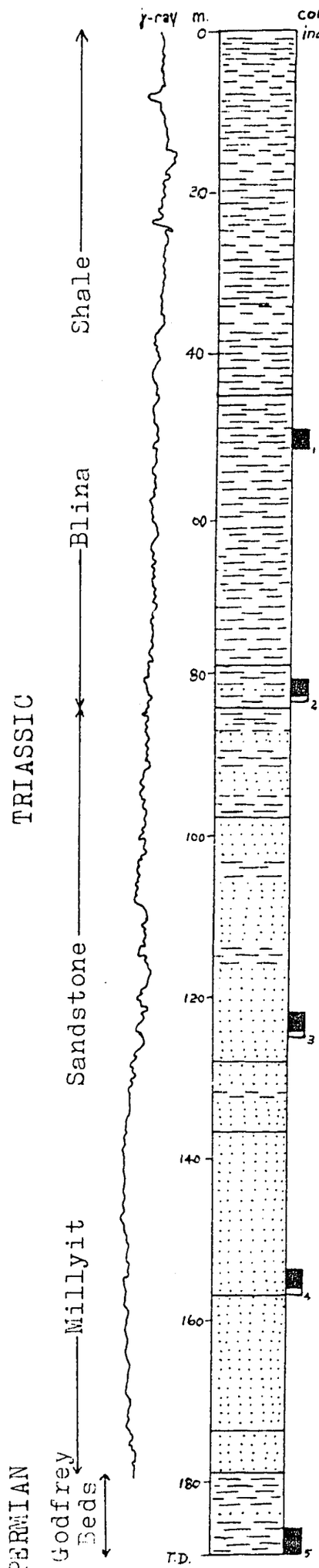
BMR CROSSLAND No2



0–4.6	Sandstone, quartz, white to brown, fine-grained, well sorted; gypsum in thin bands; weathered
4.6–44	Sandstone, quartz, grey to black, micaceous, fine-grained, variable clay matrix; some thin carbonaceous bands
44–99	Sandstone, quartz, white, fine-grained; laminated, low-angle festoon cross-bedding; interbedded with shale, black, carbonaceous
99–118.9	Shale, black, carbonaceous, interbedded with siltstone, pale grey, laminated, and sandstone, quartz, fine-grained, thin-bedded; small-scale cross-bedding, ripple cross-laminated, bioturbated
105	Thin bed of hard, grey, calcareous sandstone
118.9–131	Claystone, white to grey, with fine sand grains; laminated; minor shale, carbonaceous
123.4	Thin bed of gypsum
131–138.7	Sandstone, pale grey, fine to medium-grained, laminated low-angle cross-bedding; minor carbonaceous shale

Fig. B10 Condren Sandstone

BMR LUCAS No 13



0–45.7 Siltstone, multicoloured, micaceous, laminated, interbedded with minor claystone; weathered

32 Water table

45.7–79 Siltstone, black, grey, mauve, micaceous, laminated; thin colour bands

79–85 Siltstone, pale grey to black, micaceous, carbonaceous, laminated; minor sandstone, grey, fine-grained, cross-bedded, graded bedding

85–97.5 Interbedded siltstone and sandstone, grey, micaceous, carbonaceous

97.5–128 Sandstone, grey, fine-grained, well sorted, micaceous, carbonaceous; minor siltstone

128–137 Sandstone, grey, fine to medium-grained, micaceous, ferruginized; minor claystone

137–157 Sandstone, quartzose, white, medium to coarse-grained, high-angle cross-bedding; few scattered quartz pebbles

157–174 Sandstone, quartzose, white, fine to medium-grained

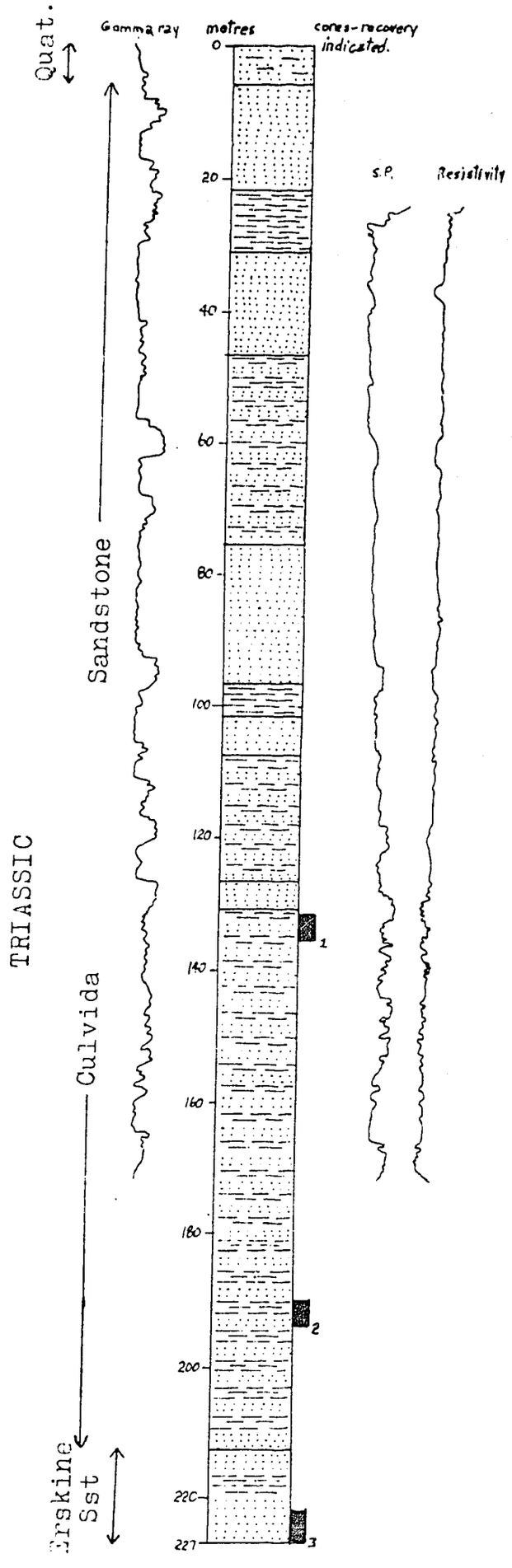
174–178 Sandstone, white, coarse to very coarse-grained

178–189 Siltstone, grey and black, carbonaceous, thin bedded; minor sandstone, fine-grained

Fig. 811 Godfrey Beds, Millyit Sandstone and Blina Shale

Record 1975/77

BMR CORNISH No 2

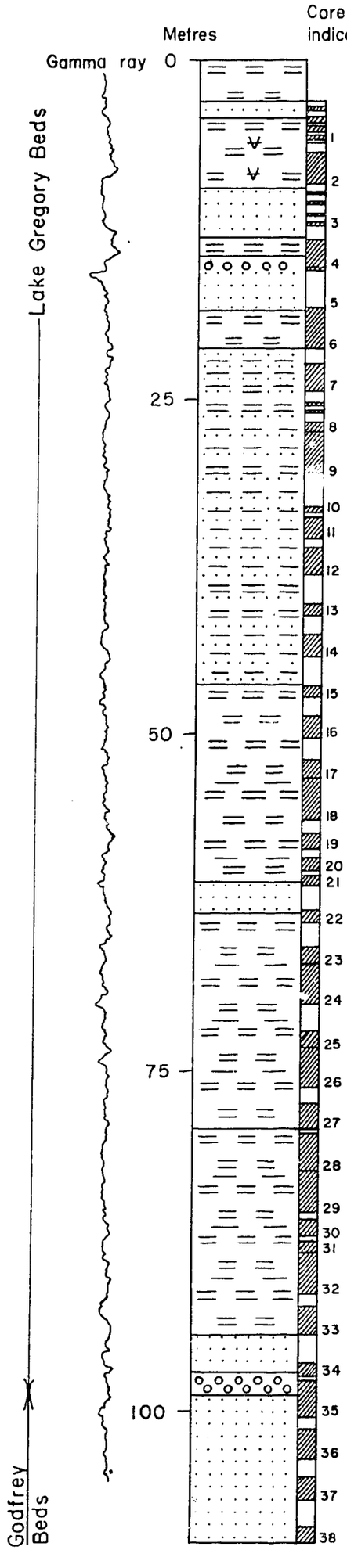


0-6	Sand, brown and red, silty; conglomerate, granule, poorly consolidated; minor calcrete
6-22	Sandstone, quartzose, fine to medium-grained, micaceous, poor to moderate sorting; quartz grains coated with hematite
22-31	Siltstone, kaolinitic, white, mauve; minor sandstone
31-47	Sandstone, quartzose, fine to medium-grained, well sorted; minor quartz granule conglomerate
47-76	Siltstone, white, mauve, kaolinitic interbedded with sandstone, quartzose to clayey, fine-grained; minor quartz granule conglomerate
76-98	Sandstone, quartzose, medium to coarse-grained; minor conglomerate
98-102	Siltstone, white, kaolinitic
102-108	Sandstone, quartzose, medium-grained; quartz grains stained by iron
108-127	Siltstone, multicoloured, kaolinitic, interbedded with sandstone, quartzose to clayey
127-131	Sandstone, quartzose, medium-grained
131-213	Siltstone, green-grey, earthy-red, black, carbonaceous, laminated, interbedded with sandstone, quartzose, fine-grained, green
213-227	Sandstone, blue-grey, very fine-grained, interbedded with siltstone, green and grey, carbonaceous, laminated

Fig. 812 Culvida Sandstone

BMR

CORNISH No.3



0-3·1m *Clay, pale green to grey, and sand, fine to medium-grained*

3·1-4·3m *Sand, red, medium to coarse-grained.*

4·3-9·4m *Clay, grey, cream, green with authigenic gypsum, cross-laminated*

9·4-13·1m *Sand, pale grey to white, fine to very fine-grained, with some clay matrix*

13·1-14·6m *Mud, grey, green, rare grains of quartz sand*

14·6-18·6m *Sand, red, fine to medium-grained, conglomeratic at top*

18·6-21·3m *Mud, grey, green, red, thin beds of lateritic pisolites at top*

21·3-46·3m *Sandy silt, red to brown; interbedded with silty clay*

29·0m *thin bed of lateritic pisolites*

42·7m *thin bed of sandstone, white, very fine grained*

46·3-61·0m *Silty clay, pale olive, brown; interbedded with sandy silt, pale green, brown*

53·3m *thin bed of conglomerate, clasts of ferruginized rock*

61·0-63·4m *Sand, pale brown, very fine-grained, well sorted*

63·4-94·5m *Silty claystone, interbedded pale green and brown, mottled, poorly lithified; some clayey siltstone*

79·2m *bed of laterite pisolites*

94·5-97·2m *Sand, light brown, very fine-grained, clay matrix*

97·2-99·1m *Conglomerate, brown clasts up to medium pebble size, clasts mainly lateritic pisolites in clay matrix*

99·1m-Base *Siltstone, multicoloured, interbedded with sandstone, very fine-grained, unconformably overlying Permian Sandstone(? Godfrey Beds)*

M(S) 362

G.G.

Fig. B13 0-99·1m Cainozoic Lake Gregory Beds.

Record 1975·77

APPENDIX C. Palynological study of cores cut in BMR stratigraphic drill holes by R. Paten and P. Price, Mines Administration Ltd.

SAMPLE	DEPTH (m)	AGE	STRATIGRAPHY		REMARKS
			BIOSTRATIGRAPHIC UNIT	INFERRED STRATIGRAPHIC LIMIT	
BMR Lucas No. 13			(Evans 1966)		
Core 1	48.8-51.8	Early Triassic	Tr2	Blina Shale	Abundant spinose Acritarchs suggest some marine influence in the depositional environment. Falcisporites sp. and Striatiti (including Lunatisporites sp.) relatively common. Rare Aratrisporites sp. present
Core 2	80.1-83.8	Early Triassic		Blina Shale	Low proportion of spinose acritarchs present suggesting some marine influence
Core 3	121.9-125	Early Triassic	Tr1b	Blina Shale	Abundant spinose acritarchs suggest some marine influence in the depositional environment. Protohaploxypinus spp. and Falcisporites spp. common
Core 5	188.9	Early Triassic	Tr1b (basal)	Blina Shale	Abundant spinose acritarchs suggest marine influence in the depositional environment. Striatiti (including P. reticulatus & "Paravittatina" sp.), Cretaceaepollenites sinuosus and Granulatisporites sp. common. Very rare Lunatisporites spp.
BMR Lucas No. 14					
Core	79.2	Early Permian	lower stage 5c	Liveringa Group probably basal	No spinose acritarchs present; probably slightly younger than the Micha Bore assemblage
Cuttings	88.4-91	Early Permian	lower stage 5a	basal Liveringa Group	Striate and non striate bisaccate pollen abundant; Kraeuselisporites spp. and Granulatisporites spp. common
Core	102.1	Early Permian	upper stage 4b	basal Liveringa Group or uppermost Noonkanbah Formation	No spinose acritarchs present; approximately the same age as or slightly older than the Micha Bore assemblage
BMR Mt Bannerman No. 1					
Core 2	113.1-115.8	Late Early to Late Permian	upper stage 5	Liveringa Group younger than the Micha Bore assemblage, LUCAS	Possibly non-marine. No spinose acritarchs observed
Core 3	141.7	Late Early to Late Permian	upper stage 5	"	as above
Core 4	162.5	Late Early to Late Permian	upper stage 5a	"	as above
Core 5	202.4-202.7	Early Permian	lower stage 5c	Basal Liveringa Group younger than Micha Bore assemblage, LUCAS	as above
BMR Mt Bannerman No. 2					
Core 1	?	Late Early to Late Permian	upper stage 5	Liveringa Group younger than Micha Bore assemblage, LUCAS	Possibly non-marine; no spinose acritarchs observed
Core 2	44.2-47.2	Late Early to Late Permian	upper stage 5	"	as above
Core 3	76.2-79.2	Late Early to Late Permian	upper stage 5	"	as above
Core 4	99.7-102.8	Late Early to Late Permian	upper stage 5	"	as above
Core 5	138.7	Late Early Permian	upper stage 5a	"	as above
BMR Mt Bannerman No. 3					
Core 3	97.7	Early Permian	stage 3 (probably lower half).	Poole Sandstone or upper Grant Formation available, evidence perhaps favours Grant	Striate and non striate pollen, Kraeuselisporites and Microbaculispora tentula common. No spinose acritarch observed. Apparently older than Bannerman 4 Core 2

APPENDIX C. (Continued)

SAMPLE	DEPTH (m)	AGE	STRATIGRAPHY		REMARKS
			BIOSTRATIGRAPHIC UNIT	INFERRED STRATIGRAPHIC LIMIT	
BMR Mt Bannerman No. 4					
Cuttings	25.9-30.5	Early Permian	Stage 3	Lower ⅓ of Noonkanbah Formation Poole Sandstone or uppermost Grant Formation	Striate and non striate bisaccate pollen common
Core 1	61.5-9	-	-	-	Very low yield of organic detritus - no identifiable forms
Core 2	112.5	Early Permian	stage 3	Low ⅓ Noonkanbah Formation, Poole Sandstone or uppermost Grant Formation	Disaccate pollen common. Probably slightly younger than Core 3 from Mt Bannerman No. 3
BMR Crossland No. 1					
Core 1	9.7-11.3	Late Permian	upper stage 5	Liveringa Group probaly towards the top	Spinose acritarchs common suggesting a marine environment
?	21.3-24.4	Late Permian	upper stage 5	"	As above (Note: No well name was given on this sample; it is presumed to be from Crossland No. 1)
Core 3	39.6	Late Permian	upper stage 5	Liveringa Group probably towards the top	Spinose acritarchs common suggesting a marine environment
Core 4	71.9	Late Early to Late Permian	upper stage 5a	Liveringa Group younger than Micha Bore assemblage, LUCAS	Possibly non-marine; no spinose acritarchs observed
Core 5	104.8	Late Early to Upper Permian	upper stage 5a	Liveringa Group younger than Micha Bore assemblage, LUCAS	Possibly non-marine; no spinose acritarchs observed
Core 6	147.5	Late Early to Late Permian	upper stage 5a	"	as above
Core 7	194.5	Early Permian	lower stage 5c	Basal Liveringa Group younger than Micha Bore assemblage, LUCAS	as above
Core 8	259.4	Late Early Permian	lower stage 5c	As above	Rare spinose acritarchs present suggest some marine influence at the time of deposition
BMR Crossland No. 2					
Core 1	10.1	Late Early to Late Permian	upper stage 5	Liveringa Group younger than Micha Bore assemblage, LUCAS	Possibly non-marine; no spinose acritarchs observed
Core 2	46.6	Late Early to Late Permian	upper stage 5	"	as above
Core 3	100.3	Late Early to Late Permian	upper stage 5	"	as above
Core 4	136.9	Late Early to Late Permian	upper stage 5	"	as above
Core 4	138.4	Late Early to Late Permian	upper stage 5a	"	as above
BMR Cornish No. 1			(Price 1973)		
Core 1	49	Early Permian	lower stage 5c	Top of the lower half of the Liveringa Group	Striate and non striate bisaccate pollen common
Core 1	49.4	Early Permian	lower stage 5c	as above	as above
Core 2	86.5	Early Permian	lower stage 5c	as above	as above

APPENDIX C. (Continued)

SAMPLE	DEPTH (m)	AGE	STRATIGRAPHY		REMARKS
			BIOSTRATIGRAPHIC UNIT	INFERRED STRATIGRAPHIC LIMIT	
BMR Cornish No. 1 (Continued)				(Price 1973)	
Core 2	87.3	Early Permian	lower stage 5c	Top of the lower half of the Liveringa Group	Striate and non striate bisaccate pollen common
Core 3	145.5	Early Permian	lower stage 5c	as above	as above
Core 3	147.4	Early Permian	lower stage 5c	as above	as above
Core 4	162.2	Early Permian	lower stage 5c	as above	as above
Core 4	164.0	Early Permian	lower stage 5c	as above	as above
BMR Cornish No. 2				(Evans 1966)	
Core 1	133	Late Early to early Middle Triassic	Tr3	Culvida Sandstone equivalent	Aratrisporites spp. and Osmundacidites spp. abundant. Falcisporites spp. extremely rare which is most unusual for the inferred biostratigraphic position. Megaspores common. No spinose acritarchs observed
Core 1	134.4	Late Early to early Middle Triassic	Tr3	Culvida Sandstone equivalents	as above
Core 3	222.5-225.5	Early Triassic	Tr2	?Erskine Sandstone	Densoisporites spp. and Kraeuselisporites spp. abundant. Very few Aratrisporites spp. and bisaccate pollen present. No spinose acritarchs observed otherwise the assemblage is similar to those recovered from cores 1 & 2 in Lucas 13 (see above). An assignment to Tr2 should not be taken to imply that the sampled horizon is a non-marine equivalent of part of the Blina Shale as the boundary between the Blina Shale and the Erskine Sandstone has not been defined precisely in terms of the Microfloral succession
BMR Cornish No. 3					
Core	114.3	Late Permian	Trla (Evans 1966)	Uppermost Liveringa Group or Blina Shale	The relation of this biostratigraphic unit to the Blina Shale/Liveringa Formation boundary is not known. Previously this biostratigraphic unit was believed to be absent from the Canning Basin sequence (see Balme & Helby, 1974). The only other assemblage of more or less comparable age recorded from samples submitted from the Canning Basin is that recovered from core 5/189 m in BMR Lucas 13. The microflora from that sample was not as diverse but may be marginally younger. Spinose acritarchs present suggesting some marine influence

APPENDIX D. Palynological study of selected surface samples by R. Paten and P. Price, Mines Administration Ltd.

SAMPLE	DEPTH	AGE	STRATIGRAPHY		REMARKS
			BIOSTRATIGRAPHIC UNIT	INFERRED STRATIGRAPHIC LIMIT	
OUTCROP SAMPLES					
M.16	Outcrop	-	-	-	No palynomorphs recovered; very low yield of opaque detritus only
M.68	Shot hole cuttings	Early Permian	upper stage 4a	Upper third of Noonkanbah Formation	No spinose acritarchs observed
M.2014	"	Early Triassic		Blina Shale	Some marine influence - spinose acritarch present
M.2057	"	Early Triassic		Blina Shale	As above
CR1703B	Outcrop	Permian or basal Triassic	No older than stage 5	? Liveringa Formation or Blina Shale	The sparse assemblage recovered was highly corroded with only long-ranging forms being recognizable. Consequently no precise age can be indicated on palynological evidence. The poor state of preservation is probably a result of near-surface oxidation
CR1735	Spoil	Early Permian	Upper stage 4a	Upper one-third of the Noonkanbah Formation	Rare spinose acritarchs present suggest some marine influence at the time of deposition
CR1736	Spoil	Late Early Permian	Lower stage 5c	Lower-half of the Liveringa Formation excluding the basal part	As above
CR1737	Spoil	Late Early Permian	Lower stage 5c	As above	As above
D1222	Outcrop	-	-	-	No organic residue recovered
D1229	"	-	-	-	As above
D1230	"	-	-	-	As above
D1237	"	-	-	-	As above
D1238	"	Early Permian	Lower stage 4	Middle-third of Noonkanbah Formation	No spinose acritarch observed
D1264	"	-	-	-	No organic residue recovered
Co 1232	"	Early Permian	Upper stage 4a	Upper-third of Noonkanbah Formation	No spinose acritarch observed
Co 1234	"	Early Permian	stage 3	Uppermost Grant Formation Poole Sandstone or basal Noonkanbah Formation.	Rare spinose acritarchs; probably some marine influence in depositional environment
Co 1235	"	Early Permian	Upper stage 4a	Upper-third of Noonkanbah Formation	As above
Co 1268	"	Early Permian	Upper stage 4b	Uppermost Noonkanbah Formation or basal Liveringa Formation	As above; slightly older than Kicha Bore assemblage

APPENDIX E. REGISTERED ROCK SAMPLES FROM CROSSLAND SHEET AREA.

REGISTERED NO.	FORMATION	ROCK TYPE	LOCATION	METHOD OF ANALYSIS
73121182	Kirkby Range Member	Sandstone	19 09 42, 125 34 54	T.S.
73121504	Condren Sandstone	Pyritic Nodule	343600	A
73121521	Lightjack Formation	Claystone	19 10 15, 125 26 12	T.S.
73121525	Kirkby Range Member	Sandstone	19 11 06, 125 27 43	T.S.
73121536	Noonkanbah Formation	Siltstone	19 03 51, 125 48 24	T.S.
73121541	Condren Sandstone	Sandstone	19 08 33, 125 27 18	T.S.
73121544	Lightjack Formation	Sandstone	19 10 54, 125 26 48	T.S.
73121561	Condren Sandstone	Sandstone	19 08 04, 125 21 30	T.S.
73121569	Condren Sandstone	Sandstone	19 07 21, 125 13 06	T.S.
73121569B	Condren Sandstone	Sandstone	19 08 00, 125 11 30	T.S.
73121575	Noonkanbah Formation	Ochreous Concretion	312598	A
73121585	Cherrabun Member	Sandstone	19 05 33, 125 09 38	T.S.
73121589	Kirkby Range Member	Sandstone	19 06 48, 125 07 27	T.S.
73121590	Hicks Range Sandstone Mbr.	Sandstone	19 07 06, 125 07 36	T.S.
73121602	Barbwire Sandstone	Sandstone	19 10 36, 125 04 00	T.S.
73121629	Barbwire Sandstone	Siltstone	19 02 30, 125 00 48	T.S.
73121631	Barbwire Sandstone	Sandstone	19 03 51, 125 00 57	T.S.
73121702	Hicks Range Sandstone Mbr.	Sandstone	19 09 33, 125 33 27	T.S.
73121703	Cherrabun Member	Sandstone	19 11 12, 125 32 54	T.S.
73121703B	Cherrabun Member	Siltstone	19 11 12, 125 32 54	T.S.
73121704	Lightjack Formation	Sandstone	19 14 09, 125 29 00	T.S.
73121735	Noonkanbah Formation	Spoil		Palynology
73121736	Lightjack Formation	Spoil		Palynology
73121737	Lightjack Formation	Spoil		Palynology

RECORD 1976/24

PERMIAN DEPOSITIONAL HISTORY OF THE NOONKANBAH 1:250 000 SHEET AREA, W.A.

by

R.W.A. Crowe (Geological Survey of Western Australia)
and R.R. Towner

CONTENTS

	Page
SUMMARY	
INTRODUCTION	1
GRANT FORMATION	2
LOWER SANDSTONE UNIT	2
MIDDLE SHALE UNIT	3
UPPER SANDSTONE UNIT	4
Sandstone below the Wye Worry Member	5
Wye Worry Member	6
Millajiddee Member	11
SUMMARY OF DEPOSITIONAL HISTORY	16
EVIDENCE OF UPLIFT AND EROSION BETWEEN DEPOSITION OF THE GRANT FORMATION AND THE POOLE SANDSTONE	17
POOLE SANDSTONE	18
NURA NURA MEMBER	18
'MIDDLE' POOLE SANDSTONE	22
CHRISTMAS CREEK MEMBER	25
SUMMARY OF DEPOSITIONAL HISTORY	26
NOONKANBAH FORMATION	27
LIVERINGA GROUP	29
LIGHTJACK FORMATION	29
CONDREN SANDSTONE	33
HARDMAN FORMATION	34
Kirkby Range Member	34
Hicks Range Sandstone Member	36
Cherrabun Member	37
SUMMARY OF DEPOSITIONAL HISTORY	40
CONCLUSIONS	40
SUGGESTIONS FOR FURTHER WORK	42
ACKNOWLEDGEMENTS	42
REFERENCES	43
APPENDIX	
Measured Sections	49
ENCLOSURES	

1. Correlation section of the Grant Formation.
2. Correlation sections of the Poole Sandstone.
3. Electric logs of the Liveringa Group.

FIGURES

1. Diagrammatic relationships of units in Poole Sandstone and Grant Formation.

2. Detailed section of graded beds interpreted as varves; Wye Worry Member of Grant Formation.

3. Sketch showing clastic dykes of pebble conglomerate (Millajiddee Member) cutting siltstone of the Wye Worry Member.

4. Section of point-bar sequence in 'middle' Millajiddee Member.

5. Diagrammatic field sketch showing relationships, lithology and environmental interpretation of Nura Nura Member at Mount Hutton.

6. Diagrammatic section of Nura Nura Member exposed near Poole Range Bore.

7. Distribution and environmental interpretation of Nura Nura Member.

8. Plot of ripple index (R.I.) against ripple symmetry index (RSI) from measurements of ripple marks in 'middle' Poole Sandstone.

9. Diagrammatic section showing relationships of units within the Liveringa Group.

10. Schematic representation of Permian sedimentation in St. George Range-McLarty Syncline area.

11. Sketch of Noonkanbah Sheet area showing location of sections described in Appendix.

PLATES (photographs)

1. A typical exposure of the Grant Formation, eastern St George Range.
2. Polygonal weathering pattern on the surface of an exposure of sandstone in the Grant Formation.
3. View, from top of Mount Tuckfield, of cliffs formed by sandstone below Wye Worry Member of Grant Formation.
4. Probable varves in Wye Worry Member.
5. Faceted dropstone, striated in two directions, Wye Worry Member.
6. Close-up of striated surface of dropstone
7. Large dropstones in siltstone, Wye Worry Member
8. Calcareous concretion, Wye Worry Member
9. Sandstone lens in Wye Worry Member, southern side of Carolyn Valley.
10. Dropstone in Wye Worry Member in Lauris Range, showing crescentic impact marks.

11. Bioturbated bedding surface, 'lower' Millajiddee Member.
12. Load casts on the underside of a bed, 'lower' Millajiddee Member.
13. Large-scale planar cross-bedding, 'middle' Millajiddee Member.
14. Grant Formation, Nura Nura Member, and 'middle' Poole Sandstone, Mount Amy (showing large slump structure in Grant Formation)
15. Close-up of slump structure in Plate 14, showing subsequent horizontal foliation.
16. Unnamed unit between Grant Formation and Poole Sandstone.
17. Wavy bedding with flasers at reference section of Nura Nura Member.
18. Symmetrical ripple marks in 'middle' Poole Sandstone.
19. Root bed in 'middle' Poole Sandstone.
20. Mount Tuckfield, St George Range.
21. Coarse sandstone of the Christmas Creek Member, showing textural immaturity.
22. Boxwork pattern in the Noonkanbah Formation.

SUMMARY

The Permian strata of the Noonkanbah 1:250 000 Sheet area are described and their origins interpreted.

The Grant Formation was laid down under glacio-lacustrine and marine conditions. Uplift and erosion preceded a further marine transgression which deposited a thin clastic sequence (Nura Nura Member) in the western part of the area. Slow uneven subsidence continued, and the Poole Sandstone was laid down under shallow-water (possibly lagoonal) conditions. After an episode of fluviatile deposition in the east, the sea transgressed the entire area, depositing the Noonkanbah Formation. During the remainder of the Permian, the environment was marine to deltaic (Liveringa Group).

It is concluded that the only substantiated period of uplift that occurred during the Permian in the area was between deposition of the Grant Formation and that of the Poole Sandstone. All other Permian stratigraphic relationships can be explained by inferring gradual subsidence of the area.

INTRODUCTION

The purpose of this report is to make available rapidly the large amount of detailed stratigraphic information that was collected in 1974 during the Second Edition mapping of the Noonkanbah 1:250 000 Sheet area*. A full stratigraphic table, a bibliography, and sections on such topics as physiography and structure will be included in the Second Edition of the NOONKANBAH Explanatory Notes (Crowe & Towner, in prep.).

The re-mapping of NOONKANBAH has enabled a more detailed study to be made of the Poole Sandstone and Grant Formation which crop out extensively on this Sheet area and until now have received relatively little attention. The main method of study used was the measuring of detailed sections in the St George and Poole Ranges, from which an assessment of the environments of deposition of these units was made.

The logs of numerous bores put down for coal exploration in the area have been examined and correlated with the stratigraphy as established on the surface. This study has also made possible an interpretation of the environment of deposition of the Liveringa Group. The results of these studies form the basis of this report.

In many cases there is insufficient evidence to determine a particular depositional environment, but a suggestion is put forward and it is made clear that further work is needed before the suggestion can be accepted.

The rocks are described according to the classification of Gilbert (in Williams et al., 1958). Grainsize is classified on the Wentworth scale and the terms used for bedding thickness are those of Ingram (1954). The classification of cross-bedding follows McKee & Weir (1953) and that of flaser and lenticular bedding follows Reineck & Wunderlich (1968). Other terms used are referenced in the text.

The subdivisions of the Grant Formation and Poole Sandstone have been defined elsewhere (Crowe & Towner, 1976) and the relationships of these units are shown in Figure 1. Yeates et al. (1975a) have defined and revised the nomenclature of other Permian units (relationships shown as Fig. 9).

Although due regard has been paid to all palynological determinations that have been made, in many cases, all that is presently available is a palynological zone number which has not yet been defined in any publication. In such cases it has been decided not to mention these determinations.

* 1:250 000 Sheet area names are typed in capitals, (i.e. MOUNT RAMSAY) to distinguish them from place names.

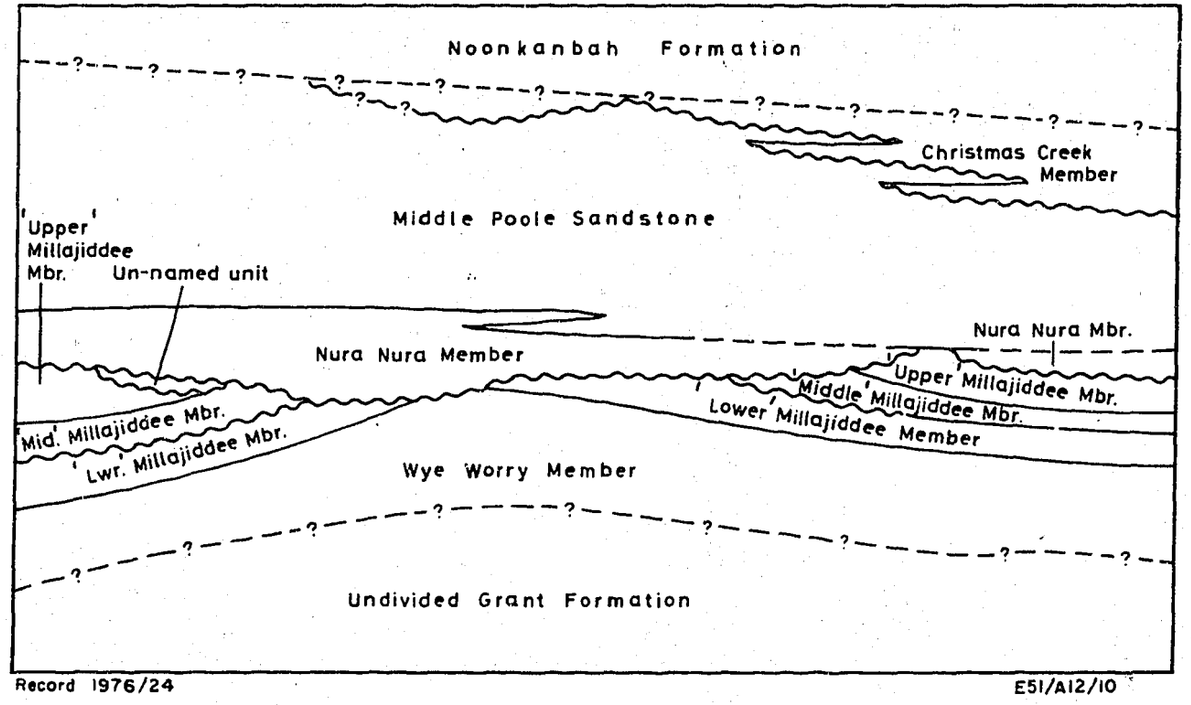


Fig. 1. Diagrammatic relationships of units in the Poole Sandstone and the Grant Formation. Solid line is conformable boundary; dashed is disconformable and wavy is erosional

The Liveringa Group is known to contain coal (Woodward, 1915; Guppy et al., 1958), and exploration has been carried out in the area by Premier Mining Co. Pty Ltd (1965-66; Baarda, 1967), Australian Inland Exploration (1970-72), Esso Exploration and Production Australia Inc. (1973-74; Galloway & Howell, 1975), Dampier Mining Co. Ltd (1973-75).

The positions of exploration holes drilled by these companies will be published on the forthcoming geological map (Crowe & Towner, in prep.) and available relevant information is included in this Record. Reports by Australian Inland Exploration and Dampier Mining Co. are not yet available to the public and have therefore not been referred to, although A.I.E. have granted permission for some of their information to be incorporated in this Record.

GRANT FORMATION

On NOONKANBAH, from subsurface information, three subdivisions of the Grant Formation (Guppy et al., 1952) have been recognized. WAPET (1973) recognize a basal sandstone unit, a middle shale unit and a top sandstone unit in Mount Hardman No. 1 well and a similar sequence was encountered in St George Range No. 1 (Continental Oil Company of Australia Ltd, 1966). These three units have also been recognized in many other petroleum exploration wells in the basin but they have not yet been formally named. The lower two units have been correlated with Permian units that crop out in the southern part of the basin (Koop, 1966) but because these correlations are in doubt (Playford et al., 1975) the names are not used here. Instead, the three subdivisions are referred to as the 'Lower Sandstone Unit', the 'Middle Shale Unit' and the 'Upper Sandstone Unit'. As far as is known, only the 'Upper Sandstone Unit' is exposed on NOONKANBAH.

As a result of the 1974 mapping, Crowe & Tower (1976) have defined part of the exposed section of the Upper Sandstone Unit as the Wye Worry Member and the Millajiddee Member of the Grant Formation. It is hoped that eventually the units recognized in the subsurface can be formally defined as formations and that the Grant Formation can then be upgraded to group status.

LOWER SANDSTONE UNIT

Distribution

The unit occurs only in the subsurface and was identified in Mount Hardman No. 1 well (WAPET, 1973). Esso No. 27 bore bottomed in it (Galloway & Howell, 1975) and St George

Range No. 1 penetrated it (Continental Oil Company of Australia Ltd, 1966). Other wells on NOONKANBAH may have penetrated this unit but positive identification is not possible. The unit has been recognized in many wells throughout the Canning Basin.

Relationships

The unit rests unconformably on Carboniferous rocks and probably on Devonian rocks and is overlain, apparently conformably, by the 'Middle Shale Unit'.

Lithology

The unit is composed mainly of fine to coarse-grained sandstone and minor silt and clay. Poorly sorted lithicwacke conglomerate and scattered lithic fragments near the base were penetrated in Mount Hardman No. 1. In St George Range No. 1 the lower half is calcareous. The unit contains carbonaceous siltstone and rare coal.

Thickness

The unit is 381 m thick in Mount Hardman No. 1 and 652 m in St George Range No. 1. These figures indicate thickening of the unit into the centre of the Fitzroy Trough. To the southeast, in the Gregory Sub-basin, the unit is 406 m thick in Lake Betty No. 1 (WAPET, 1972a). Only 10 m of the unit is present in Barbwire No. 1, but it thickens again farther to the south (WAPET, 1972b).

Age

Probably Late Carboniferous, based on palynological evidence from Mount Hardman No. 1 well (Dolby, in WAPET, 1973).

Environment of deposition

Microfossils from Mount Hardman No. 1 and Lake Betty No. 1 indicate 'no evidence of a marine environment' (Dolby, in WAPET, 1973). The carbonaceous siltstone and coal recorded in St George Range No. 1 well suggest a continental or transitional environment. The lithic conglomerate in Mount Hardman No. 1 was interpreted by WAPET (1973) as tillite, but we regard the interpretation as tentative. Consequently a possibly cold, continental environment of deposition is indicated.

MIDDLE SHALE UNIT

Distribution

The unit occurs only in the subsurface and was identified in Mount Hardman No. 1, Esso No. 27 bore and St George Range No. 1. Other wells on NOONKANBAH may have

intersected this unit, but positive identification is not possible. The unit has been identified in many wells elsewhere in the Canning Basin.

Relationships

The Middle Shale Unit appears to overlie the Lower Sandstone Unit conformably.

The upper boundary is gradational.

Lithology

In St George Range No. 1 the unit consists of calcareous and carbonaceous siltstone and shale, and minor sandstone. The siltstone and shale contain minor pyrite. In Mount Hardman No. 1 and Esso No. 27 bore the unit consists of non-calcareous argillaceous sandstone, and minor siltstone and shale.

Thickness

The unit is 57 m thick in Mount Hardman No. 1 well, 40 m in Esso No. 27 bore, and 225 m in St George Range No. 1.

These figures show that this unit thickens towards the middle of the Fitzroy Trough. In Barbwire No. 1 the unit is thinner again (64 m), and like the Lower Sandstone Unit it thickens southwards into the Kidson Sub-basin (WAPET, 1972b).

Age

Sakmarian (sensu lato), based on palynological evidence. The lower part may range into the Late Carboniferous (Dolby, in WAPET, 1973).

Environment of deposition

Microfossils indicate 'no strong evidence of a marine influence' (Dolby, in WAPET, 1973). The substantial thickness of shale in St George Range No. 1 indicates quiet water deposition, so that, if the microfossil evidence is correct, the unit may have been deposited under freshwater conditions. The coarser nature of the sediment in Mount Hardman No. 1 may reflect proximity to a source area.

UPPER SANDSTONE UNIT

Crowe & Towner (1976) have defined parts of the exposed section of the Upper Sandstone Unit as the Millajiddee Member and the underlying Wye Worry Member. Rocks below the

Wye Worry Member have been mapped as undivided Grant Formation (Crowe & Towner, in prep.).

As far as is known, all the exposed rocks of the Grant Formation belong to the Upper Sandstone Unit.

Distribution

The major part of this unit is not exposed. North of the Fitzroy River and east of Christmas Creek the unit is exposed in scattered hills and ridges. Identification of members in these exposures is more tentative than to the south of the Fitzroy River and west of Christmas Creek, where the unit is well exposed in the St George and Poole Ranges. The lower part of the unit is known from bores in the Poole Range and near Prices Creek. St George Range No. 1 spudded in the unit just below the Wye Worry Member and Mount Hardman No. 1 and Esso No. 27 also penetrated the unit.

Just east of the Sheet area the unit is well exposed and one locality on Mount Ramsay is described in this report, as it has a bearing on the geology of NOONKANBAH.

Each subdivision of the unit is now dealt with in turn.

Sandstone below the Wye Worry Member (including unexposed part)

Relationships

A sandstone sub-unit below the Wye Worry Member, lies, apparently conformably, on the 'Middle Shale Unit', but as overlying beds overlap onto Carboniferous and Devonian units this part of the formation may do so also. The sandstone sub-unit is overlain, apparently conformably, by the Wye Worry Member.

Lithology

In the subsurface, the sub-unit is composed of interbedded clean and argillaceous, fine to coarse-grained sandstone and minor siltstone. The sorting varies from poor to excellent. It is calcareous in parts, and conglomerate occurs throughout. Many of the well-rounded grains are frosted. On the surface the sub-unit is composed of medium to coarse-grained quartz wacke, feldspathic wacke and minor quartz arenite. It is moderately sorted, and forms cliffs because of its poorly-

bedded nature (Plate 1). Many of the exposures are weathered in a polygonal pattern which apparently bears no relation to tectonic or sedimentary structures (Plate 2). The upper part of the sub-unit is better bedded, fine-grained, well-sorted, and bioturbated (see Section No. 12). In the Poole Range the sub-unit contains fossil wood fragments and trace fossils.

At the western end of the St George Range, near Mount Tuckfield, the sub-unit forms rugged hills (Plate 3) and is composed of a series of fining-up cross-bedded cycles which are interpreted as point-bar deposits (Section 13a). Normally, the bedding is too indistinct and obscured by weathering to enable the sedimentary structures to be identified.

Thickness

St George Range No. 1 well was spudded just below the base of the Wye Worry Member and intersected 652 m of the Upper Sandstone Unit. The Upper Sandstone Unit as a whole thins northwards towards the basin margin, as only 217 m was intersected in Mount Hardman No. 1 (WAPET, 1973). The Upper Sandstone Unit most probably also thins to the south onto the Barbwire Terrace, because farther south it wedges out completely. To the northwest and southeast of the area it is present in the Fitzroy Trough and Gregory Sub-basin respectively.

Age

Sakmarian (sensu lato), based on palynology (Dolby, in WAPET, 1973).

Environment of deposition

Palynological results indicate 'no evidence of a marine influence' (Dolby, in WAPET, 1973); however the homogeneity of the sub-unit is not typical of a continental sequence. On the other hand the interpretation of point-bar deposits near Mount Tuckfield suggests a fluviatile or deltaic environment. Reports of well-rounded frosted quartz grains from the sub-surface (WAPET, 1973) suggest that parts of the sequence may have been derived from an aeolian source (see Pettijohn, 1957, p. 70).

Present knowledge does not allow interpretation of any specific environment.

Wye Worry Member

Relationships

The base of the Wye Worry Member (Crowe & Towner, 1976) is exposed in the centre and western end of the St

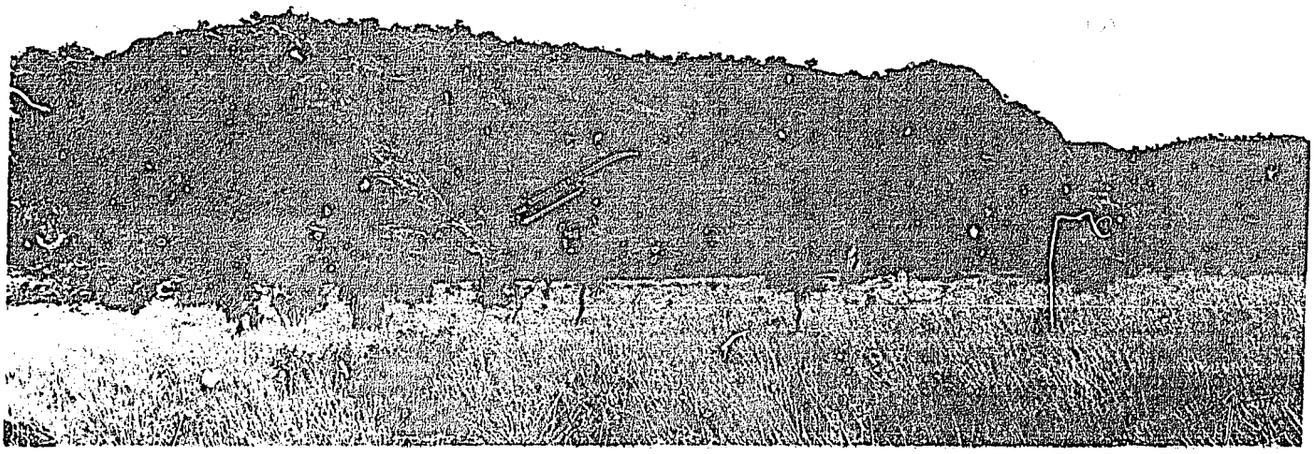


Plate 1 Typical exposure of the Grant Formation in the eastern St George Range. The steep cliffs are a result of the poorly bedded nature of the formation. Lat. 18°49'12"S, long. 125°30'30"E

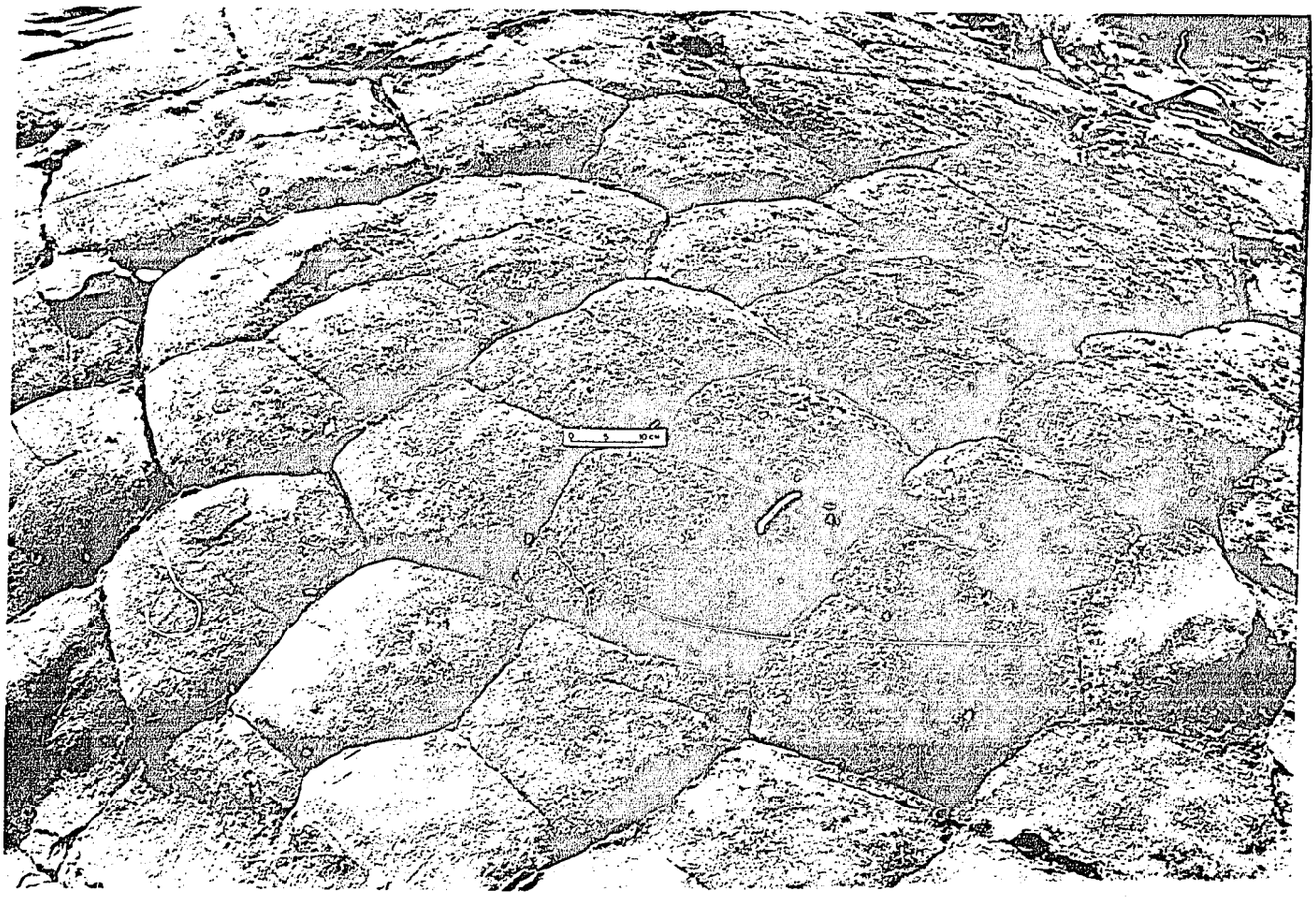


Plate 2 Polygonal weathering pattern on the surface of an exposure of the Grant Formation. This pattern is apparently unrelated to tectonic or sedimentary structures.

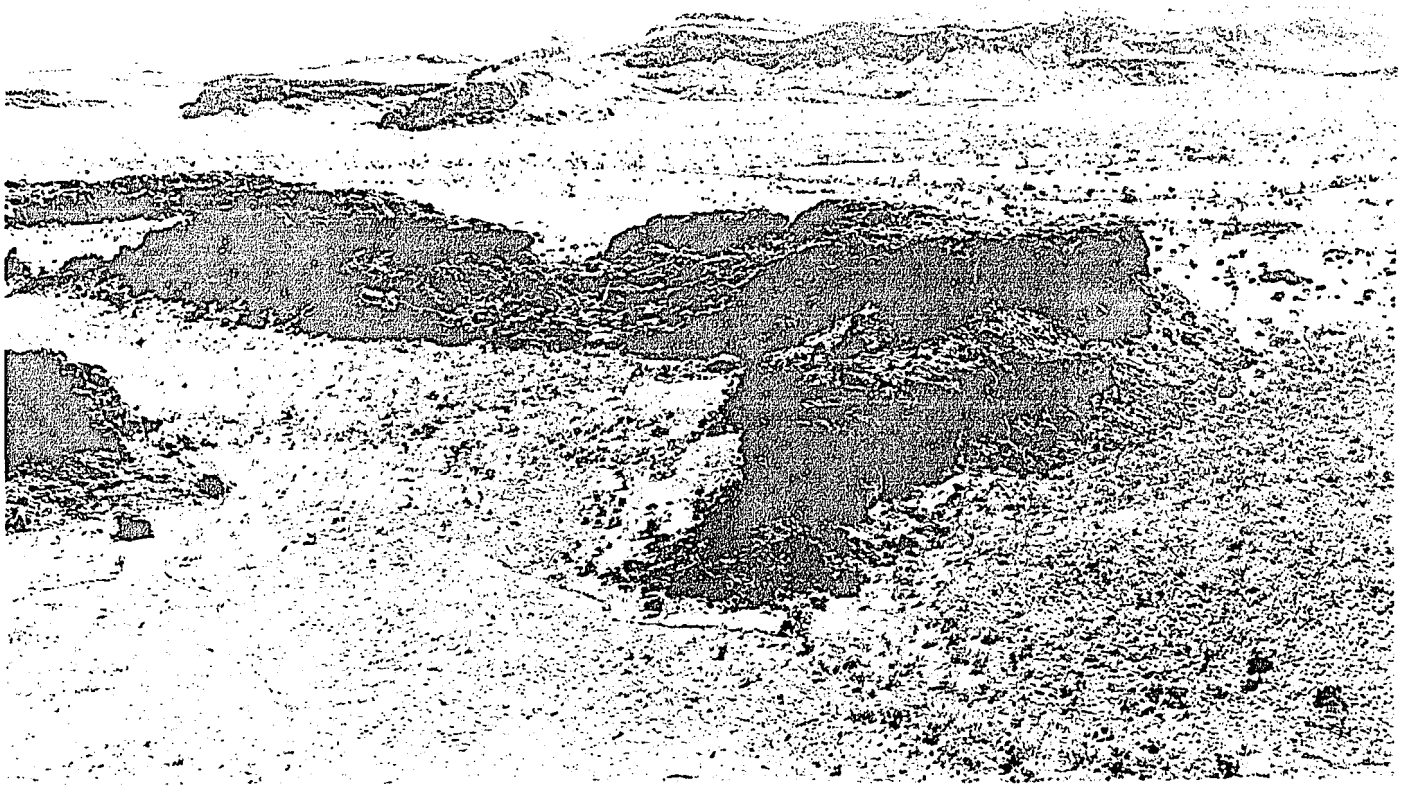


Plate 3 Looking northeast from the top of Mount Tuckfield across the Carolyn Valley. The sandstone below the Wye Worry Member is exposed in the rugged hills in the foreground.

George Range (Sections 12 and 17) and in the centre of the Poole Range. It is marked by a change from non-calcareous well-sorted sandstone to calcareous, poorly sorted sandstone containing dropstones. Exposures are not good enough to enable one to tell whether the relationship is conformable or disconformable.

The member is overlain by the Millajiddee Member. In the Poole Range and St George Range the upper contact is conformable, but on MOUNT RAMSAY and in the Lauris Range it is a disconformity.

Lithology

The Wye Worry Member varies both laterally and vertically (Enclosure 1). In the eastern St George Range it is repetitively exposed in a series of north-trending fault blocks. Section 9 (Location sketch, Enclosure 1) has been designated the type section by Crowe & Towner (1976). The base of the member is not exposed in Section 9; the lowest part of the sequence consists of calcareous and silicified, grey, laminated and thinly bedded very fine-grained quartz wacke, siltstone and claystone. The individual laminae average 5 mm thick and the silt and clay in each lamina are sharply separated into layers (Fig. 2 and Plate 4). The beds are laterally continuous, and contain minor, small-scale, slump-and-flowage structures, together with some burrows and a few dropstones of igneous and metamorphic rocks. In places about 50 percent of these dropstones have well faceted and striated faces (Plates 5 & 6). Many of the boulders and cobbles are well rounded also. Some of the dropstones are of boulder size (Plate 7) but the majority are cobbles or smaller. The large variety of lithologies present, the faceted and striated faces of the boulders, and the fact that they occur in very fine-grained sediment indicate that these dropstones were released by floating ice, so that the deposits may be classed as tillite.

The graded silt and clay laminae are interpreted as glacial varves. According to the classification in Duff et al. p. 51 (1967) most of these varves are diatactic, that is, the silt and clay are separated. Some of the varves are also composite, that is, there are several silt-clay alternations within a particular varve (Fig. 2).

Above the graded laminae sequence the Wye Worry Member consists of unsorted silty claystone and clayey siltstone containing an increasing abundance of dropstones. Conglomerate lenses occur, consisting in places of faceted and striated clasts in a granule and pebble matrix. Farther up

the sequence the silt and clay become increasingly calcareous, and calcareous concretions are common (Plate 8). Scattered well-rounded quartz grains are present throughout the sequence and have frosted surfaces. Towards the top of the member, plant fragments occur in siltstone and very fine-grained sandstone. However, in places there is some graded bedding associated with small slump-and-flowage structures. Because of these features, the beds could be interpreted as turbidites. However, typical sequence of turbidite internal structures (Bouma, 1962, p. 49) could not be found.

To the west of the type section, in the central St George Range, the Wye Worry Member becomes thinner and more difficult to recognize. The lithology is similar. However, the graded laminae are not present and, instead, the base of the unit consists of very poorly sorted conglomerate, which is crudely bedded and cross-bedded. The middle part of the member is generally more sandy than at the eastern end of the St George Range (Section 12).

In the western St George Range the member is more sandy than in the centre (Section 17), and contains a well-defined wedge-shaped sandstone sub-unit in the middle. This sandstone is mainly medium-grained and cross-bedded, but it becomes finer grained where it lenses out towards the east (Plate 9).

In the eastern part of the area, in the Poole Range, the Wye Worry Member is coarser grained than in the eastern St George Range. However, in the Poole Range rheotropic structures (both hydroplastic and quasi-solid; Conybeare & Crook, 1968 pp. 36-43) make recognition of the members very difficult. In some parts of this area (e.g. Mount Thorlan, Section 3) the lithology is very similar to that in the St George Range, however elsewhere the lithologies are difficult to map as a result of slumping. It has not been possible to differentiate the two members everywhere in the Poole Range area at 1:250 000 scale on the geological map (Crowe & Towner, in prep.).

The general lithology of the member in the Poole Range is sandy siltstone and silty sandstone. In cliff exposures the member is non-calcareous, but in exposures near plain level the rock is commonly grey and calcareous, suggesting that the higher exposures were calcareous before being de-calcified by weathering. On the south side of the Poole Range a relatively undeformed section was measured in detail (Section 4a), and shows regular alternations of sandstone and siltstone, which are possibly symmict varves (i.e. no separation of silt and clay). However, the absence of well-defined grading makes this identification tentative.

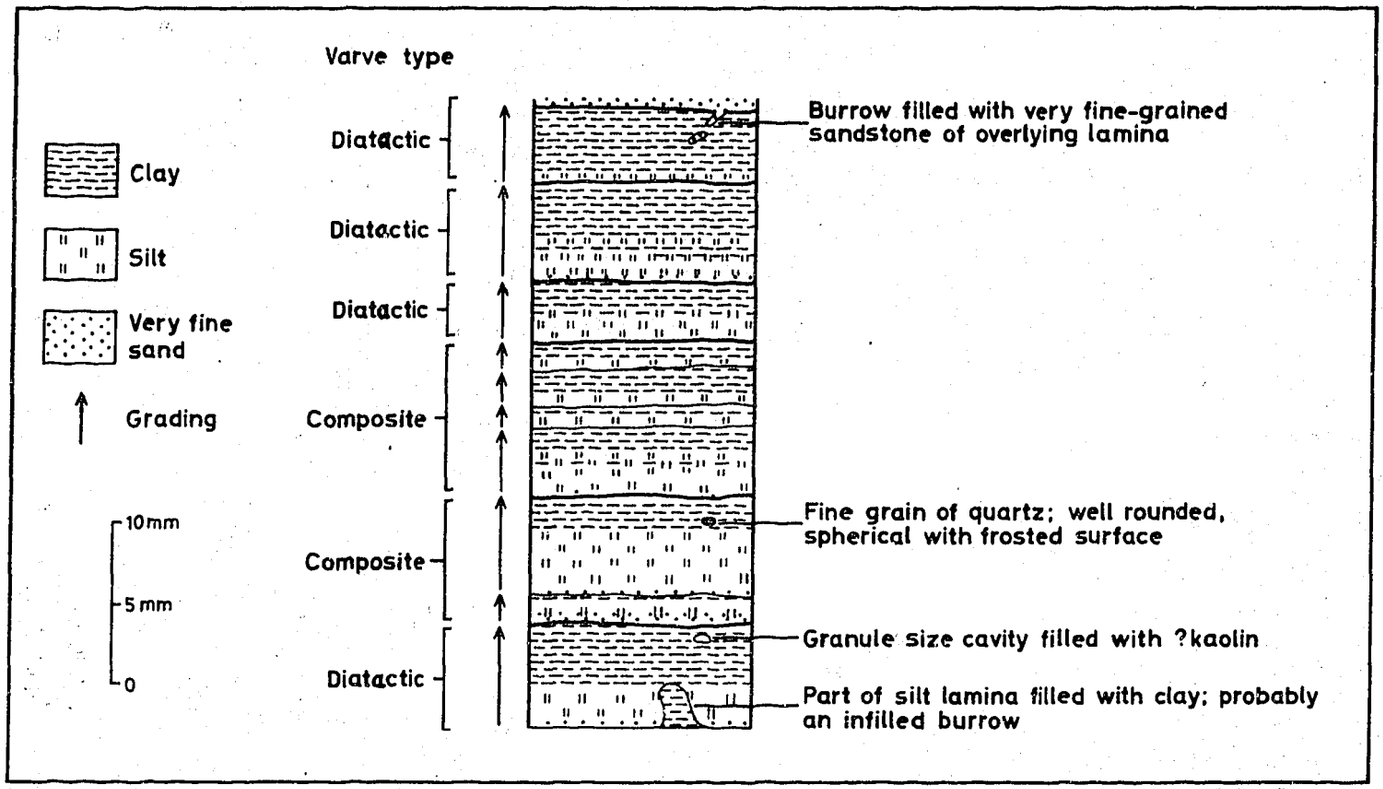


Fig. 2. Wye Worry Member; detailed section of graded beds interpreted as varves from microscopic examination of slabbed sample. Lat. 18°45'30"S, long. 125°18'50" E

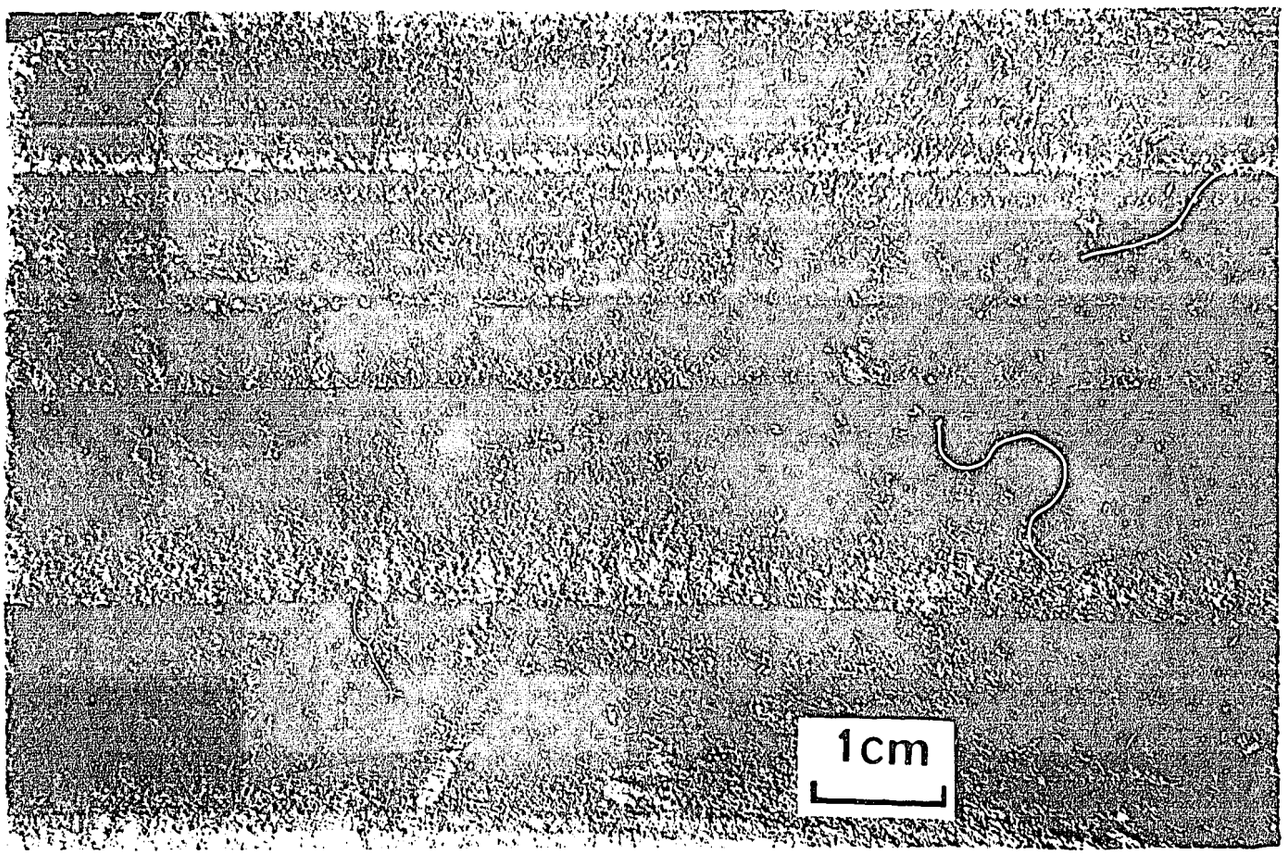


Plate 4 Wye Worry Member, Grant Formation. Laminated graded siltstone and claystone interpreted as varves. The claystone is darker than the siltstone. Lat. 18°46'30"S, long 125°18'50"E

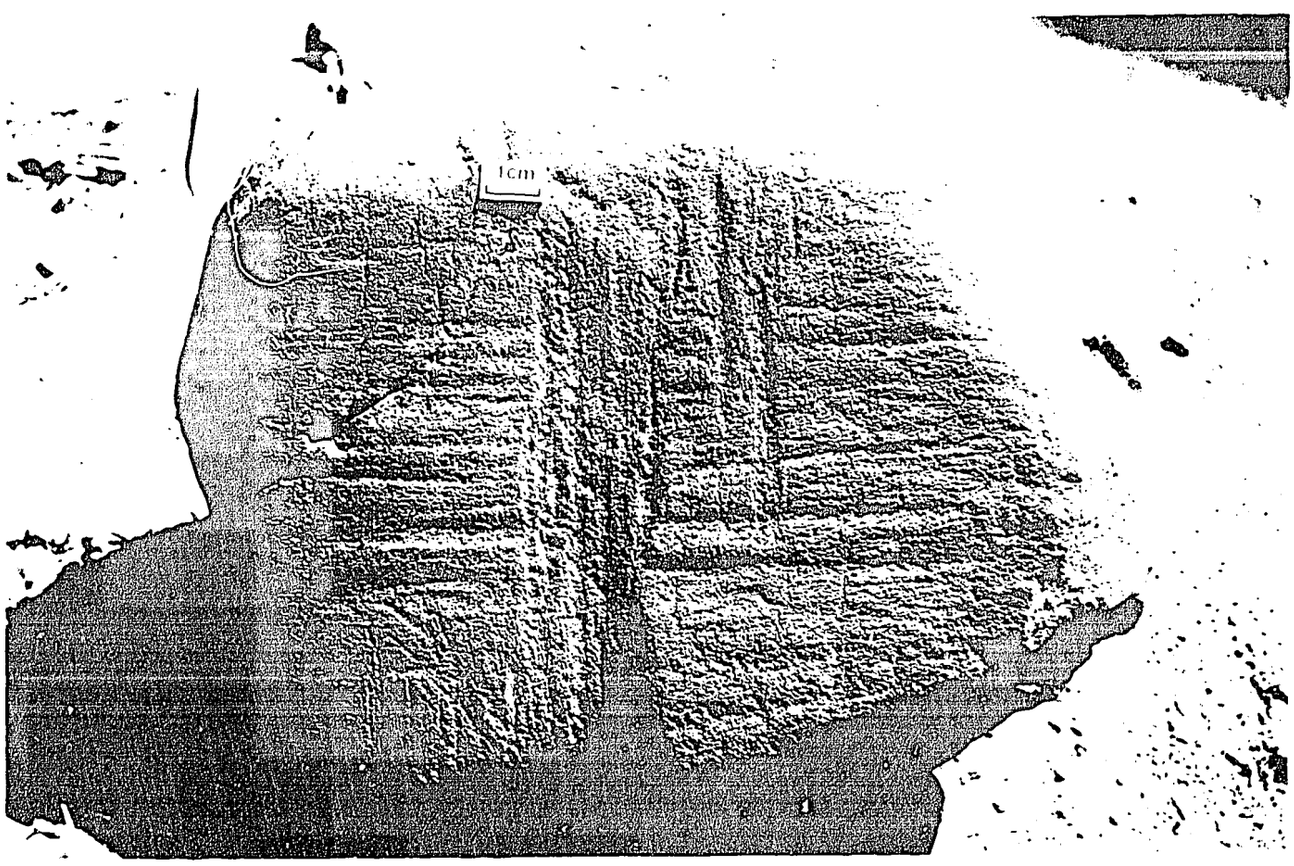


Plate 5 Faceted dropstone, striated in two directions. Wye Worry Member, Grant Formation. Lat. 18°46'30"S, long. 125°18'50"E.



Plate 6 Close-up of striated surface of dropstone, Wye Worry Member.

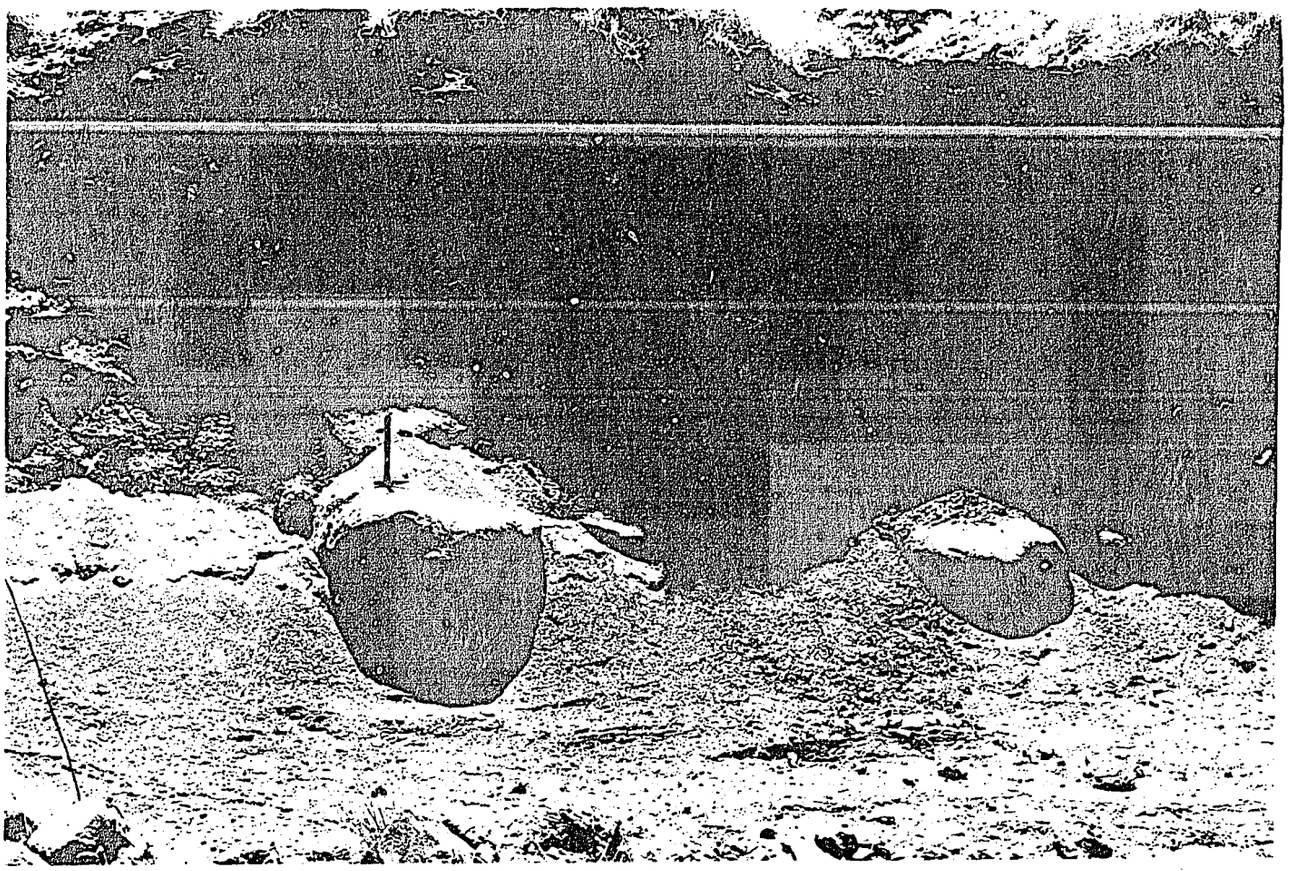


Plate 7 Large dropstones in siltstone, near type section of the Wye Worry Member.
Lat. 18°47'00"S, long. 125°18'36"E

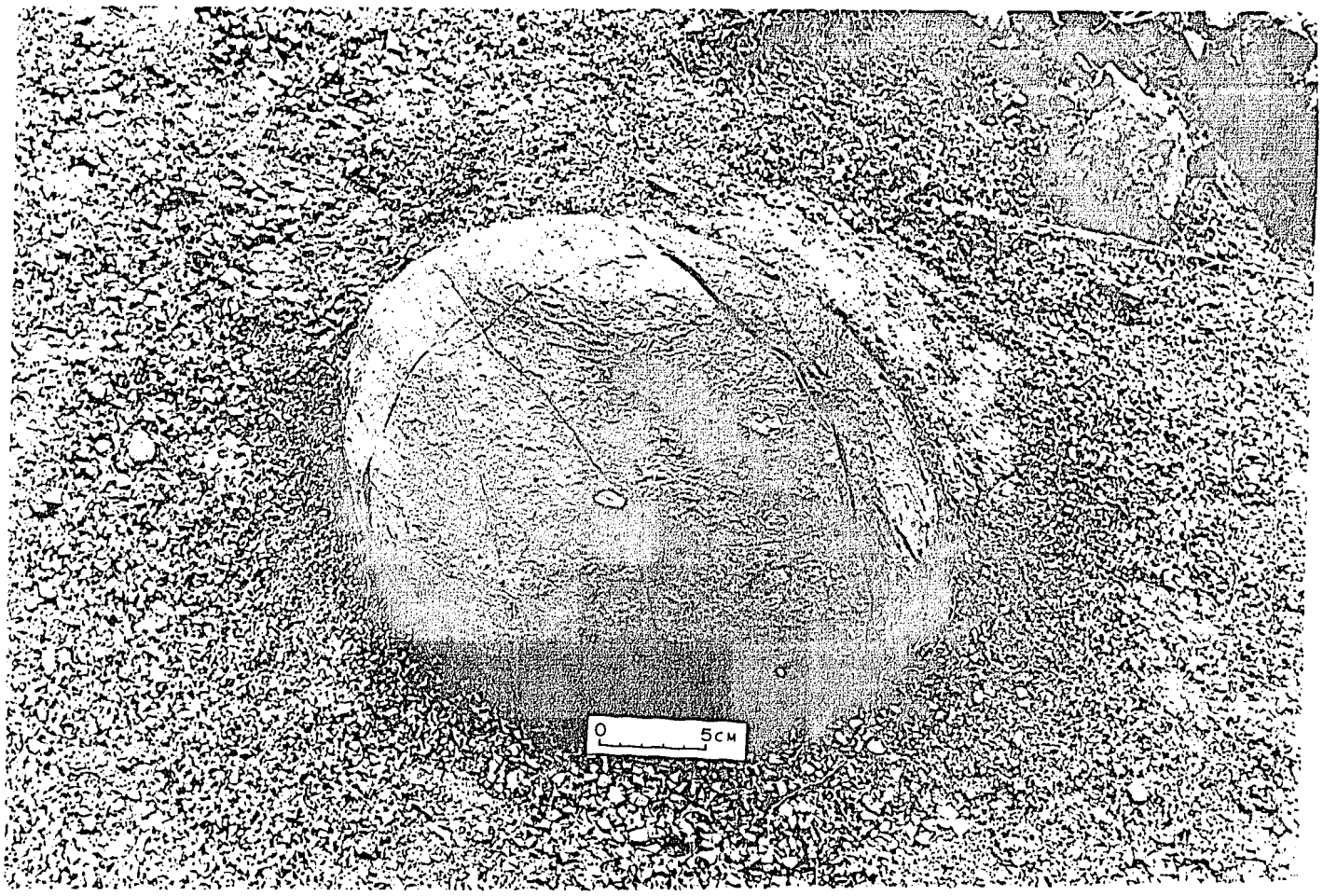


Plate 8 Calcareous concretion from the middle of the Wye Worry Member, at the type section. Note small dropstone pebble near centre of concretion.
Lat. 18°46'30"S, long. 125°18'50"E

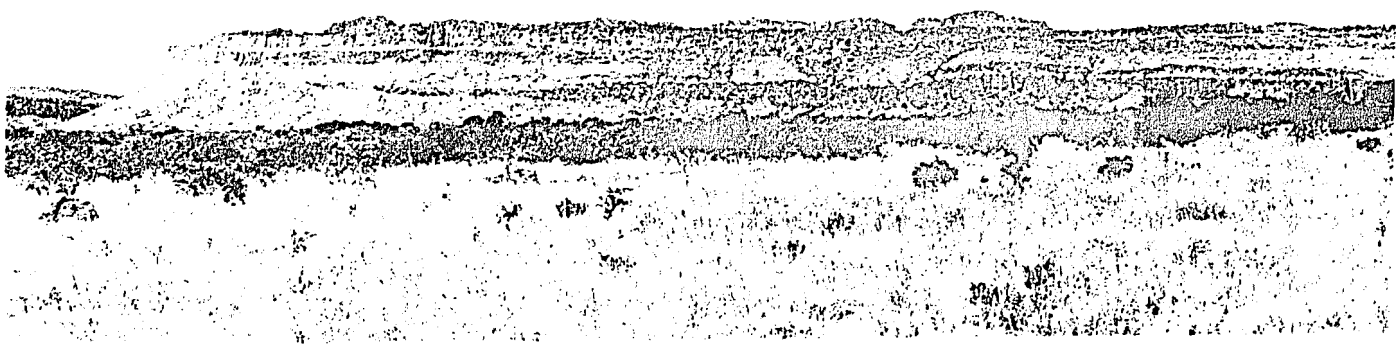


Plate 9 Sandstone lens in Wye Worry Member, southern side of Carolyn Valley.

The Wye Worry Member also crops out on MOUNT RAMSAY at latitude 18°50'30"S, longitude 126°07'00"E, where it is very similar to exposures in the east St George Range. At this locality, in a very weathered outcrop, the siltstone is cut by several clastic dykes which contain pebbles; some of the pebbles are faceted and striated. The dykes widen upwards their relationships are shown in Figure 3. These dykes are interpreted as fossil ice wedges, as they are similar to Pleistocene ice-wedge casts described by Dionne (1975) (see Millajiddee Member, environmental interpretation).

To the north of the Fitzroy River, in the Lauris Range, the Wye Worry Member is similar to sections of the member in the east St George Range. As in the Poole Range, there is much rheotropic deformation. In the Lauris Range area the surfaces of the dropstones bear crescentic impact marks (Plate 11), as well as later facets and striations. Similar boulders occur in exposures of the Grant Formation around Fitzroy Crossing, and on this basis such exposures are identified as Wye Worry Member.

Thickness

Poole Range	45 m +	(Section 3)
East St George Range	95 m +	(estimated)
Mid St George Range (variable)	25 m	(Section 12)
West St George Range	65 m	(Section 17)

In most areas the member is probably about 50 m thick; it is thinnest (25 m) in the central St George Range and thickest in the east St George Range (95 m +). The Member is tentatively identified in Esso No. 27 bore where it appears to be about 30 m thick.

Age

The following marine macrofossils were found at latitude 18°39'36"S, longitude 124°58'36"E;

Pelecypods:

Eurydesma? sp. ind
Deltopecten lyonsensis Dickins 1957
Etheripecten cf. tenuicollis (Dana) 1847
Streblopteria sp.

Gastropods:

Keenia? sp. ind.

Brachiopods:

Unidentifiable dielasmatids and spiriferids

Bryozoans:

Fenestella sp.

Crinoids:

Calceolispongidae sp. nov.

According to Dickins et al. (in press) these species indicate a Late Sakmarian age. Accurate vertical positioning of these fossils was not possible, but they were found in the middle part of the member. Indeterminate wood fragments and plant stem fossils were also found, but are not age-diagnostic.

Environment of deposition

The base of the member, where exposed, consists of lenses of cross-bedded conglomerate containing faceted and striated clasts interpreted as glacial in origin. The cross-bedding indicates these deposits were laid down by currents. Similar lenses occur in the lower part of the type section in the eastern St George Range.

In the type section of the member interpreted diatactic varves occur near the base of the unit. Kuenen (1951 pp. 75) has reviewed the literature which shows that separation between silt and clay is not possible in waters whose salinity is more than 1/50th of that of normal sea water. When the salinity rises above that value, the silt and clay settle simultaneously. Thus the water in which the varves were deposited was probably fresh, and had little or no connection to the open sea. Moreover, the laterally persistent bedding and grading, which are characteristic of varves, indicates that the mudstones were deposited in a quiet, standing body of water. The presence of glacial dropstones throughout the sequence indicates that icebergs or ice sheets periodically floated over the area.

Above the varved part of the sequence there is no grading of silt and clay, which would indicate that the salinity of the waterbody was high enough to cause simultaneous settling. The presence of marine fossils in this part of the sequence supports this hypothesis. Dropstones are also present in this part of the sequence, so that the area was still under the influence of a glacial climate; moreover, the fossils are thick-shelled varieties and are indicative of a cold-water



Plate 10 Well-rounded dropstone in Wye Worry Member in Lauris Range, showing crescentic impact marks. These boulders also have faceted and striated faces. Lat. 18°10'20"S, long 125°25'30"E

environment (Dickins et al., in press). Where dropstones are concentrated inlenses in a conglomerate matrix the lens is interpreted as the load of a single iceberg, dropped when the iceberg melted.

Frosted, well-rounded sand grains are distributed throughout the freshwater and marine parts of the sequence. Frosting of the surface of sand grains is normally indicative of an aeolian environment so that these grains are interpreted as having been transported into the environment by wind.

In the western St George Range there is no separation of silt and clay within the Wye Worry Member, and the sequence is generally more sandy. This may mean that the water body was always too saline or that conditions were not quiet enough for the suspended load to settle out.

In the Poole Range area also, the member is more sandy than in the eastern St George Range. At one locality symmict varves have been tentatively interpreted (Section 4a), so that deposition from a standing body of water is suggested. However, the presence of laterally persistent conglomerate indicates that parts of the sequence were also deposited by currents.

Farther east, on MOUNT RAMSAY, the member is similar to sections in the east St George Range. In the Lauris Range the section is also similar and contains dropstones that are well rounded and have crescentic impact marks, as well as facets and striations. According to Conybeare & Crook (1968, p. 18) such impact marks indicate high-velocity water flow. So the clasts were originally derived from a high-energy fluviatile environment in an area of Precambrian outcrop. They were then transported by glaciers to a large standing body of water where icebergs were formed, and which later melted and dropped their loads.

Millajiddee Member

Relationships

The Millajiddee Member (Crowe & Towner, 1976) overlies the Wye Worry Member everywhere except at Mt Thorlan and in the southwest of the St George Range, where it is cut by the unconformity at the base of the Nura Nura Member of the Poole Sandstone (Fig. 1). The lower contact is conformable in the St George Range, and probably also in the Poole Range. On MOUNT RAMSAY and in the Lauris Range it is a disconformity.

Subdivision

The member is a sandstone unit which generally has three recognizable subdivisions; a lower fine-grained part ('lower' Millajiddee Member), a middle medium and coarse-grained part ('middle' Millajiddee Member), and a fine-grained upper part ('upper' Millajiddee Member), which is characteristically slumped, and commonly cut out by the unconformity at the base of the Nura Nura Member.

Complete sections of the Millajiddee Member were only seen in the southeastern and west central parts of the St George Range. The St George Range section (No. 15) has been designated the type section by Crowe & Towner (1976).

Lithology

'Lower' Millajiddee Member: The 'lower' Millajiddee Member is well exposed in the western St George Range (Section 15). It consists of thinly bedded siltstone and fine-grained quartz wacke and contains climbing ripples, wavy bedding, assymmetrical ripple marks, and minor trough cross-bedding. In section 15 this part of the member is disconformably overlain by the 'middle' Millajiddee Member.

In the central St George Range (Section 10) the 'lower' Millajiddee Member is coarser grained, consisting of medium-grained quartz arenite which grades upwards into fine-grained quartz arenite and quartz wacke. It contains abundant ripple cross-stratification and interference ripple marks; it also contains abundant load casts and is extensively bioturbated near the base (Plates 11 & 12). Fossils found include wood fragments and plant impressions.

In the eastern St George Range the lithology is similar, consisting of medium and fine-grained, massive, poorly-bedded, quartz arenite and quartz wacke. The unit crops out as straight-sided cliffs in many of the hills in this area and lacks any well-defined internal structure.

In the Poole Range the lithology is similar but the unit occurs as slide and slump blocks within the underlying Wye Worry Member, so that on the geological map (Crowe & Towner, in prep.) the two units are locally undivided.

On MOUNT RAMSAY and in the Lauris Range the 'lower' Millajiddee Member is missing. However, on MOUNT RAMSAY, this part of the member is represented by the material filling clastic dykes in the Wye Worry Member (Fig. 3). Overlying this material is a thin siltstone unit with erosional upper and lower contacts. A similar siltstone is present at the same level in the Lauris Range.

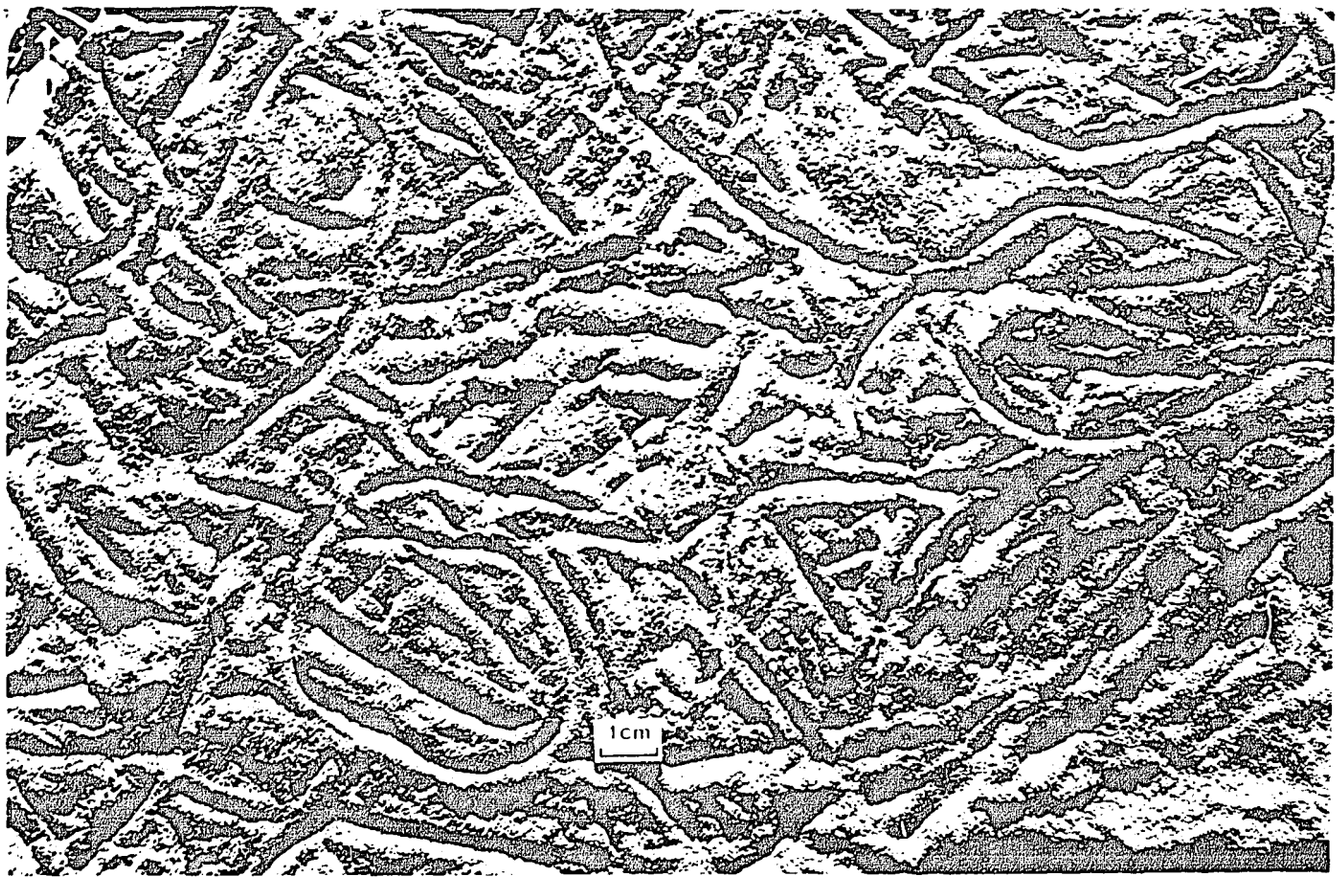


Plate 11 Bioturbated bedding surface, 'lower' Millajiddee Member, central St George Range. Lat. 18°43'52"S, long. 125°07'52"E

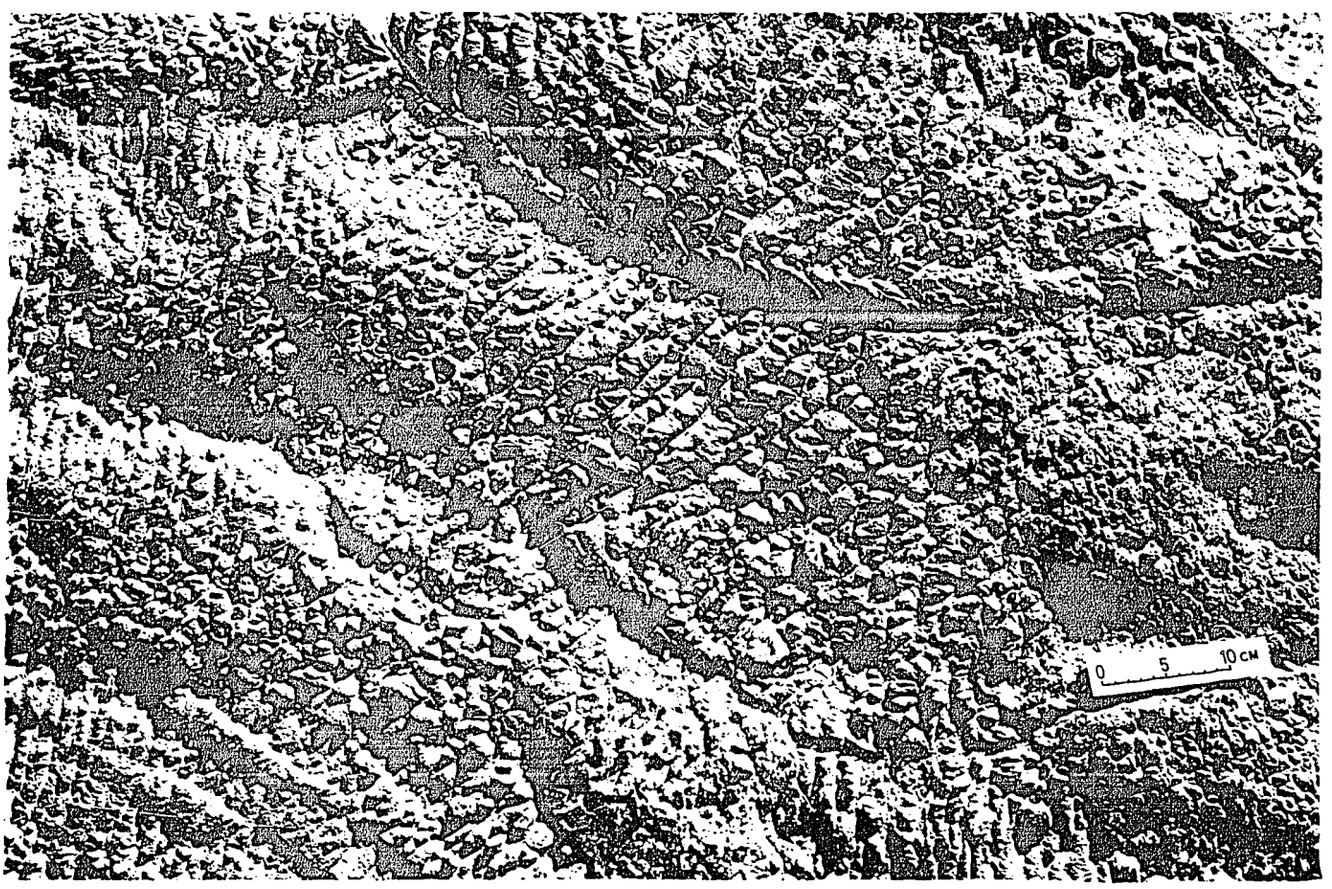


Plate 12 Load casts on the underside of a bed, 'lower' Millajiddee Member, central St George Range. Lat. 18°43'52"S, long. 125°07'52"E

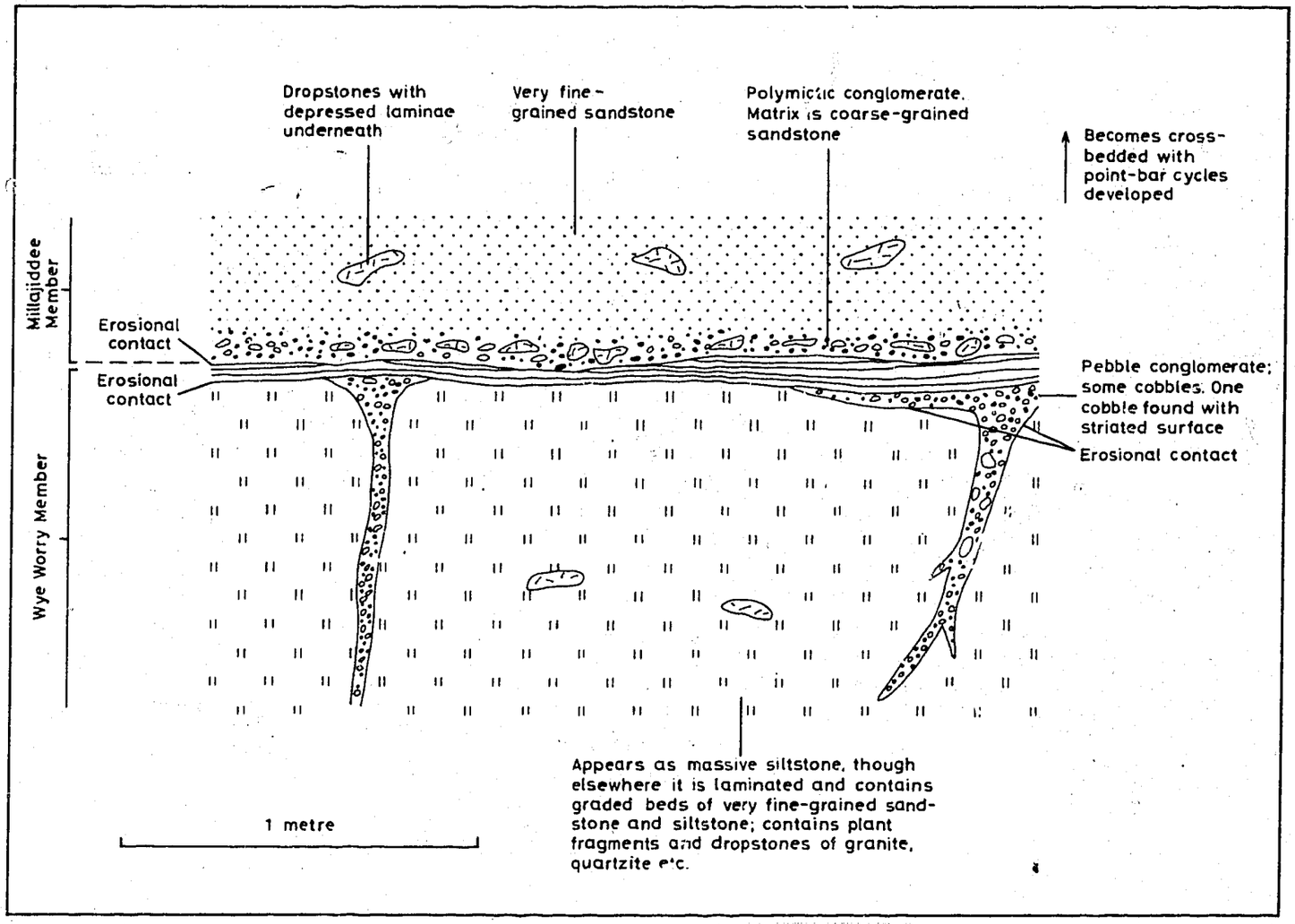


Fig. 3. Clastic dykes of pebble conglomerate (Millajiddee Member) cutting siltstone of the Wye Worry Member. The dykes are interpreted as infilled ice-wedges. Lat. 18°50'30" S; long. 126°07'00" E (Mount Ramsay)

'Middle' Millajiddee Member: In the western point of the St George Range (Section 15) the 'middle' Millajiddee Member unconformably overlies the finer-grained 'lower' Millajiddee Member, and consists of medium to fine-grained quartz wacke with minor quartz arenite at the base. It contains pebble conglomerate, many erosional contacts, and trough cross-bedded fining-upwards and coarsening-upwards sequences. The fining-upwards sequences are topped by thin-bedded units containing asymmetrical ripple marks and are interpreted as point-bar deposits. Elsewhere in the western St George Range, planar cross-bedding is abundant (Plate 13).

In the centre of the St George Range (Section 10) the 'middle' Millajiddee Member consists of medium and fine-grained quartz wacke with minor lithic wacke. It contains both planar and trough large-scale cross-bedding and has some fining-upwards sequences characterized by basal quartzite-pebble and clay-pellet channel lag deposits.

Towards the southeastern part of the range the 'middle' Millajiddee Member thickens (Section 8) and consists of moderately to poorly sorted feldspathic wacke and quartz wacke. Much of the cross-bedding around Section 8 is of the festoon type (planar) and in places well-developed point-bar sequences occur (Fig. 4).

In the Lauris Range this part of the member is only a few metres thick and is lithologically similar to the sections in the St George Range; on MOUNT RAMSAY, however, the unit contains dropstones at the base. (Fig. 3).

'Upper' Millajiddee Member: The 'upper' Millajiddee Member is everywhere characterized by more or less extensive large-scale slump structures, which commonly obscure the smaller sedimentary structures.

In the western part of the St George Range this part of the member consists of very fine-grained quartz wacke inter-bedded with siltstone. Planar cross-bedding was recognized, but slump structures predominate. At the top of the unit climbing ripples-in-drift (McKee, 1965) were identified.

In the central St George Range the 'upper' Millajiddee Member is absent and is thought to have been eroded before deposition of the Nura Nura Member, but in the eastern part of the range the lithology is similar to that in the west except that parts of the unit are coarse-grained.

The 'upper' Millajiddee Member was identified at Mount Amy and Mount Hutton (Section 5), where large-scale slump structures are well exposed (Plate 14). The beds involved

in the slumped masses show a post-deformational horizontal lamination which indicates that further compaction of the sediment took place after the slumping (Plate 15).

In the Poole Range many of the slump and slide blocks of sandstone in the Wye Worry Member appear to have been derived from this part of the member, but as already stated it was not possible to map the members in this area.

In the Lauris Range (Section 18) the sediments are locally undeformed and consist of thin planar-bedded siltstone and very fine-grained quartz wacke and quartz arenite. Large-scale planar cross-sets occur in the upper part of the section and contain intraformational breccia blocks up to a metre in diameter. Above this the rock is interpreted as a mudflow deposit; it is a mass of slumped and brecciated blocks with intervening beds of siltstone and intraformational conglomerate.

Age

The Wye Worry Member is dated as Late Sakmarian (Dickins et al., in press). The overlying Nura Nura Member has been dated as Sakmarian (Glenister & Furnish, 1961); therefore, by inference, the Millajiddee Member is of Late Sakmarian age.

Thickness

'lower' Millajiddee Member

Western St George Range	15 m	(Section 15)
Central St George Range	25 m	(Section 10)
Southeast St George Range	20 m	(Section 8)
Poole Range		probably present

'middle' Millajiddee Member

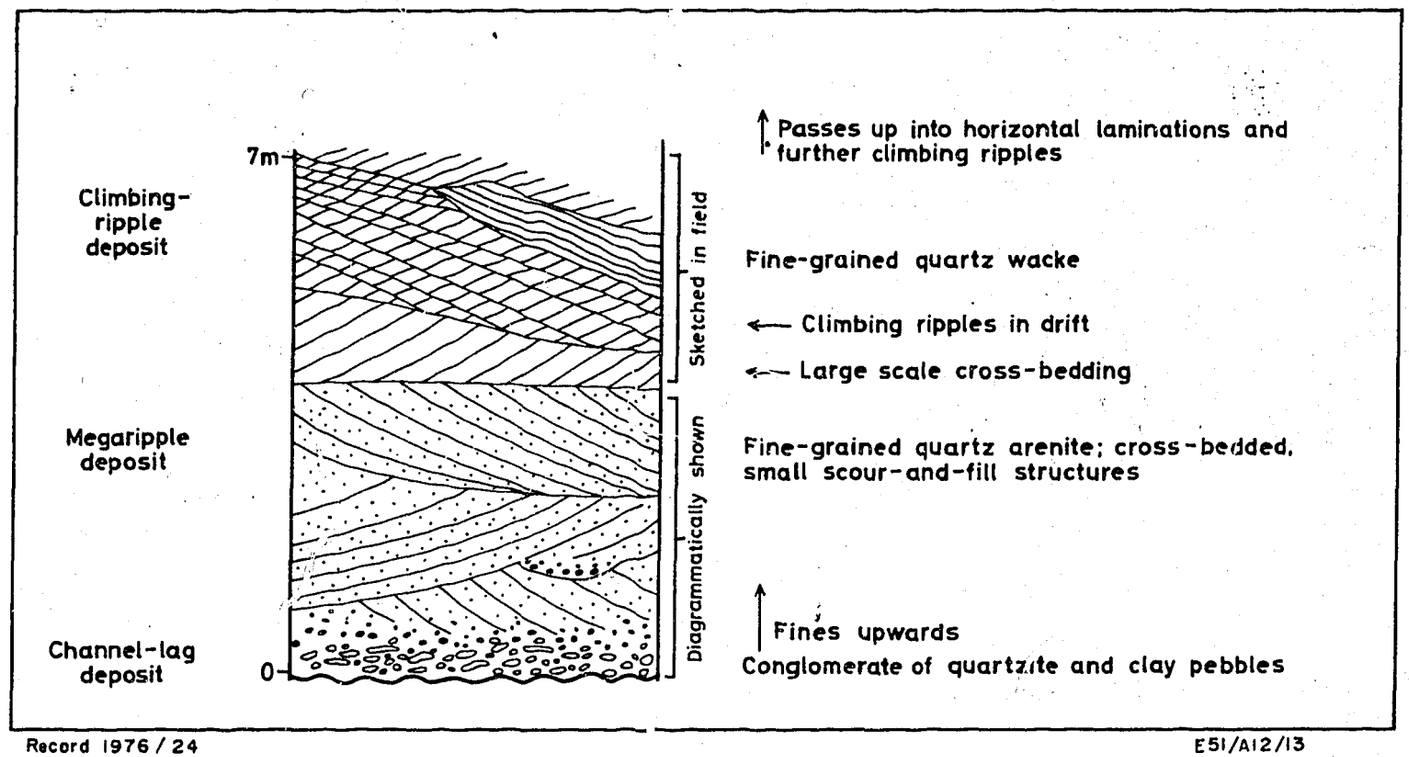
Western St George Range	30 m	(Section 15)
Central St George Range	40 m	(Section 10)
East St George Range	30 m	(Section 7)
Southeast St George Range	60 m +	(Section 8)
Poole Range		probably present
Lauris Range	5 m	(Section 18)

'upper' Millajiddee Member

Western St George Range	25 m	(Section 15)
Eastern St George Range	25 m	(Section 7)
Mt Hutton	15 m +	(Section 5)
Poole Range		probably present
Lauris Range	25 m +	(Section 18)



Plate 13 Large-scale planar cross-bedding in the 'middle' Millajiddee Member at the type section. Western part of St George Range. Lat. 18°44'20"S, long. 124°55'52"E



Record 1976 / 24

E51/A12/13

Fig. 4. Section of point-bar sequence in 'middle' Millajiddee Member in south eastern part of St George Range; lat. 18° 50' 37" S. long. 125° 18' 40" E

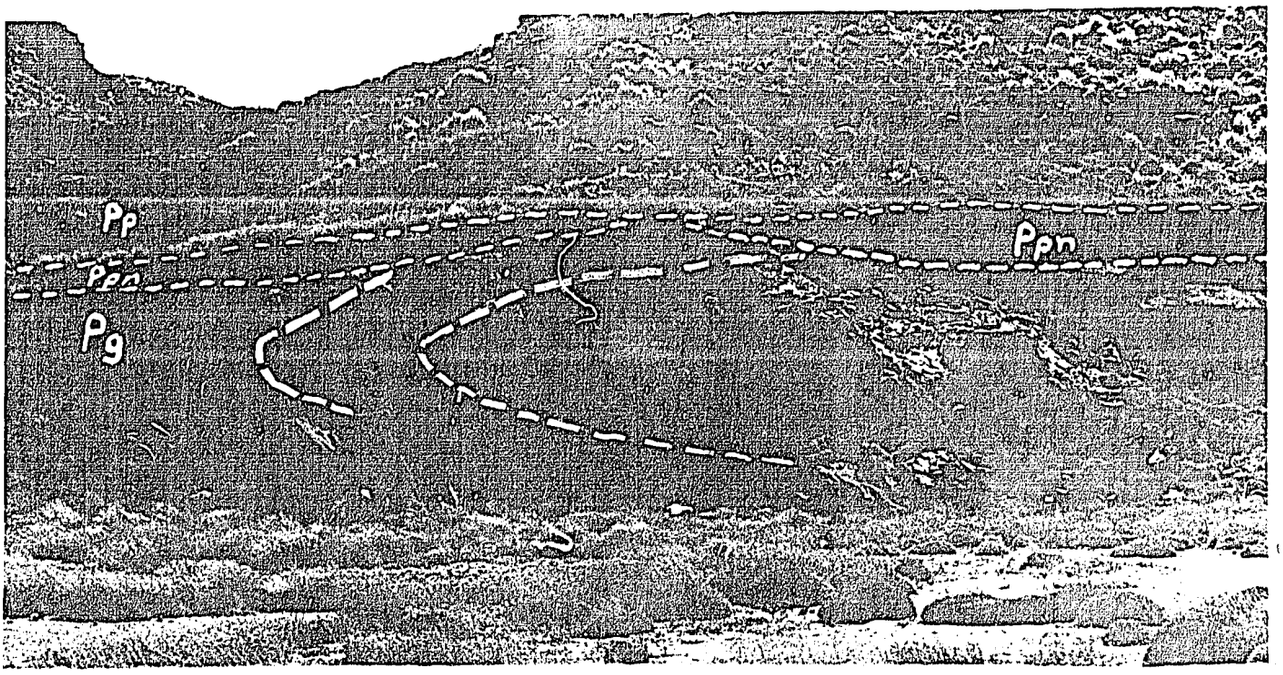


Plate 14 Grant Formation (Pg), Nura Nura Member (Ppn) and 'middle' Poole Sandstone (Pp), at base of Mount Amy. A large slump structure in the Grant Formation is outlined. Plate 17 is a close-up of the middle, light-coloured part of this slump. Inked-in Figure at base of cliff indicates scale.

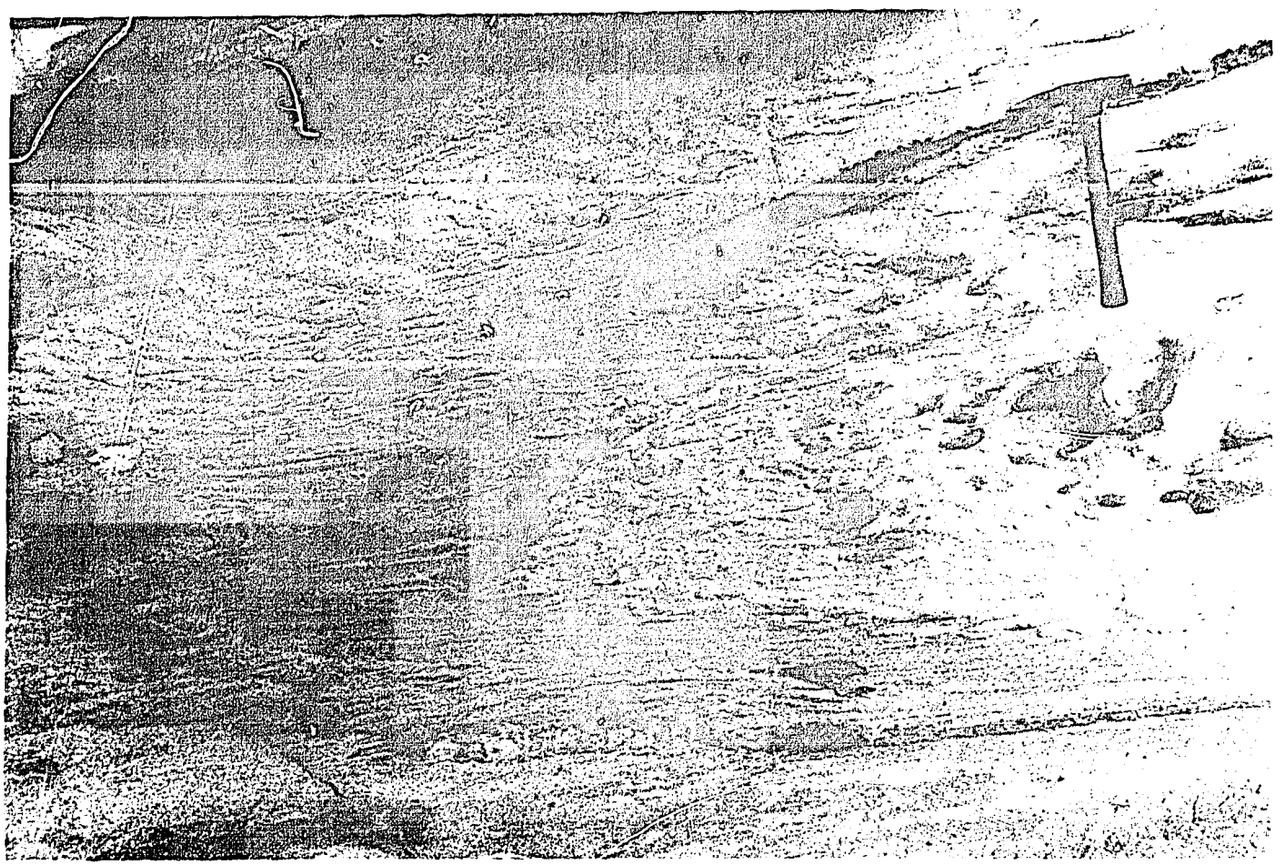


Plate 15 Close-up of slump structure in Plate 16, showing overturned beds. The horizontal foliation was caused by compaction of the sediment after it had slumped.

The 'lower' Millajiddee Member is not present in the Lauris Range, nor on MOUNT RAMSAY. The middle part is very thin in the Lauris Range; it is of a fairly uniform thickness over the rest of the area, but thickens to the south in the eastern St George Range to at least 60 m and probably to about 100 m. The Millajiddee Member is also tentatively identified in Esso No. 27 bore where it is possibly 15 m thick.

Environment of deposition

If the Millajiddee Member is considered together with the underlying Wye Worry Member (the boundary is gradational) it can be seen that the lithology passes from siltstone and shale (Wye Worry Member) through interbedded siltstone and sandstone (lower part of Millajiddee Member) into cross-bedded sandstone (middle part of the Millajiddee Member). The sequence shows an overall upward increase in grainsize and sorting, which suggests that it represents a regression (Visher, 1965). To determine whether the regressive shoreline represented by the sequence was linear or deltaic, it is necessary to examine the crossbedded sandstone in more detail. According to Selley (1970, p. 107), the main difference between the two types of regressive sequence is that the lower contact of the cross-bedded sandstone unit is an abrupt erosional one in deltaic sequences and in linear shoreline sequences it is more or less gradational. Moreover in deltaic sequences the cross bedded unit contains fining-upwards point-bar deposits.

Thus in the western St George Range (Section 15) a deltaic interpretation is most appropriate. Similarily in the southeastern part of the range (Section 8) the point-bar deposits could belong in the upper part of a deltaic sequence. On the other hand, in the eastern St George Range (Section 7), a linear shoreline sequence is indicated by the gradational change and the absence of any channel deposits.

Detailed observations help to bear out the interpretation of a regression. The interbedded siltstone and sandstone of the 'lower' Millajiddee Member corresponds well with descriptions of prodelta deposits (Selley, 1970, p.81). For instance, extensively bioturbated zones (Plate 12) are common in this part of the sequence and the presence of glauconite (noted in thin section) indicates that this part is marine in origin.

In the eastern part of the St George Range (Sections 7 and 9), the sequence is somewhat different. The upper part of the Wye Worry Member is similar and agrees well with a prodelta or shelf interpretation. This sequence passes gradationally up into ripple-marked, bioturbated, 'lower'

Millajiddee Member and then, also gradationally, into planar-cross-bedded, fine and medium-grained quartz wacke and quartz arenite of the 'middle' Millajiddee Member. The gradational nature of the boundaries, the better sorting and the absence of point-bar deposits indicate a linear-shoreline (barrier-beach) sequence (Selley, 1970, p. 107).

On MOUNT RAMSAY the 'lower' Millajiddee Member is represented by the clastic dykes, which are interpreted as infilled ice wedges, and the overlying siltstone unit. The ice-wedge interpretation implies that, while pro-delta deposits were being laid down in the west, the extreme eastern part of the area (MOUNT RAMSAY) was above sea level and was being subjected to a periglacial climate.

The 'upper' Millajiddee Member also fits the interpretation of a regression. The topmost part of a deltaic or shoreline sequence normally consists of lagoonal and delta-plain subaerial deposits (Selley, 1970, p. 108). Such deposits are characterized by their fine grainsize, among other features. On NOONKANBAH the environment of the 'upper' Millajiddee Member is hard to interpret, due to hydroplastic deformation but the fine grainsize throughout suggests that low-energy conditions prevailed. Consequently the delta-plain environment seems a possible interpretation.

Esso hole No. 27 intersected small coal seams which are further evidence for a delta-plain origin.

SUMMARY OF DEPOSITIONAL HISTORY

The rocks below the Wye Worry Member were probably deposited in both marine and non-marine environments but there is insufficient evidence collected to differentiate them.

The Wye Worry Member was laid down in a glacial environment. Where it is thickest, its basal part shows evidence of deposition in a freshwater lake but elsewhere basal freshwater indicators are lacking. The lake then became connected with the sea and the rest of the Wye Worry Member was deposited under marine conditions. In Millajiddee Member times, the eastern and northern parts of the area became emergent and permafrost conditions prevailed, while in the south and west the coastline regressed farther, leaving deltaic and shoreline deposits of the 'lower' and 'middle' Millajiddee Member. The area by now had become entirely non-marine, and possible low-energy fluviatile delta-plain deposits were laid down in the south and west.

EVIDENCE OF UPLIFT AND EROSION BETWEEN DEPOSITION OF GRANT FORMATION AND POOLE SANDSTONE

Guppy et al. (1958) described the 'distinct unconformity' between the Grant Formation and the Poole Sandstone, but later Veevers & Wells (1961) claimed the boundary was, at best, a disconformity and that Guppy et al. may have been misled by slumping at the top of the Grant Formation. The slumped beds at the top of the Grant Formation are clearly unconformably overlain by what we now identify as the Nura Nura Member of the Poole Sandstone. Thus it would seem that, at least on NOONKANBAH, Guppy et al. were correct.

From measuring detailed sections, particularly in the St George Range, we are now able to demonstrate that this contact is regionally an angular unconformity and that in at least two places (Sections 3 and 16) the whole of the Millajiddee Member is cut out (Fig. 1; Encl. No. 1), indicating that uplift and erosion occurred prior to deposition of the Nura Nura Member.

In the western St George Range there is an un-named unit which lies unconformably on the Millajiddee Member and unconformably below the Nura Nura Member. This unit is tentatively interpreted as the remnant of an alluvial-fan deposit, which would indicate a period of erosion between the overlying and underlying members, thus supporting the suggestion of an erosional break at the end of Grant Formation deposition.

The unnamed unit consists of a lens (lat. 18°44'20"S, long. 124°55'52"EE) about 20 m long and 1 metre thick containing crudely crossbedded breccia interbedded with sandstone (Plate 16). The breccia blocks consist of angular intraformational clasts and reworked tillitic boulders. The tillitic beds (Wye Worry Member) occur about 100 m below (in the same section), so that the reworked boulders must have been derived from areas where the overlying Millajiddee Member had been stripped off (e.g. near Millajiddee homestead, about 35 km to the east). Moreover the marked angularity of the intraformational blocks indicates very little transportation. The interlayering of such beds with relatively well-sorted current deposits is a characteristic of alluvial fans (Blissenbach, 1954). This deposit may correlate with similar deposits identified in the Lauris Range, although the beds in the Lauris Range have been included in the Millajiddee Member because there is no break in the sequence in that area.

The uplift needed to expose the underlying tillitic beds and to form these deposits could well also have been responsible for the large amount of rheotropic deformation that took place prior to deposition of the Poole Sandstone.

POOLE SANDSTONE

Guppy et al. (1958) described a basal marine member in the Poole Sandstone (Guppy et al., 1952) in the south-western St George Range. They correlated this member with the Nura Nura Member, which occurs on adjoining MOUNT ANDERSON. We have carried the correlation further and have everywhere identified a basal member of the Poole Sandstone which we have called the Nura Nura Member.

The main part of the Poole Sandstone, herein referred to as the 'middle' Poole Sandstone, has not been subdivided.

The top part of the Poole Sandstone, which crops out best in the Poole Range, was previously described as part of the Noonkanbah Formation, (Guppy et al., 1958), but Crowe & Towner (1976) have named it the Christmas Creek Member; as it has an interfingering boundary with the underlying 'middle' Poole Sandstone and appears to have a planar contact with the overlying Noonkanbah Formation.

NURA NURA MEMBER

Section 14 (lat. 18°47'45"S, long. 124°57'33"E.) is proposed as a reference section for the Nura Nura Member (Guppy et al., 1952). However, the lithology of the member varies markedly from place to place, and the other measured sections of the unit should also be taken into account (see particularly Sections 7 and 5, and Figures 5 and 6).

Distribution

The member occurs throughout the St George and Poole Ranges and between these areas it is poorly exposed on the plains. Some outcrops north of the Fitzroy River have been tentatively assigned to this unit. The member has been recognized in the subsurface in Mount Hardman No. 1 well (WAPET, 1973) and in Esso No. 27 bore, where it is fossiliferous.

Relationships

The lower boundary with the Grant Formation is an angular unconformity, although the angular relationship is not always apparent. The upper boundary with the 'middle' Poole Sandstone is conformable in the western part of the area and disconformable in the east. In the eastern part of the St George Range the member interfings with the 'middle' Poole Sandstone.

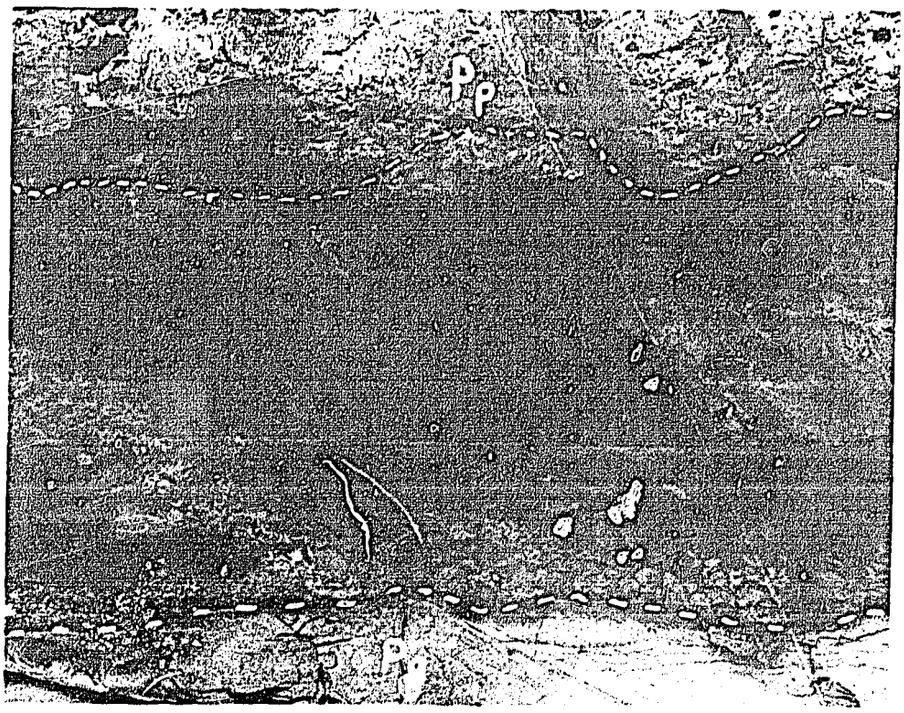


Plate 16 View of un-named unit between Grant Formation (Pg) and Poole Sandstone (Pp). The unit consists of a breccia overlain by sandstone. Western part of St George Range, lat. 18°44'20"S, long. 124°55'52"E

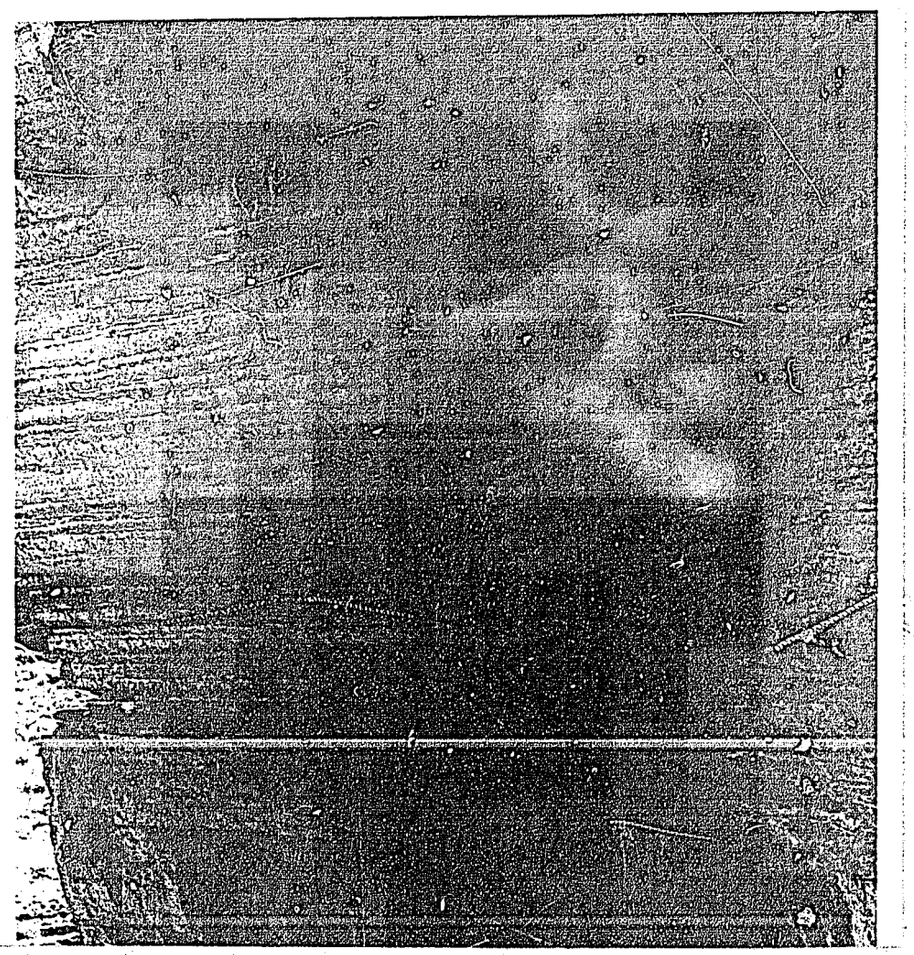


Plate 17 Part of reference section of Nura Nura Member showing wavy bedding with flasers. The photograph covers approximately 5 m of the section. Lat. 18°47'45"S, long. 124°57'33"E.

Lithology

In the west of the St George Range the Nura Nura Member consists mainly of fine-grained quartz wacke and siltstone. Parts of the sequence are calcareous and contain marine fossils. The base of the member is generally marked by a fossiliferous conglomerate which contains boulders of granite, quartzite, etc. derived from the Wye Worry Member of the underlying Grant Formation. Further up the sequence the member contains abundant ripple cross-laminations, wavy bedding, flaser bedding, and minor lenticular bedding (Plate 17). Erosional contacts are common, together with scour-and-fill structures which in places have shell debris constituting the fill. Graded bedding was also noted (Section 14), and bioturbation and vertical burrows are common throughout. In places large-scale cross-bedding is developed, and at one locality near Mount Tuckfield climbing ripples occur near the base. The top 10 m of the member in the reference section consists of massive fine and very fine-grained, well-sorted quartz wacke which contains some faint large-scale festoon cross-bedding.

In the central St George Range the Nura Nura Member is not easily distinguished from the rest of the Poole Sandstone. It appears on the aerial photographs as a darker band overlying the Grant Formation, and this reflects the ferruginization that is present in outcrop. The basal part consists of cross-bedded conglomerate which fines upward into poorly bedded silty sandstone and sandy siltstone. Fossils were found in the member near Tullock Peak on the south side of the range but none were found farther to the north or east. From studies of the aerial photographs in conjunction with the contoured topographic maps (1: 100 000 scale) it is evident that the member thickens abruptly in certain parts of the range. For instance, at a cliff 2.5 km east of Dukes Dome the member thickens from 10 m to 40 m within a distance of about 1 km.

In the eastern part of the St George Range the member is coarser grained than in the west of the range, and consists of a basal sequence of fine to medium-grained quartz wacke which contains numerous vertical burrows, similar to those seen in the member in the western end of the range. This lower part contains small-scale cross-bedding with flasers and lenses of intraformational conglomerate. This passes up into medium-bedded, medium-grained, well-sorted, quartz wacke in which the grains are well-rounded. Above this there is a sequence of fining-upwards cycles consisting of trough cross-bedded coarse to medium-grained quartz wacke and quartz arenite; channel-lag conglomerate occurs at the base of each cycle. The cycles are topped by asymmetrical ripple marks, on some of which trace fossils are preserved. Wood fragments are common in the cross-bedded parts of the sequence.

The Nura Nura Member is well exposed at Mount Hutton, between the St George Range and the Poole Range. At this locality it consists mainly of a fossil root bed which unconformably overlies the slumped Grant Formation (Fig. 5; Plate 15). In detail the Nura Nura Member sequence consists of cross-bedded, fine-grained, quartz-wacke containing some root impressions. This is overlain by a poorly sorted, medium-grained, massive bed, containing very abundant fossil roots, which interfingers laterally with shaly mudstone containing fossil leaf fragments and scattered coarse-grains of sand. This bed is commonly about 2 m thick but it is laterally discontinuous; it is overlain by a completely silicified white quartz arenite bed. Above the silicified white quartz arenite bed. Above the silicified bed are rocks of the 'middle' Poole Sandstone which also contain root impressions. The relationships of these beds are shown in Figure 5.

Farther east, in the Poole Range, the Nura Nura Member consists of various lithologies. At one locality (lat. 18° 47'30"S, long. 125° 47'30"E) overturned foresets were observed. At another locality near Poole Range Bore (lat. 18° 52'33"S, long. 125° 47'53"E) there is a fining-upwards sequence of cross-bedded quartz wacke (Fig. 6). At Mount Thorlan, just to the north of the Poole Range, the Nura Nura Member consists of root beds, silicified quartz arenite and minor conglomerate (Section 5).

The lithology of the Nura Nura Member to the north of the Fitzroy River and the east of Christmas Creek is not known in any detail, as exposures are poor and identification of the member in these areas is either not possible or, at best, tentative. However Mount Hardman No. 1 well intersected the member and showed that it consists mainly of siltstone in that area (WAPET, 1973).

Thickness

Western St George Range	30 m	(Section 14)
Middle St George Range	?12-40 m	(Section 10 and estimation)
Eastern St George Range	27 m	(Section 7)
Mt Hutton	0-12 m	(Section 5)
Poole Range	5-15 m	(Section 3 and others)
Esso No. 27 bore	15 m	

An overall thickening to the west is indicated but local variations occur in the middle of the St George Range area.

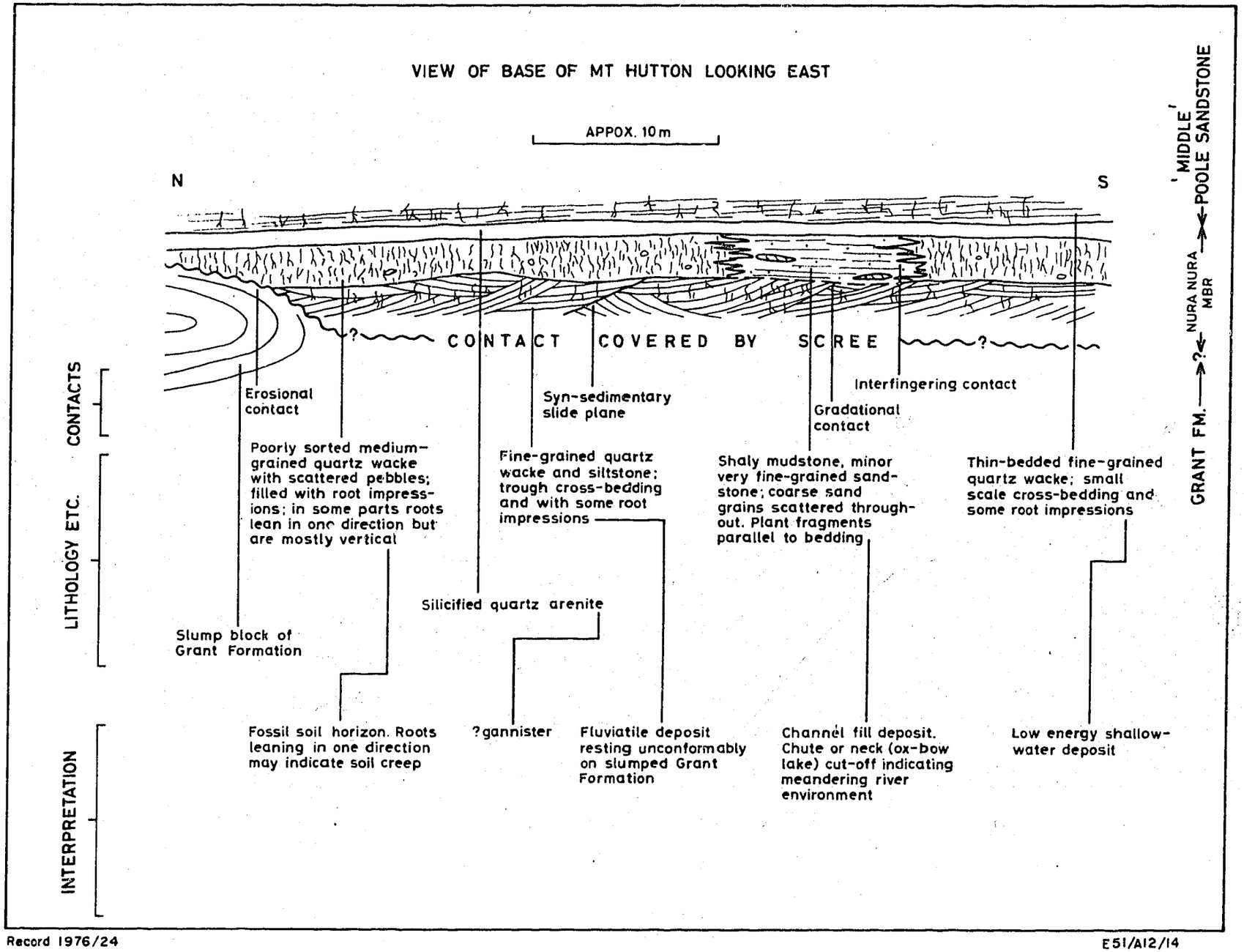


Fig. 5. Diagrammatic field sketch showing relationships, lithology and environmental interpretation of Nura Nura Member at Mount Hutton

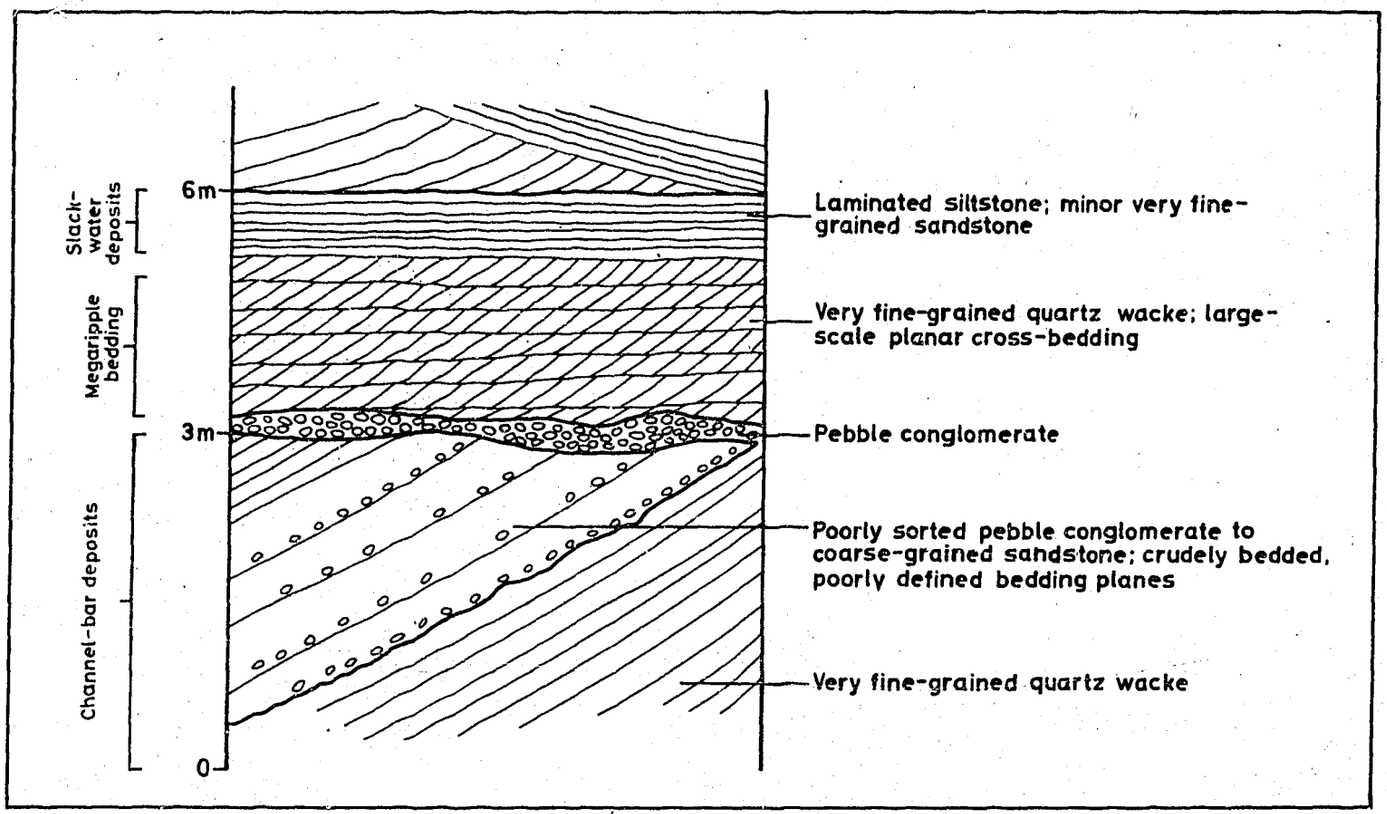


Fig. 6. Diagrammatic section of Nura Nura Member exposed near Poole Range Bore; lat. 18° 52' 33" S. long. 125° 47' 53" E

Age

Guppy et al. (1958) provide faunal lists for the Nura Nura Member and give the age as Early Artinskian. However, this has been amended to Late Sakmarian (sensu lato) by Glenister & Furnish (1961). J.M. Dickins has assigned a Late Sakmarian (sensu lato) age to fossils he collected from near Section 14.

Environment of deposition

In the west of the St George Range the fossils in the member indicate a marine environment of deposition. The basal fossiliferous conglomerate containing clasts derived from underlying units indicates reworking by marine processes as the sea transgressed the area. Further up the sequence the abundant flaser and lenticular bedding is characteristic of shallow-water deposition and the abundance of vertical burrows tends to confirm this interpretation. The beds containing scour-and-fill structures, large-scale cross-bedding and climbing ripples are interpreted as tidal channel deposits. The presence of graded bedding (Section 14) is difficult to explain in shallow-water marine sediments but may be due to deposited suspension loads of either density currents or storm-disturbed water. The relatively clean, fine-grained, well sorted and poorly bedded nature of the massive sandstone at the top of the Nura Nura Member in Section 14 indicates conditions in which the sediment was highly winnowed. Such winnowing is normally attributed to wave action in shallow-marine sediments, and consequently this deposit is interpreted as a beach or sand-bar deposit. The position of this deposit in the vertical sequence (see Visher, 1965) suggests that it may have been a barrier bar.

In the central St George Range little detail is available. The sediments may have been laid down in lagoons, as they are similar to the overlying 'middle' Poole Sandstone.

At the eastern end of the St George Range the overall coarsening-upwards of the sequence indicates regressive marine conditions. The lower part of this section is similar to the sequence at the western end of the range and the abundant burrows and lenticular thin bedding indicate a shallow-marine environment. This part of the section is overlain, with an erosional contact by fining-up cycles interpreted as point-bar deposits. According to Selley (1970, p. 77) such a section is typical of a regressive deltaic sequence and this is the interpretation placed on the member in the eastern St George Range.

At Mount Hutton, the lower part of the sequence is composed of fine-grained cross-bedded sandstone containing

root impressions. The fossil roots indicate a continental environment and the cross-bedding suggests fluviatle deposition. Above these deposits is a root-filled bed which is interpreted as a fossil soil horizon. Figure 5 shows how the fossil soil interfingers laterally with undisturbed shaly mudstone. Because this mudstone interfingers with the soil, it must have been deposited at the same time as the soil was supporting vegetation. The absence of current structures in the mudstone indicates that it was deposited from suspension in a standing body of water. The coarse grains of sand distributed throughout the mudstone were probably carried into the water body by wind or on vegetation rafts. Because this mudstone deposit is of limited lateral extent (less than 10 m) it is interpreted as a channel-fill (ox-box lake) deposit similar to those described by Reineck & Singh (1973, p. 245). Thus the Nura Nura Member at Mount Hutton is interpreted as representing meandering river deposition in a vegetated area. Further work in the area may show that other types of meandering river deposit are also present at this level.

In the Poole Range area several environments may be represented. For instance, the essentially plane-bedded part of the sequence at Mount Thorlan consists of graded sandstone and siltstone containing fossil root beds (Section 3). Such deposits were probably deposited on a flood plain, although the high degree of disruption of bedding due to root growth makes this identification tentative. Elsewhere in the Poole Range the available evidence suggests deposition by currents. The overturned foresets indicate high-energy currents and the fining upwards sequence near Poole Range Bore suggests a fluviatile environment. This sequence (see Fig. 6) bears a close resemblance to the typical braided-river sequence shown by Reineck & Singh (1973, p. 241). Features to note in this sequence are the wide range of grain size, the unidirectional current readings and the inclined conglomeratic foresets. Thus in the Poole Range area the environment of deposition is interpreted as a fast-flowing braided river together with its flood plain.

It can be seen, then, that the Nura Nura Member represents a transition from high-energy fluvial conditions in the east through to a shallow-water marine environment in the west (Fig. 7), and therefore that the palaeogradient probably sloped towards the west. Nothing, however, is known about the Nura Nura Member to the north or south of the belt of outcrop, so the environmental interpretation is tentative.

'MIDDLE' POOLE SANDSTONE

Distribution

The 'middle' Poole Sandstone forms rounded hills which flank the St George Range, and comprises the upper part

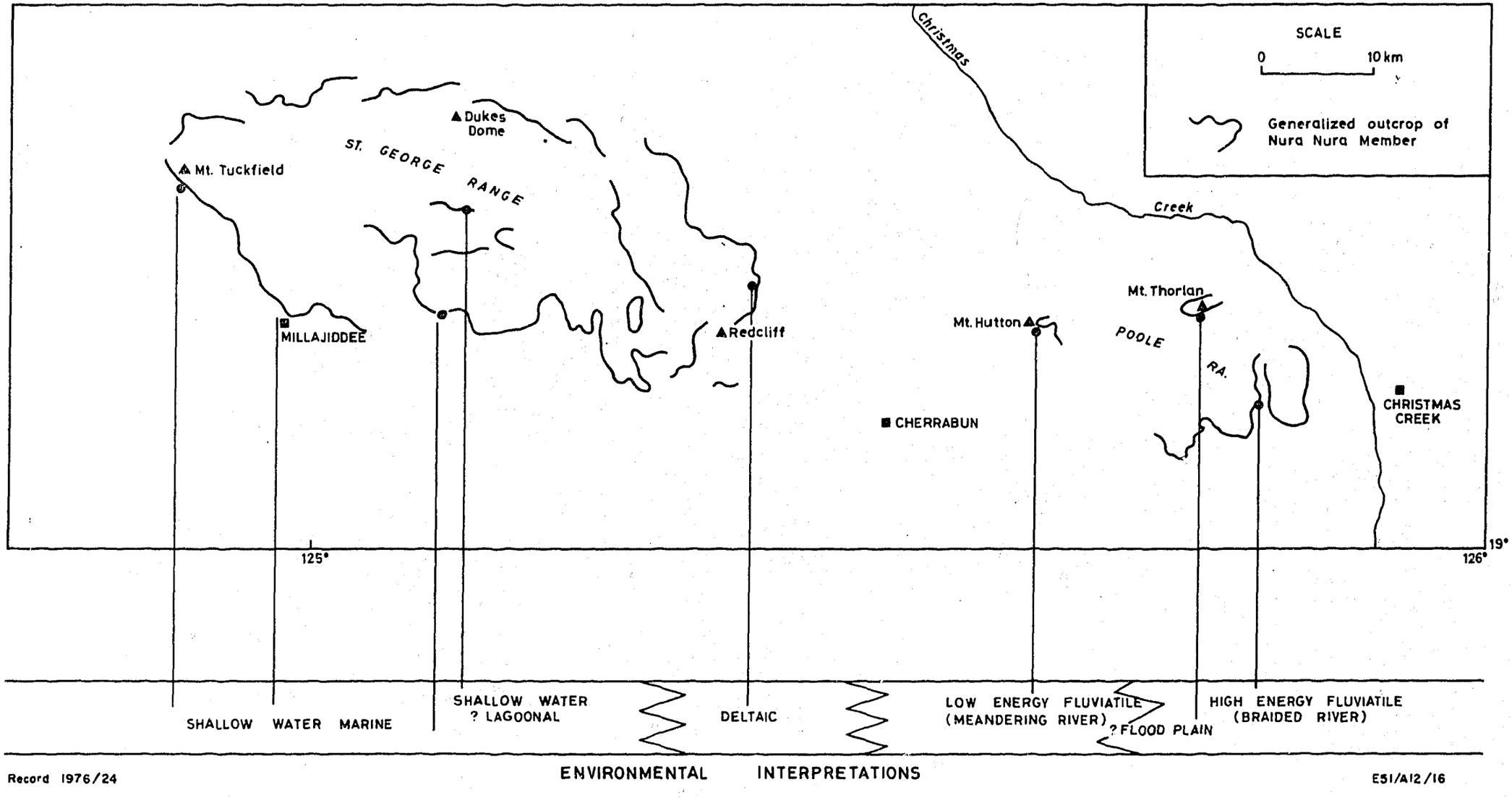


Fig. 7. Distribution and enviromental interpretation of Nura Nura Member. The black dots mark localities where enviromental interpretation have been made

of the sequence at Mount Amy, Mount Hutton and in the Poole Range. Smaller exposures are found in other parts of NOONKANBAH and the unit crops out in gravel plains between such exposures.

Relationships

The 'middle' Poole Sandstone lies conformably or, in places, slightly disconformably on the Nura Nura Member. In the northern part of NOONKANBAH this boundary was not seen, although it was intersected in Mount Hardman No. 1 well (WAPET, 1973).

The upper boundary with the Christmas Creek Member, in the eastern part of the Sheet area, is an interfingering relationship (Encl. 2) which appears erosional in places (Sections 2 and 3). To the west the Christmas Creek Member pinches out and the overlying Noonkanbah Formation rests directly on the 'middle' Poole Sandstone.

Lithology

Unlike the previously described unit, this part of the sequence does not vary much laterally.

The 'middle' Poole Sandstone consists mainly of very fine and fine-grained, quartz wacke and quartz arenite with a varied mica content. It is almost always thin-bedded and fissile. Large scale cross-bedding is rare, but as exposures are commonly covered by scree the sedimentary structures are often obscured. Large-scale planar cross-bedding was noted in the Poole Range in fine-grained, well-sorted, quartz arenite.

The most common sedimentary structure, which occurs throughout the sequence, is small scale cross-bedding, which can generally be found to be cross-sections of symmetrical ripple marks (Plate 18). As other sedimentary structures are rare in the unit some time was spent in studying symmetrical ripple marks. Measurements of their width, wavelength and amplitude were made and the ripple index and ripple symmetry index computed. The resulting figures were then plotted graphically following the method of Tanner (1967). According to Tanner it should be possible to differentiate between ripple marks of different origins on such a graph. All the ripple mark plots obtained fall within the wave-formed bracket (Fig. 8) and although there are insufficient readings to enable positive identification, this strongly suggests that the majority of the ripple marks in the 'middle' Poole Sandstone were formed by waves.

Marine fossils have not been found in this part of the Poole Sandstone, but plant fragments are common. The

majority of these are pieces of transported fossil wood, but in the eastern part of the area root beds occur throughout the sequence (Plate 20); fossil leaves commonly occur in adjacent beds. In the western part of the area bedding - surface trace fossils and bioturbated beds appear to be more common than in the east (Section 13). Lenticular intraformational conglomerate is also more common in the west and may indicate stronger currents in that area.

Thickness

Mount Tuckfield, Western St George Range	245 m +	(Section 13)
Central St George Range	140 m	(estimated)
Eastern St George Range	105 m +	(Section 6)
Mount Hutton	70 m +	(Section 5)
Mount Thorlan	20 m	(Section 3)*
Northern Poole Range	45 m	(Section 2)*

*interfingering upper boundary

Centre Poole Range	65 m	(Section 1)
Southern Poole Range	25 m	(Section 4)

Two trends are obvious from these figures (Encl. No. 2): there is an overall thickening from about 35 m in the east to about 250 m or more in the west (Mount Tuckfield, Plate 20); and in the Poole Range the unit is thicker in the centre of the anticline than on its northern and southern flanks. This latter trend probably continues to the west in the St George Range anticline as the two structures are continuous.

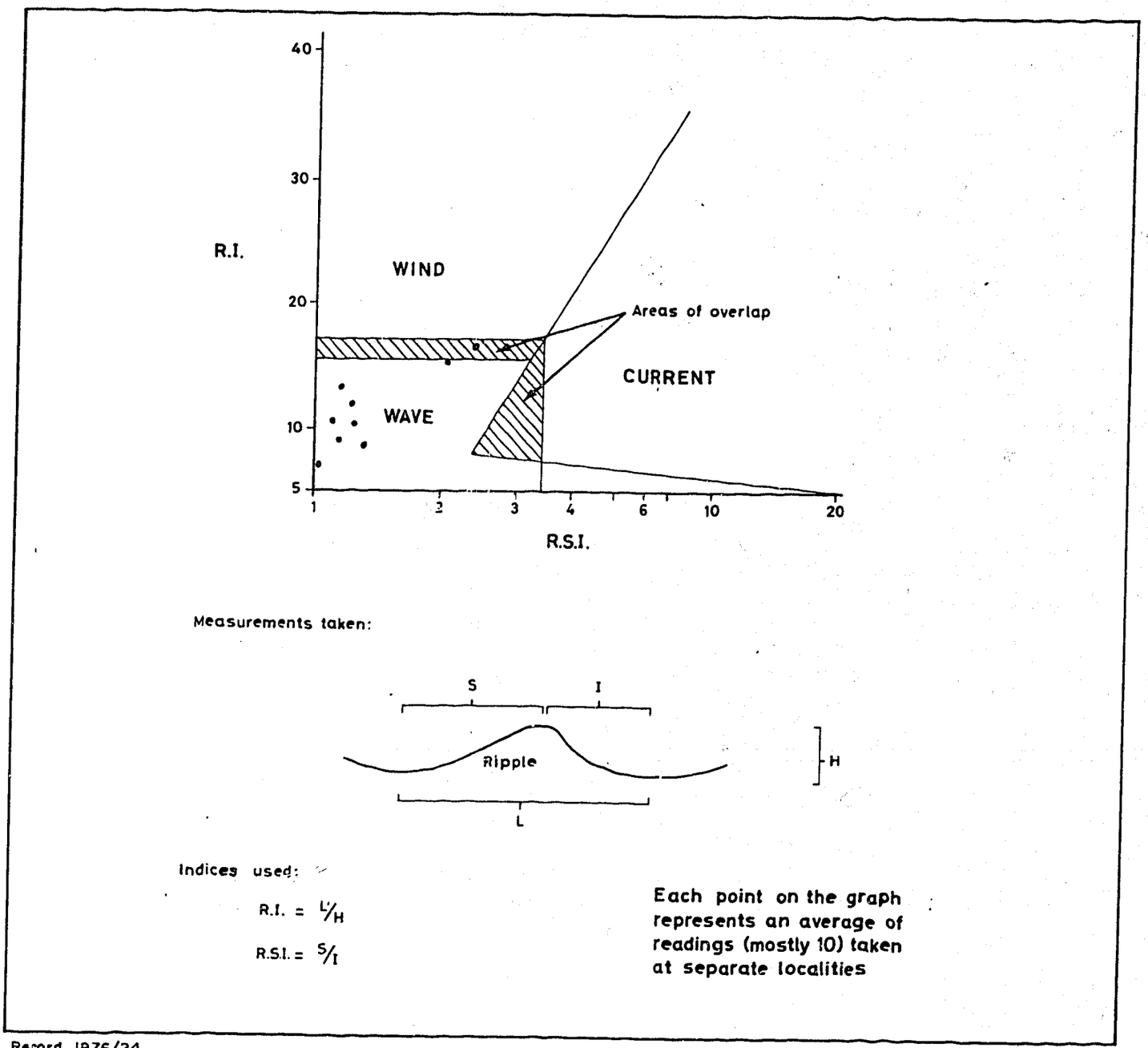
Age

Microfossils from the Poole Sandstone, elsewhere in the basin, indicate an early to late Artinskian age (Yeates et al., 1975b). Plant fossils in the unit in the eastern part of the Sheet area are not age-diagnostic. No marine fossils were found.

Environment of deposition

The thin, laterally continuous bedding containing abundant wave-formed ripple marks indicates a shallow-water environment. The fine grainsize and good sorting throughout the unit are consistent with this interpretation, as wave action causes much winnowing and reworking in such an environment. The frequent presence of root horizons in the eastern part of the area suggests periodic emergence.

The absence of marine fossils in the unit is peculiar, as shallow-water marine sediments normally contain a rich fauna. This suggests that the water may have been either too fresh or too saline to support a normal marine fauna.



Record 1976/24

E 51/A12/17

Fig. 8. Plot of ripple index (R.I.) against ripple symmetry index (R.S.I.) from measurements of ripple marks in 'middle' Poole Sandstone



Plate 18 Symmetrical ripple marks in the 'middle' Poole Sandstone, near the top of Mount Tuckfield.

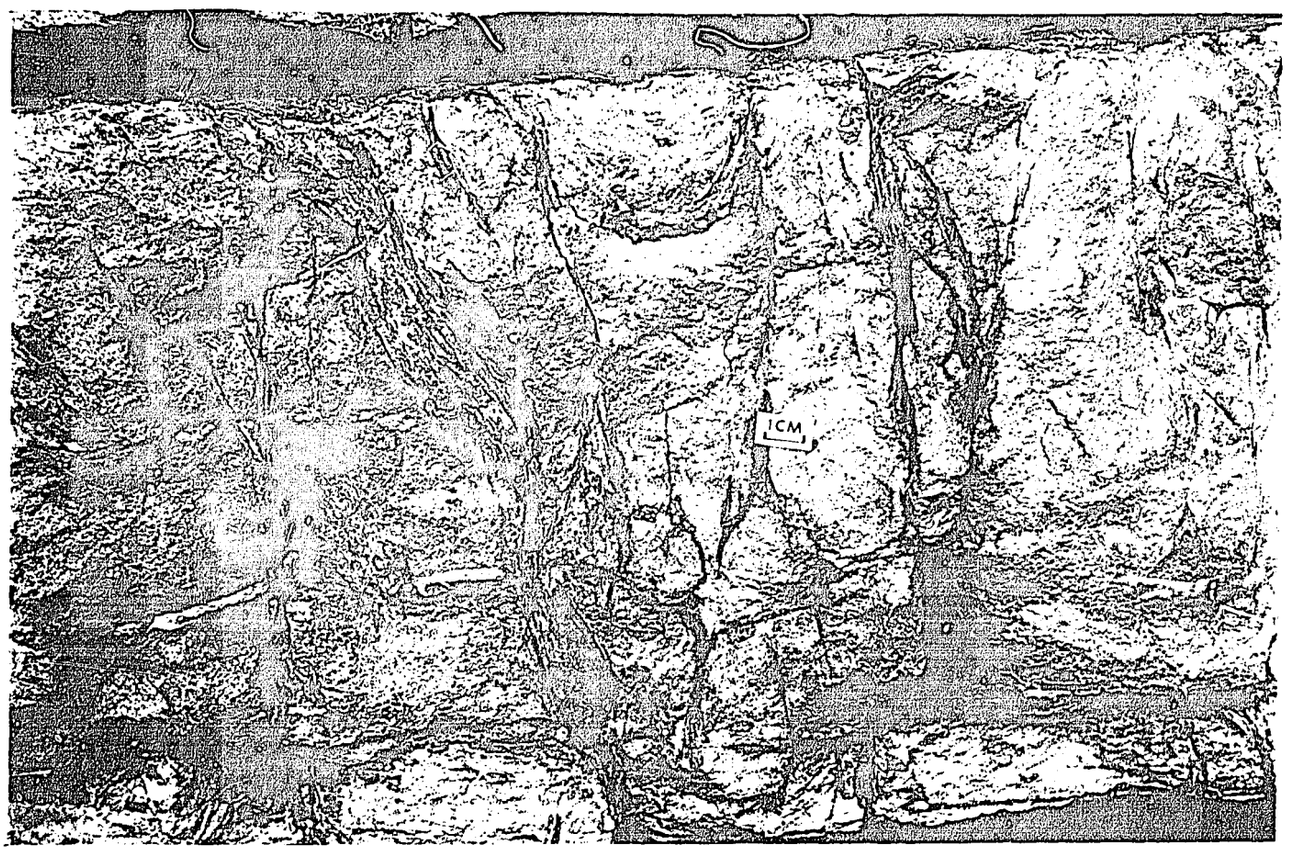


Plate 19 Root bed in the 'middle' Poole Sandstone in the eastern St George Range. Lat 18°50'36"S, long. 125°18'06"E

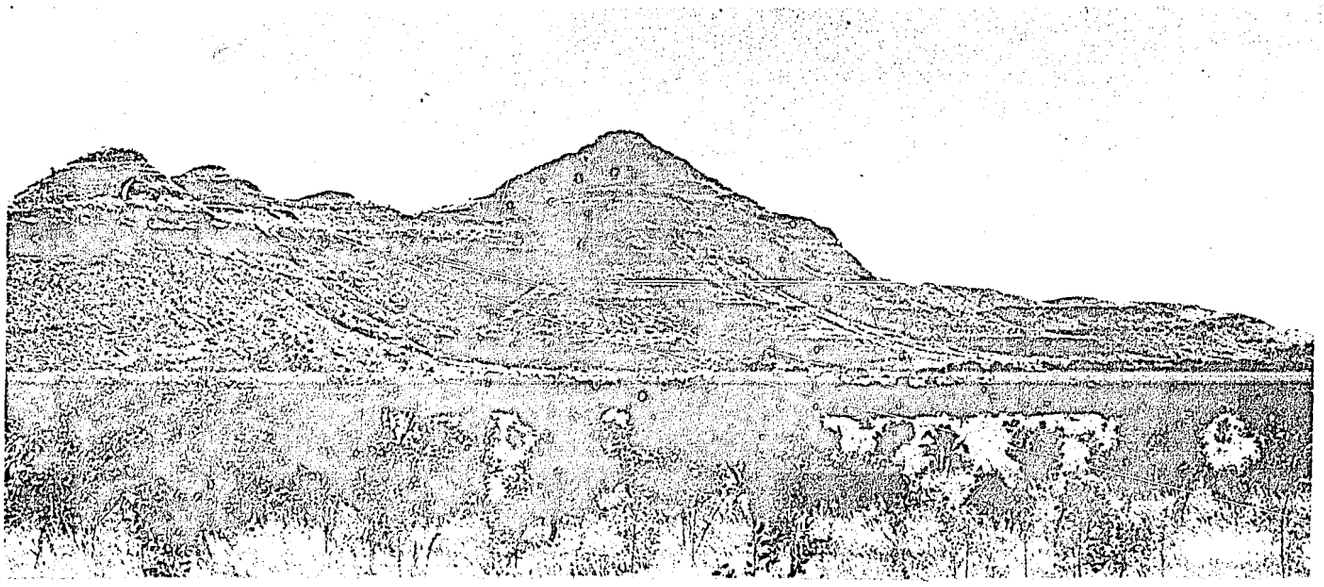


Plate 20 Mount Tuckfield, one of the highest peaks in the St George Range. The summit is about 170 m above the plain.

The interpretation of a barrier-bar or beach deposit at the top of the Nura Nura Member (see above) supports this hypothesis, as this bar may have restricted circulation with the open sea. More detailed work is needed in the eastern St George Range to map the boundaries of the possible barrier-bar deposit; however, if the above theory is correct that the 'middle' Poole Sandstone may have been laid down in a lagoonal environment.

The uniformity of the 'middle' Poole Sandstone from bottom to top indicates that subsidence of the area was occurring contemporaneously with sedimentation, allowing the sediments to be preserved. In the Poole Range (and probably along the axis of the St George Range Anticline) the greater thickness of the unit along the axis of the anticline compared with the flanks, indicates that subsidence was greater in the area now, occupied by the axis. Moreover, the overall thickening to the west suggests a greater amount of subsidence in that direction.

CHRISTMAS CREEK MEMBER

Distribution

The Christmas Creek Member (Crowe & Towner, 1976) is well exposed in the Poole Range and along the northern flank of the St George Range. Smaller exposures occur on the plains to the east of the St George Range and to the northeast and west of Mount Hutton. The member is not present in the western and southern St George Range.

Relationships

The member rests on the underlying 'middle' Poole Sandstone and the contact is interfingering, although in places it is erosional. The Christmas Creek Member is overlain by the Noonkanbah Formation and although the contact is poorly exposed it appears planar and is evidently either conformable or disconformable.

Lithology

The member consists of large-scale trough cross-bedded, poorly sorted, granule conglomerate and fine to coarse-grained, lithic wacke and quartz wacke. The textural maturity is low, as the grains are mostly angular (Plate 21). The bedding is medium to thin and in places it is graded. Fining-upward cycles capped by asymmetrical ripple marks occur (Section 1) and are interpreted as point-bar deposits.

Thickness

No complete sections of the member were measured. The greatest thickness encountered in the Poole Range was 15 m and from photo-interpretation the actual thickness is not thought to exceed 25 m anywhere. However the member varies greatly in thickness and is only a few metres thick to the west of Mount Hutton.

Age

Early Artinskian, because the overlying and underlying units are so dated.

Environment of deposition

The probable point-bar sequences, together with the immaturity of the rock, suggest a fluviatile origin.

SUMMARY OF DEPOSITIONAL HISTORY

After the continental deposits of the Millajiddee Member were laid down the area was uplifted. Some areas appear to have been raised higher than others and in these places the Millajiddee Member was eroded allowing the tillite in the Wye Worry Member to be reworked in a high-energy continental environment. This uplift was probably also responsible for much of the rheotropic deformation of the sediments in the Millajiddee Member.

A shallow sea then transgressed over the area now occupied by the St George Range. Farther to the east a river system existed which appears to have flowed from the east and to have discharged into the sea in the eastern St George Range area, where it formed a delta (Nura Nura Member).

The whole area apparently then became part of a shallow-water (possibly lagoonal) environment, where deposition kept pace with the subsidence. Certain parts subsided at a greater rate than others. The eastern part of the area supported vegetation and was eventually covered by coarser-grained fluviatile material. The sea then transgressed the entire area, and the Noonkanbah Formation was laid down.

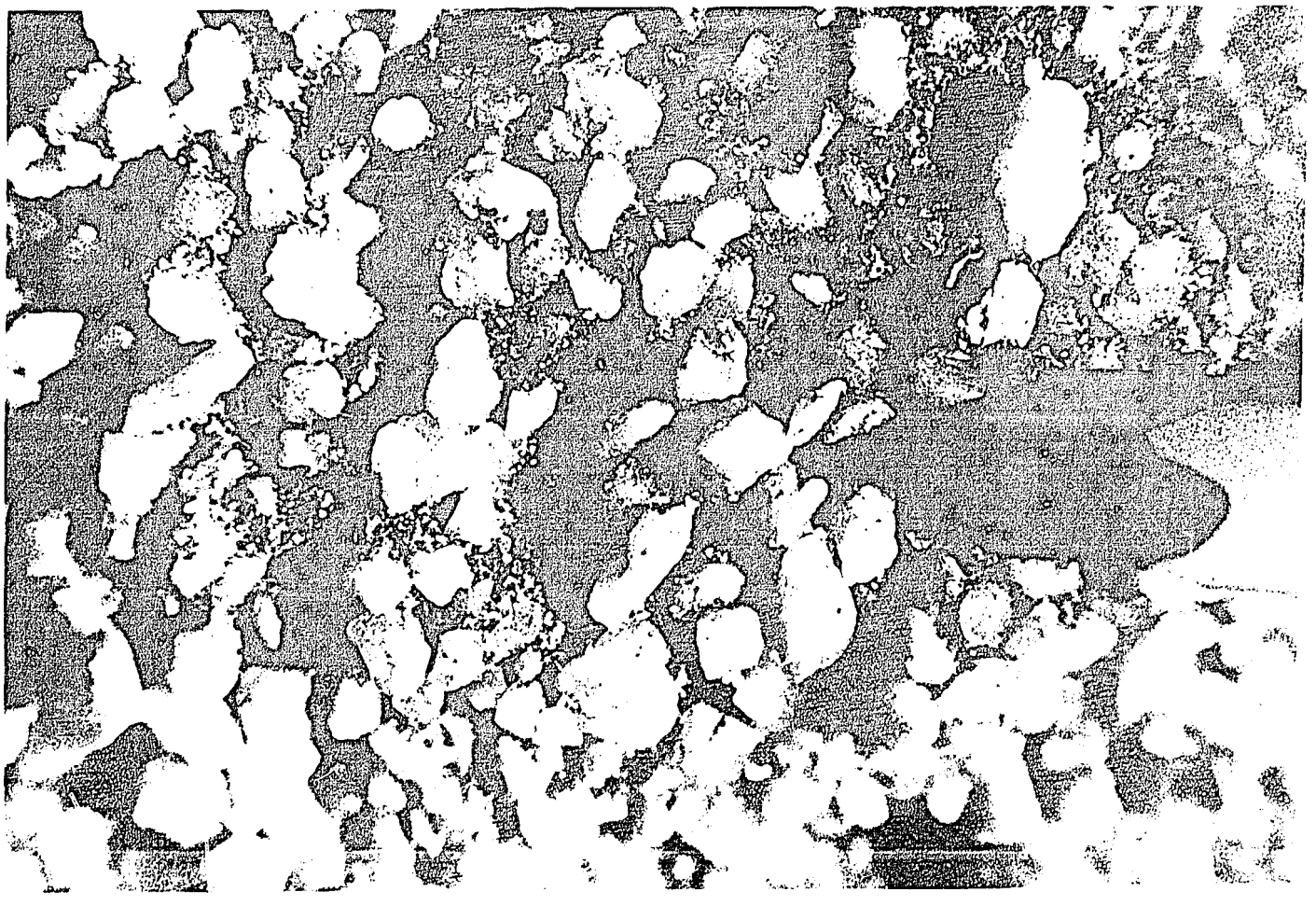


Plate 21 Close-up of coarse sandstone of the Christmas Creek Member showing textural immaturity.

NOONKANBAH FORMATION

Distribution

The Noonkanbah Formation (Guppy et al., 1952) is not well exposed; it underlies many of the blacksoil plains around the St George and Poole Ranges and Cherrabun and Noonkanbah Homesteads. Limestone and sandstone beds within the unit crop out in ledges on these plains and other exposures are present in the creeks and gullies around Noonkanbah Homestead and on the northern side of the St George Range.

The formation has been intersected in a number of bores within the Sheet area including Mount Hardman No. 1, Paradise No. 6, and many Esso boreholes north and south of the Fitzroy River.

Relationships

No clear exposure of the lower contact was seen. From bore information in the western and northern parts of the Sheet area, laminated siltstone of the Noonkanbah Formation overlies well-sorted, fine-grained quartz wacke of the Poole Sandstone (e.g. Mount Hardman No. 1, WAPET, 1973). In the southeastern part of the area the change is more pronounced with the Noonkanbah Formation siltstone overlying coarse-grained cross-bedded sandstone of the Christmas Creek Member. As there is a marked change in lithology across this boundary it may be a disconformity.

The contact with the overlying Lightjack Formation is conformable and gradational; the boundary is placed at the top of the uppermost bed of limestone in the sequence.

Lithology

In the subsurface, the formation consists of thinly interbedded shale, siltstone, sandstone and minor limestone. The shale and siltstone are black to dark grey, micaceous, and slightly calcareous. The sandstone is usually light grey to white, very fine-grained, silty, micaceous and calcareous. The thin beds of limestone are grey and finely crystalline. Fossil fragments are abundant in places in the sandstone and limestone beds, but are less common in the siltstone and shale.

Sedimentary structures seen in cores include small-scale cross-bedding and slumps; graded bedding is present locally, and burrowed intervals are common.

Similar lithologies appear on the surface, although the siltstone and shale intervals are rarely preserved. Where preserved from erosion the siltstone is seen to be grey, micaceous, slightly calcareous, laminated to thin-bedded, and contains small-scale ripple cross-lamination. In very weathered exposures the siltstone is commonly ferruginized in a boxwork pattern (Plate 22).

Sandstones and limestones are better exposed, although only minor constituents of the formation. The sandstone is composed of very fine to medium-grained quartz wacke containing scattered coarse grains and granules of quartz, which are subrounded to rounded. It is light grey or brown, moderately to poorly sorted, thin-bedded and has a calcareous matrix. Lenses of very coarse-grained sandstone and granule conglomerate are commonly present in these beds, and contain dispersed shell fragments. Some low-angle ripple cross-lamination is also present.

The limestones are commonly argillaceous or arenaceous, thin to medium-bedded, and micaceous. They generally contain concentrations of well preserved marine macrofossils.

Intraformational small-pebble conglomerate forms lenses in some areas; e.g. on the plains to the north of Cherrabun Homestead. The clasts are subrounded, up to 3 cm in diameter, and consist of mudstone and very fine-grained sandstone, commonly red or purple. Other constituents are quartz granules and shell fragments.

Guppy et al. (1958, p. 100) give a description of the formation at Brutens Yard (lat. 18°44'S, long. 125°38'E). This is one of the best sections of the unit in the Sheet area, but the amount of effective exposure depends on the vegetation cover, which during 1974 was quite dense.

Lateral variations of lithology in the Noonkanbah Formation are not obvious from a study of outcrops. Similarly, drilling by Esso (Galloway & Howell, 1975) indicates that there is little variation in the subsurface to the north of the Fitzroy River. However, in exposures adjacent to the Fenton Fault, just to the east of Mount Fenton, there is a higher percentage of sandstone in the upper part of the formation than was seen elsewhere. Sandstone is also common in the lowest part of the formation where it is exposed on the northwest flank of the St George Range. This lower sandstone part may not continue to the northern edge of the Sheet area as it does not appear in the logs of Mount Hardman No. 1. (WAPET, 1973).

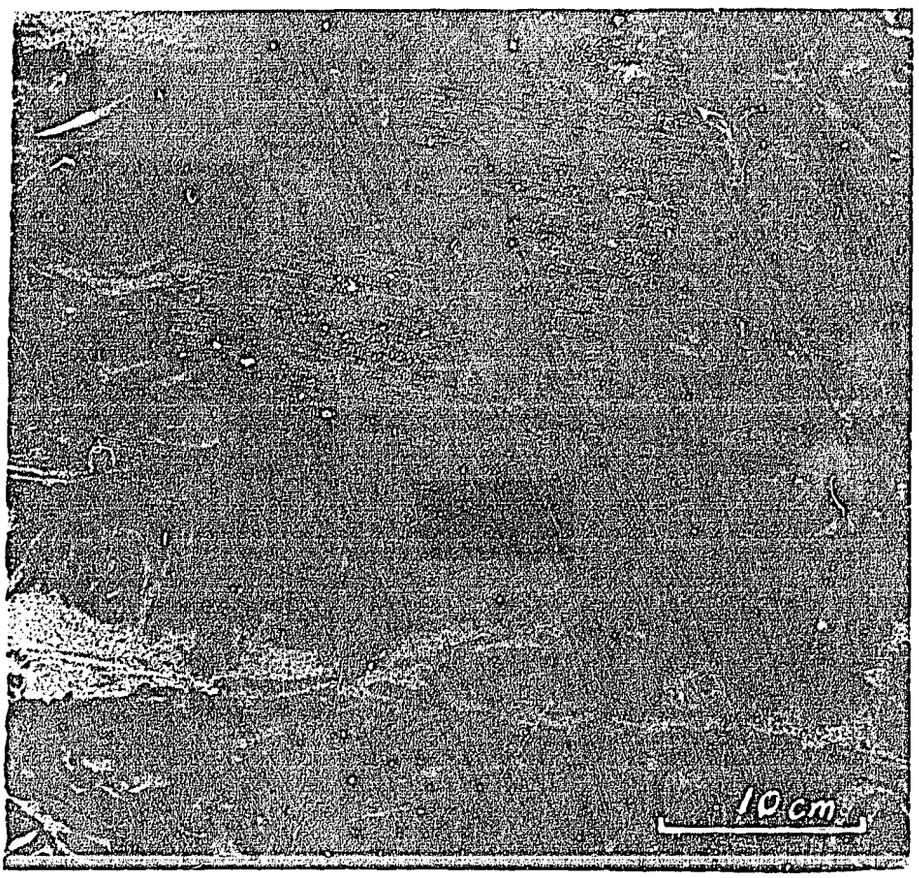


Plate 22 Boxwork pattern in the Noonkanbah Formation caused by intense ferruginization.

Thickness

Surface:	Bruten Yard Section	405.7 m
Subsurface:	Mount Hardman No. 1	311 m
	Paradise No. 6	243.8 m (incomplete)

Age

The formation contains a rich faunal assemblage which is listed by Guppy et al. (1958). They consider the age to be Artinskian.

Further collections of fossils were made during this survey by J.M. Dickins but identifications are not yet available.

Environment of deposition

Marine fossils occur throughout the formation. The lenses of intraformational granule conglomerate and ripple cross bedding indicate that parts of the sequence were deposited from bedload by currents. However most of the formation consists of thinly bedded and laminated mudstone which was deposited from suspension. The inter-laminated silt and shale of the middle parts of the unit suggest deposition below wave base or very quiet conditions in shallow water. The unit contains mainly a 'brachiopodal' assemblage which indicates a water depth of 33-55 m (Thomas, 1958).

The presence of sandstone with some cross-bedding near the base of the unit indicates that this part was deposited in shallower water.

LIVERINGA GROUP

The Liveringa Group (Guppy et al., 1952 & 1958), as redefined by Yeates et al. (1975a), consists of three formations: the Lightjack Formation at the base, the Condren Sandstone and the Hardman Formation. The Hardman Formation is subdivided into three members. All these units were recognized on NOONKANBAH but the Condren Sandstone is not present in the northwestern part of the area. The relationships of the units that comprise the group are shown in Figure 9.

LIGHTJACK FORMATION

Distribution

On NOONKANBAH the Lightjack Formation (Guppy et al., 1958; Yeates et al., 1975a) is exposed over a greater area than the other formations of the Liveringa Group. Where the

tops of the hills are composed of sandstone the unit forms ranges (e.g. the Shore Range). Elsewhere the formation is exposed in buttes such as Lightjack Hill and Bucknalls Pinnacle and low rounded hills and ridges (e.g. McLarty Syncline area).

In the subsurface the formation has been intersected in Mount Hardman No. 1, and Paradise Nos. 1 and 2 wells on NOONKANBAH, and Myroodah No. 1 just to the west of the Sheet area. Many of the Esso boreholes (Galloway & Howell, 1975) penetrated the Lightjack Formation although the Esso geologists did not use the name. Esso's Unit A1 and the lower half of Unit A2 are equivalent to the Lightjack Formation.

Relationships

The Lightjack Formation conformably overlies the Noonkanbah Formation with a gradational contact. In the Balgo area to the southeast (LUCAS) this contact is marked by a ferruginized clay-pellet conglomerate (Yeates et al., 1975b), but as this conglomerate is not well developed on NOONKANBAH the boundary is placed above the uppermost limestone bed in the sequence.

The contact between the Lightjack Formation and the overlying Condren Sandstone was not observed. South of the area, in the Millyit Range (CROSSLAND), this contact is conformable and it is probably similar in the McLarty Syncline area. However, farther north the Condren Sandstone wedges out (Galloway & Howell, 1975) and the Lightjack Formation is overlain by the Hardman Formation.

Lithology

In the subsurface, the Lightjack Formation in Mount Hardman No. 1 consists of yellow-brown, very fine-grained, silty sandstone which is slightly calcareous and contains a few medium-sized grains of quartz. In the Paradise and Esso boreholes, the formation consists of interbedded siltstone and fine-grained sandstone containing common fining-upwards, cycles each of which has current-rippled sandstone at the base; bidirectional flaser bedding is present; bioturbation is common throughout and shelly fossils occur locally. The wireline logs show an overall gradation in grainsize from siltstone at the base to medium-grained sandstone at the top of the middle sandstone unit (see below).

On the surface the formation is seen to consist of a distinctive sequence of (from bottom to top) fossiferous shale and siltstone, followed by fine-grained, cross-bedded quartz arenite and quartz wacke, overlain by siltstone again.

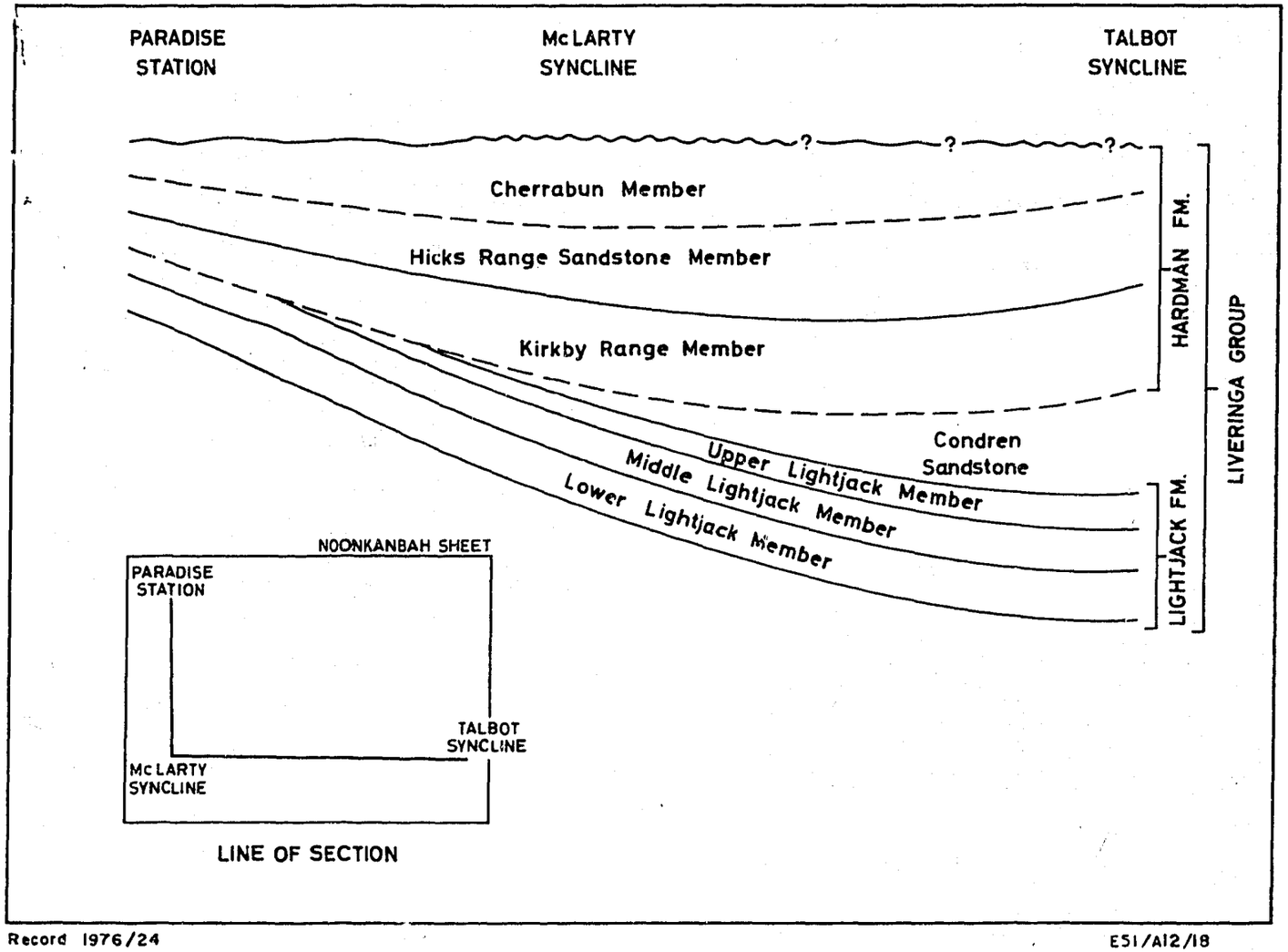


Fig. 9. Diagrammatic section showing relationships of units within the Liveringa Group; symbols as for Fig. 1

In the Shore Range and at Lightjack Hill (Sections 21 and 22) the base of the formation consists of alternating calcareous sandy siltstone and silty claystone together with fossiliferous grey and brown, very fine-grained quartz wacke and minor limestone. These beds are overlain by micaceous, grey, laminated to thinly bedded lithic-wacke and siltstone together with lenses of richly fossiliferous intraformational pebble conglomerate containing some angular granules of quartz. Near the base of the Lightjack Formation, in the Christmas Creek area, a thin bed of fine to medium-grained sandstone containing ooliths is present. The ooliths are composed of 50% Fe_2O_3 (see Edwards, 1953).

The fine-grained basal part of the formation is conformably overlain by a middle sandstone unit (Section 22) which ranges up to 25 m thick and commonly forms a prominent bench. It is composed of yellow-brown, slightly micaceous, fine-grained quartz arenite and quartz wacke which is well sorted, laminated to thin-bedded, and in which the clasts are sub-rounded to rounded. The unit contains abundant large-scale, low-angle planar cross-bedding (type of Allen, 1963) and ripple cross-lamination. Exposures of this part of the formation on the southwestern flank of the St George Range contain abundant fossil root horizons together with some highly silicified beds. These beds are probably the weathered equivalents of coal seams which were intersected down-dip in Esso No. 41 bore (Galloway & Howell, 1975). The coal-bearing beds reach a thickness of 2.5 m. The coal is of poor quality and has not so far been found to be economic.

Overlying the middle sandstone unit is a sequence of interbedded siltstone and fine-grained quartz wacke which ranges up to 45 m thick. The sequence is laminated to thin-bedded, micaceous, ferruginized and contains abundant interference wave-ripple marks, trace fossils and concretions. Thin lenses of medium to coarse, well-sorted, quartz arenite with rounded clasts are present within this part of the section.

In low rounded hills and on the plains the original lithology is commonly masked due to intense ferruginization. However some sedimentary structures, such as ripple marks, are often well preserved, as are fossiliferous clay-pellet conglomerate beds.

Thickness

On the surface the Lightjack Formation is 97 m + thick at Lightjack Hill (Section 22) and 120 m + in the Shore Range (Section 21). Both these sections are almost complete. In the subsurface, we have interpreted it to be 80 m thick in A.I.E. Paradise Nos 1 and 2, and 135 m in the Esso holes in the McLarty Syncline.

The formation thins to the north. This is confirmed by the fact that according to the logs of the Esso boreholes the siltstone at the top is missing to the north of the Fitzroy River.

Age

Guppy et al. (1958) list the rich fauna. The assemblage is predominantly a molluscan assemblage in the Lightjack Hill area and a brachiopodal assemblage in parts of the Shore Range (Thomas, 1958). The fossils are found below the middle sandstone unit. The formation is considered to be late Artinskian to Kungurian in age (J.M. Dickins, pers. comm.).

Environment of deposition

The increase in grain size and sorting from poorly sorted sandy siltstone at the base to well-sorted, medium-grained quartz arenite at the top of the middle sandstone unit (Sections 21 and 22) indicates a regressive marine sequence (Visher, 1965). The fossiliferous intraformational conglomerate lenses below the base of the middle sandstone unit are identified as channel deposits, possibly of tidal origin. The contact between the middle sandstone unit and the underlying siltstone-sandstone sequence is gradational in the Shore Range and at Lightjack Hill, and the sequence is therefore interpreted as a linear shoreline regressive sequence (Selley, 1970, p. 95) in which the middle sandstone unit represents barrier-bar or beach deposits.

In the west, near Millajiddee Homestead, the sandstone unit contains root horizons which are interpreted as fossil soils; in the subsurface, the root horizons contain interbeds of coal.

The siltstone and sandstone sequence above the middle sandstone member is interpreted as lagoonal because of the abundance of wave-formed ripple marks and its stratigraphic position above the interpreted barrier bar deposits (see Visher, 1965). The lenses of coarse-grained sediment in this part of the sequence are interpreted as channel deposits.

According to Thomas (1958) the predominantly molluscan assemblage of the Lightjack Hill area suggests a shallow-water environment in which the water depth was between 18 and 33 m (above wave base), whereas the brachiopodal assemblage of parts of the sequence in the Shore Range indicates water between 33 and 55 m deep. However this information is of limited use, as the precise stratigraphical positions cf these fossil assemblages are not known.

The contact between the Lightjack Formation and the Hardman Formation to the north of the Fitzroy River was not seen in outcrop. However, where the contact was seen in the subsurface (Esso bore logs) the upper part of the Lightjack Formation is missing. It is not known if this is due to erosion or non-deposition.

In conclusion, the Lightjack Formation is interpreted as representing a change from open-marine conditions (Noonkanbah and lower Lightjack Formations) to a lagoonal environment (upper Lightjack Formation). It is thought that this change was caused by a prograding beach or barrier-bar. As the sequence is regressive it must also be diachronous.

CONDREN SANDSTONE

Distribution

The Condren Sandstone (Casey & Wells, 1964; Yeates et al., 1975a) is represented in only one outcrop in the Sheet area, situated on the northern flank of the McLarty Syncline at lat. 18°49'00"S, long. 124°48'15"E. The formation probably also occurs in the Talbot Syncline on NOONKANBAH, as it crops out in this syncline on MOUNT RAMSAY. The unit occurs to the south on CROSSLAND and to the southeast on MOUNT BANNERMAN (Yeates et al., 1975b).

In the subsurface, the formation was intersected in Esso boreholes in the McLarty Syncline, and north of the Fitzroy River in the Quanbun Homestead area. It wedges out towards the northwest, and is absent in the Paradise boreholes, and in many of the Esso boreholes north of the Fitzroy River.

Relationships

The Condren Sandstone conformably overlies the Lightjack Formation on CROSSLAND (Yeates et al., 1975b) and a similar relationship probably exists on NOONKANBAH, although the boundary was not observed. The boundary with the overlying Kirkby Range Member of the Hardman Formation is described as conformable and gradational on CROSSLAND (Yeates et al., 1975b). On NOONKANBAH, however, logs of the Esso boreholes (Encl. 3) indicate an abrupt change from coarse sandstone upwards into interbedded sandstone and siltstone (Galloway & Howell, 1975). On this evidence and the environmental interpretations it is suggested that the boundary on NOONKANBAH is disconformable.

Lithology

The exposure at lat. 18°49'00"S, long. 124°48'15"E represents the basal part of the formation and consists of

coarse to medium-grained quartz arenite and quartz wacke which are crows-bedded and moderately to poorly sorted; the grains are angular and the strata contain possible fossil roots. Pebbles of quartzite on the surrounding plain indicate that the formation is partly conglomeratic.

In the subsurface the unit is described as mainly coarse-grained with little vertical variation (Galloway & Howell, 1975). In BMR Mount Bannerman No. 2 bore coal was recorded in the formation (Yeates et al., 1975b).

Thickness

According to our interpretation of the Esso bore data the formation is about 50 m thick in the McLarty Syncline and Quanbun Homestead areas. However, the unit thins to extinction in the direction of the Paradise bores (Galloway & Howell, 1975) and thickens to the south and southeast on CROSSLAND and MOUNT BANNERMAN (see Yeates et al., 1975b).

Age

No fossils were found in the formation on NOONKANBAH but it contains a rich fossil flora in exposures elsewhere (White, in Veevers & Wells, 1961; White & Yeates, in prep.). The age of this flora is Permian.

Environment of deposition

The relative textural immaturity of the sediment and its cross-bedded, conglomeratic nature indicate deposition by currents, possibly under fluviatile conditions. The tentative identification of fossil roots would, if confirmed, support a continental interpretation, especially in view of the rich flora found in neighbouring areas. When considered in relation to the sequence as a whole, the fluviatile interpretation fits in well, as the Condren Sandstone conformably overlies the regressive sequence of the Lightjack Formation.

HARDMAN FORMATION

The Hardman Formation (Guppy et al., 1958) as redefined by Yeates et al. (1975a) consists of three members; the Kirkby Range Member at the base, the Hicks Range Sandstone Member and the Cherrabun Member at the top. All three units are recognized on NOONKANBAH.

Kirkby Range Member

Distribution

The Kirkby Range Member (Yeates et al., 1975a) crops out poorly in the Sheet area, where it forms low discontinuous strike ridges composed of the more resistant parts of the

sequence. The exposures are confined to the southern side of the McLarty Syncline and to the area between the Fitzroy River and Shedforth Bore. An exposure on the southern flank of Warrimbah Hill is also tentatively assigned to this member.

In the subsurface the unit was intersected in many of the Esso boreholes both north and south of the Fitzroy River. The member was also intersected in Paradise coreholes Nos. 1 2 and 3.

Relationships

The contacts of the member were not seen. It is thought that the lower boundary is a disconformity. The upper boundary is conformable to the south on CROSSLAND (Yeates et al., 1975b) and logs of the Esso bores (Encl. 3) indicate a gradational change in lithology.

Lithology

From subsurface information the member is seen to consist predominantly of interbedded siltstone and fine-grained sandstone, the sandstone predominating towards the top. The sequence is red bioturbated throughout, and fossil shells are common in the upper part. Wavy and lenticular bedding are abundant, and mud cracks are present in the basal part of the sequence. The sandstone beds near the top contain both large and small-scale cross-bedding.

Exposures are preferentially weathered, so that the unit appears coarser grained than in the subsurface. The exposed rocks consist of calcareous fine-grained sandstone, limestone (biosparudite), and micaceous siltstone. Ferruginous concretions are common in extensively weathered exposures. The bedding is thin or laminated; other sedimentary structures are rarely seen.

Thickness

No surface sections were measured, but Esso drilling results (Galloway & Howell, 1975) show that in the area north of the Fitzroy River the member thickens southwards from about 75 m along the northern margin of the Sheet area to over 300 m to the south of Mount Hardman. In the McLarty Syncline the member thickens southeast from about 190 m near the western edge of the Sheet area to 250 m just south of Millajiddee Homestead.

Age

The rich marine fauna has not yet been fully studied, but it indicates a Late Permian age (J.M. Dickins, pers. comm.).

Environment of deposition

The unit is marine, and the presence of cross-bedded sandstone, particularly near the top, suggests deposition by currents. Mudcracks occur near the base and suggest intermittent intertidal conditions for that part of the unit. The gradation to sandstone in the upper part of the sequence may indicate the start of a regression (see below).

Hicks Range Sandstone Member

Distribution

The Hicks Range Sandstone Member (Yeates et al., 1975a) crops out in the western portion of the Sheet area in the vicinity of Mount Hardman and in the McLarty Syncline. Outcrops are limited and occur as low strike ridges (e.g. at Mount Abbot), isolated hills (e.g. Mount Noreen) or as low, undulating, rubble-covered hills.

Relationships

The lower contact was not seen on the surface, but electric logs of the Esso drill holes (see Encl 3) indicate the boundary is gradational. Likewise, the upper contact is not exposed; from subsurface data it is thought to be a disconformity (see below).

Lithology

The following account of the vertical sequence is taken mainly from borehole descriptions (Galloway & Howell, 1975). The lower three-quarters of the member is composed mainly of interbedded shale and siltstone, and sporadic beds of sandstone. This part of the sequence contains flaser bedding and wavy bedding, thin coal loads and mudcracks. Surface observation shows that these beds are generally thin-bedded, and contain wave-formed ripple marks and some large-scale planar cross-bedding. Bioturbation and trace fossils are abundant.

The upper quarter of the member is mainly quartz wacke and quartz arenite, with minor interbeds of siltstone. Subsurface data show that fining-upwards cycles are common in this part, although many of the cycles are truncated. The sandstone is moderately to well sorted, and contains scattered lithic pebbles.

Thickness

An incomplete section of the member at Mount Noreen is about 30 m thick. Esso bore logs show that the unit thickens from about 100 m near the northern boundary of the Sheet area to over 325 m near Warrimbah and Millajiddee Homesteads.

Age

No macrofossils have been found in this unit. The faunas in the Kirkby Range Member and the Cherrabun Member indicate that the Hicks Range Sandstone Member is Late Permian in age, possibly lower-most Tatarian.

Environment of deposition

Galloway & Howell (1975) interpret the overall upward increase in grainsize within this member as a regressive marine sequence from shallow-water marine sediments at the base up to deltaic or tidal channel deposits at the top. In our opinion however, the sequence is better interpreted as the top part of a regressive sequence (Visher, 1965) which starts in the underlying Kirkby Range Member. Thus we interpret the basal Hicks Range Sandstone Member as being deposited in lagoonal conditions and the top part in a fluvial (flood plain) environment. The basis for our interpretation is that the lower boundary of the member is apparently conformable and the basal part of the unit contains mudcracks, wave ripple marks and thin coal horizons. Although marine macrofossils are apparently absent, yet spinose acritarchs are recorded, suggesting some connection with the sea. Such features are more typical of lagoonal conditions than an open-marine environment. The upper part of the member also fits this interpretation, as the repeated fining-upwards cycles within it are best interpreted as channel point-bar deposits (Galloway & Howell, 1975).

Thus the Kirkby Range Member and Hicks Range Sandstone Member together are interpreted as representing the typical regressive sequence described by Visher (1965).

Cherrabun Member

Distribution

The Cherrabun Member (Yeates et al., 1975a) is better exposed on NOONKANBAH than the other members of the Hardman Formation. South of the Fitzroy River it crops out around Davies Bore, between Rodneys and Andys Bore and in small scattered outcrops 15 km south of Gum Hole Billabong. It is

also exposed as low strike ridges along the edge of the Sheet area to the southwest of Kalyeeda Hills. North of the Fitzroy River the unit crops out at and around Mount Hardman, at a small hill near Mount Cedric, at Howes Hill and as long strike ridges around Sears Bore.

The member was intersected in many of the Esso bore holes and was penetrated in AIE Paradise No. 4.

Relationships

The lower contact was not observed on the surface. In the subsurface it is distinguished by a sudden reduction in grainsize which stands out well on the electric logs (Encl. 3); the contact is therefore thought to be a disconformity.

In the McLarty Syncline on the western edge of the Sheet area the Cherrabun Member is overlain by pebble conglomerate, thin-bedded, ripple-marked, fine-grained quartz wacke and siltstone with some trace fossils (Section 19), although exposure is incomplete. The contact is interpreted as an angular unconformity since there is an obvious divergence of the strike ridges on the aerial photographs. The conglomerate, quartz wacke, and siltstone are tentatively correlated with the Triassic Millyit Sandstone which overlies the Cherrabun Member in the Millyit Syncline on CROSSLAND (Yeates et al., 1975b).

North of the Fitzroy River the Cherrabun Member is to be overlain by the Blina Shale (Esso boreholes). Again the contact is not exposed at the surface. However, palynological information from the Esso boreholes suggests that there is a time gap between the two units (Galloway & Howell, 1975), and as the basal Triassic Millyit Sandstone is missing, it is thought that the contact is a disconformity which may be slightly discordant in places.

In conclusion, the Liveringa Group on NOONKANBAH is overlain by the Triassic Millyit Sandstone and Blina Shale. Previously there had been some doubt about the nature of the Permian-Triassic boundary in the Fitzroy Trough (see Veevers & Wells, 1961, p. 109). It has now been established that the contact is, in at least one place, an angular unconformity but in other areas may be merely disconformable.

Lithology

Subsurface information shows that the member grades from mudstone in the lower part, to sandstone at the top, and that thin coal horizons occur in the upper part of the unit (Galloway & Howell, 1975).

On the surface the best exposure of the member is the type section of the Hardman Formation at Mount Hardman (Section 20). The Esso drilling results indicate that this section represents only the top part of the member. In this section the lower part of the member is sandy mudstone with thin beds of bioclastic limestone. The sequence is shaly in parts and contains some thin beds of bioturbated fine-grained feldspathic wacke. This passes gradationally up into interbedded and bioturbated siltstone and fine-grained quartz wacke which is well sorted and contains well-rounded grains. Some arenites containing symmetrical ripple marks occur in this part of the sequence. The upper part of the member is a fining-upwards sequence of coarse to fine-grained quartz wacke which contains asymmetrical ripple marks at the top, and this is overlain, with a sharp contact, by fine and medium-grained, well-sorted quartz wacke which contains intra-formational conglomerate and large-scale planar cross-bedding. To the north of Mount Hardman, near Sears Bore, plant fossils and wood fragments were found in the uppermost part of the member.

From scattered outcrop data in the area south of the Fitzroy River, the lower and middle parts of the sequence are known to be mainly mudstone but they also contain poorly sorted sandstone beds and minor granule conglomerate. Marine fossils are abundant in these outcrops.

Thickness

The section at Mount Hardman (Section 20) is 50 m thick, but it is incomplete. In AIE Paradise No. 4 the member is approximately 100 m thick, but it appears thicker to the south in the McLarty Syncline (field evidence and Galloway & Howell, 1975).

Age

The Cherrabun Member contains a rich fauna which is listed by Guppy et al. (1958). Another extensive collection was made by J.M. Dickins during 1974 and is currently being studied. The fauna is of Late Permian (possibly Tatarian) age (Thomas, 1954; Coleman, 1957; Dickins, 1963).

The plant fossil Glossopteris occurs in the uppermost part of the unit.

Environment of deposition

Most of the Cherrabun Member is composed of fossiliferous mudstone with thin sandy interbeds which indicate marine probably shallow-water, conditions. The gradation upwards into ripple-marked interbedded sandstone and siltstone is inter-

preted as being due to a shallowing of water, and the fining-upwards sequence near the top of the member at Mount Hardman is interpreted as a tidal channel-fill deposit. This part of the sequence passes up into planar cross-bedded, well-sorted sandstone which is tentatively identified as a beach deposit because of its position in the vertical sequence and its well sorted nature.

Thus the Cherrabun Member is interpreted as another regressive cycle. This interpretation is supported by the overall upward increase in grainsize and degree of sorting (Visher, 1965), and the change from a marine fauna in the middle and lower parts of the unit to a flora with minor coal near the top of the sequence.

SUMMARY OF DEPOSITIONAL HISTORY

Taken as a whole, the depositional history of the Liveringa Group is interpreted as a series of three regressions separated by two transgressions. This may have been due to cyclic tectonic or eustatic changes. Alternatively, the cyclicity can be explained by a process of imbricate deltaic deposition into a continually subsiding area similar to the process described by Scruton (1960) to explain the Mississippi delta deposits. The theory explains how a delta lobe builds out into the sea and deposits a regressive sequence until it is abandoned due to lateral migration of the river. When this happens, a new delta lobe is built elsewhere; the old one becomes compacted and may be partly reworked and/or buried, before another change in river course deposits a further regressive sequence above the first one. In this way a cyclic vertical sequence is built up.

In our opinion this latter theory is the simplest explanation of the cyclicity in the Liveringa Group and there is no need to invoke tectonic or eustatic changes. Thus the deposits of the Liveringa Group are interpreted as deposits of a large delta system.

CONCLUSIONS

Although only minor changes have been made in the outcrop and structure patterns of the formations for the new NOONKANBAH map, most of the formations have now been subdivided.

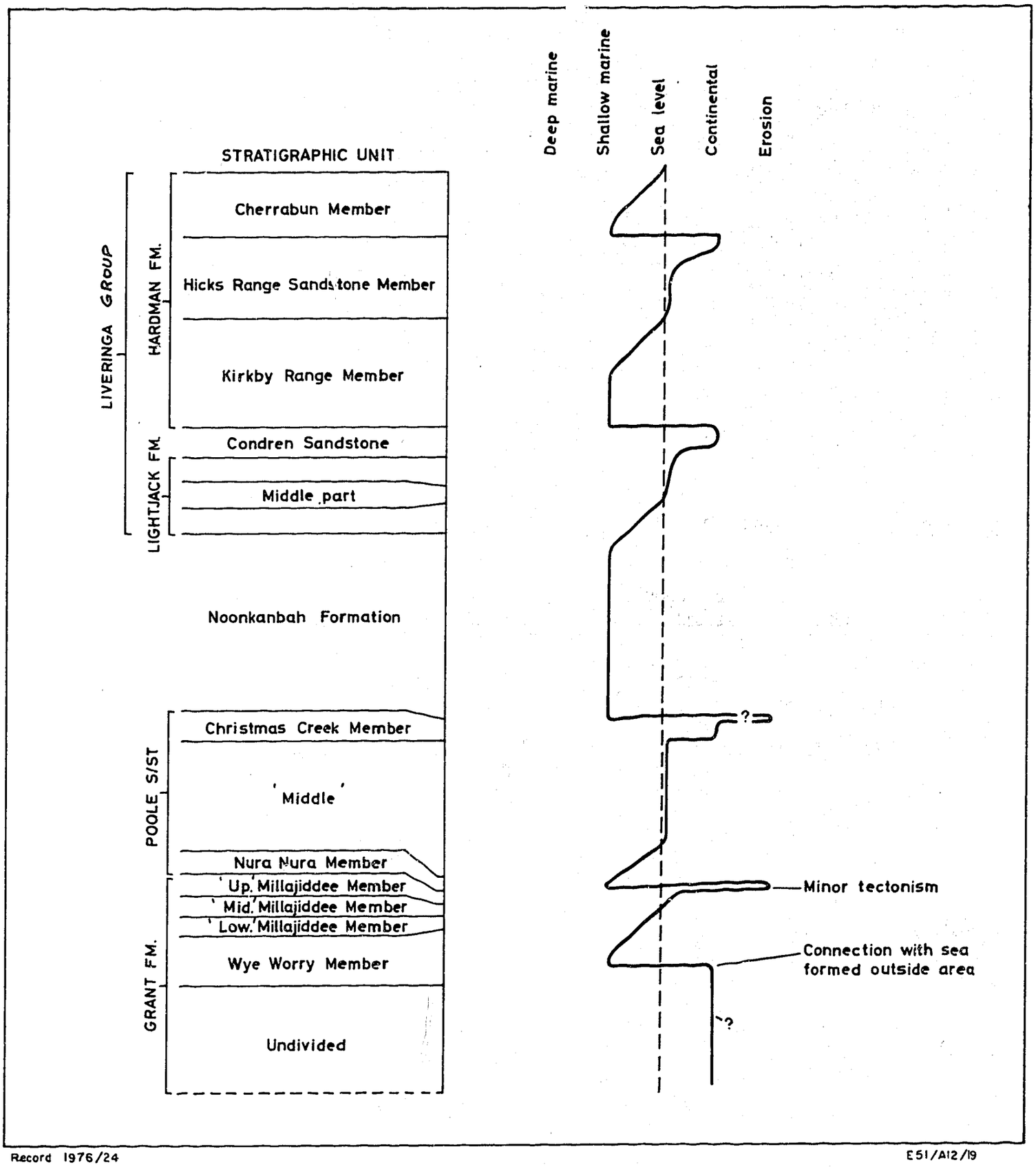


Fig. 10. Schematic representation of Permian sedimentation in St George Range—McLarty Syncline area

In subdividing the units on NOONKANBAH we have purposely not named every facies within formations and members as this is impractical at 1:250 000 scale mapping and we believe it is often more confusing than useful to name every facies variation. By collating these detailed facies variations in the measured sections it has been possible to arrive at a better understanding of the environments of deposition of the succession (although, because of the reconnaissance nature of the mapping, many of these interpretations are tentative). Fig. 10 shows the history of sedimentation schematically, but it should be realized that the sea in which the Noonkanbah Formation was deposited probably remained either in the area or just outside it until the end of the Permian. The regressions and transgressions of the Liveringa Group were probably the result of changes of the shoreline due to the influx of sediment (in a deltaic environment) rather than changes in sea level and/or land level. Thus the history of subsidence in the area is probably simpler than was indicated by previous reports, but the history of regression and transgression is more complicated (cf. Veevers & Wells, 1961, p. 104). The only substantiated period of uplift that occurred during the Permian on NOONKANBAH was between deposition of the Grant Formation and that of the Poole Sandstone. All other Permian relationships can be explained by inferring gradual subsidence of the area.

The most significant contributions made to geological knowledge of the area during the 1974 field season were the following:

1. Discovery of marine macrofossils in the Grant Formation in the Fitzroy Trough.
2. Interpretation of the uppermost part of the Grant Formation as a regressive sequence which contains evidence suggesting permafrost conditions prevailed.
3. Mapping of an eastward extension of the Nura Nura Member of the Poole Sandstone.
4. Identification and mapping of the Christmas Creek Member at the top of the Poole Sandstone.
5. Mapping of the subdivisions of the Liveringa Group and correlation of these divisions with subsurface sections.
6. Interpretation of the Liveringa Group as a series of regressive cycles probably laid down in a deltaic environment.

SUGGESTIONS FOR FURTHER WORK

1. To study in detail the marked facies variations that occur within the Wye Worry and the Millajiddee Members of the Grant Formation particularly between the northern and southern flanks of the St George Range.

2. To further determine the environment of deposition of the Poole Sandstone with particular study of its contact with the Grant Formation.

3. To gather more information on the environments of deposition of the Liveringa Group and the relationships between the units within it, paying particular attention to diachronous relationships.

4. To study the relationship between tectonsim and sedimentation with particular reference to changing rates of subsidence in certain areas (i.e. Poole Sandstone in Poole Range Anticline and Grant Formation in St George Range Anticline).

Any work in the St George Range will be hampered by poor access. The only practicable method of mapping in the range is by traversing on foot, as the area is a maze of canyons which are mostly inaccessible to vehicles. At least the range is no longer as difficult as it used to be when, in the words of Woolnough (1933): "it had been less fully explored than have most of the other mountains. This is due partly to its comparative inaccessibility and partly to the fact that it has long been the refuge of the more truculent and treacherous of the aboriginals remaining in the district".

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the many helpful field discussions that took place with geologists from Esso Exploration and Production Aust. Inc., without which many of the correlations between surface and subsurface sections would not have been possible. We would like to thank Australian Inland Exploration for permission to incorporate information from exploration that they undertook in the area. Last but not least we thank the many station managers throughout the area who gave valuable guidance on the positions and condition of the tracks and bores on their properties.

REFERENCES

ALLEN, J.R.L., 1963 - The classification of cross-stratified units, with notes on their origin. Sedimentology, 2, 93-114.

BAARDA, F.D., 1967 - Geological report on coal investigations, West Kimberley area, Western Australia - Temporary Reserves 3426H-3434H and 3754H. Company Rep, Premier Mining Co. Pty Ltd (unpubl.).

BLISSENBACH, E., 1954 - Geology of alluvial fans in semi-arid regions. Bull. Geol. Soc. Amer., 65, 175-190.

BOUMA, A.H., 1962 - SEDIMENTOLOGY OF SOME FLYSCH DEPOSITS. Amsterdam, Elsevier.

CASEY, J.N., & WELLS, A.T., 1964 - The geology of the north-east Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 49.

COLEMAN, P.J., 1957 - Permian Productacea of Western Australia. Bur. Miner. Resour. Aust. Bull. 40.

CONTINENTAL OIL COMPANY OF AUSTRALIA LTD, 1966 - St Georges Range No. 1 well completion report. Company Rep. (unpubl.).

CONYBEARE, C.E.B., & CROOK, K.A.W., 1968 - Manual of sedimentary structures. Bur. Miner. Resour. Aust. Bull. 102.

CROWE, R.W.A., & TOWNER, R.R., 1976 - Permian stratigraphic nomenclature, Noonkanbah 1:250 000 Sheet, Western Australia. Geol. Surv. W.Aust. Ann. Rep. for 1975.

CROWE, R.W.A., & TOWNER, R.R., in prep. - Noonkanbah, W.A. - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SE51-12.

DICKINS, J.M., 1963 - Permian pelecypods and gastropods from Western Australia. Bur. Miner. Resour. Aust. Bull. 63.

DICKINS, J.M., TOWNER, R.R., & CROWE, R.W.A., in press, - A Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia. In Yuri A. Orlov Memorial Volume: Palaeontological Soc. of India.

DIONNE, J-C., 1975 - Palaeoclimatic significance of late Pleistocene ice-wedge clasts in southern Quebec, Canada. Palaeogeog., palaeoclim., palaeoecol. 17, 65-76.

DUFF, P. McL. D., HALLAM, A., & WALTON, E.K., 1967 - CYCLIC SEDIMENTATION. Amsterdam, Elsevier.

EDWARDS, A.B., 1953 - An oolitic iron formation from north-western Western Australia. C.S.I.R.O. (Melb.) Miner. Inv. Rep. 540.

GALLOWAY, M.C., & HOWELL, D.J., 1975 - Relinquishment report of TR 5851H to 5896H, 5878H to 5880H, Fitzroy Trough, Western Australia. Company Rep., Esso Exploration and Production Aust. Inc. and Dampier Mining Co. (unpubl.).

GLENISTER, B.F., & FURNISH, W.M., 1961 - The Permian ammonoids of Australia. J. Paleont., 35(4), 673-736.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1952 - The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. XIXieme Cong. geol. int. Gondwana Symposium, Alger, 1952.

GUPPY, D.J., LINDER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1958 - The geology of the Fitzroy Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 36.

INGRAM, R.L., 1954 - Terminology for the thickness of stratification and parting units in sedimentary rocks. Geol. Soc. Amer. Bull., 65, 937-938.

KOOP, W.J., 1966 - Sahara No. 1 well, stratigraphic nomenclature Appendix 1 in WAPET 1966, Sahara No. 1 Well. Bur. Miner. Resour. Aust. Petrol. Search Subs. Acts Publ. 80.

KUENEN, P.H., 1951 - Mechanics of varve formation and the action of turbidity currents. Geol. Foren. Stockholm Forh., 73, 69-84.

McKEE, E.D., 1965 - Experiments on ripple laminations. In MIDDLETON, G.V. (Ed.), PRIMARY SEDIMENTARY STRUCTURES AND THEIR HYDRODYNAMIC INTERPRETATION. Spec. Publ. Soc. Econ. Paleont. Miner., 12, 66-83.

McKEE, E.D., & WEIR, G.W., 1953 - Terminology for stratification and cross-stratification in sedimentary rocks. Geol. Soc. Amer. Bull., 64, 381-390.

PETTIJOHN, F.J., 1957 - SEDIMENTARY ROCKS (2nd edn.). N.Y., Harper & Row.

PLAYFORD, P.E., COPE, R.N., LOW, C.H., COCKBAIN, A.E., & LOWRY, D.C., 1975 - GEOLOGY OF WESTERN AUSTRALIA. Geol. Surv. W. Aust. Mem. 2.

REINECK, H.E., & SINGH, I.B., 1973 - DEPOSITIONAL SEDIMENTARY ENVIRONMENTS, WITH REFERENCE TO TERRIGENOUS CLASTICS. Heidelburg, Springer-Verlag.

REINECK, H.E., & WUNDERLICH, F., 1968 - Classification and origin of flaser and lenticular bedding. Sedimentology, 11, 99-104.

SCRUTON, P.C., 1960 - Delta building and the deltaic sequence: In SHEPHARD, F.P., PHLEGER, F.B., & ANDEL, T.H., van, (Eds), in RECENT SEDIMENTS, NORTHWEST GULF OF MEXICO. Amer. Assoc. Petrol. Geol. Tulsa Oklahoma, 82-102.

SELLEY, R.C., 1970 - ANCIENT SEDIMENTARY ENVIRONMENT. London, Chapman & Hall.

TANNER, W.F., 1967 - Ripple mark indices and their uses. Sedimentology, 9, 89-104.

THOMAS, G.A., 1954 - Report on Permian brachiopods from the Fitzroy Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1954/9.

THOMAS, G.A., 1958 - Permian Orthotetacea from Western Australia. Bur. Miner. Resour. Aust. Bull. 39.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 60.

VISHER, G.S., 1965 - Use of vertical profile in environmental reconstruction. Bull. Amer. Assoc. Petrol. Geol., 49(1), 41-61.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1972a - Lake Betty No. 1 well completion report. Company Rep (unpubl.).

WAPET, 1972b - Barbwire No. 1 well completion report. Company Rep. (unpubl.).

WAPET, 1973 - Mt Hardman No. 1 well completion report. Company Rep. (unpubl.).

WHITE, M.E., & YEATES, A.N., in prep. - Report on 1972 and 1973 collections of plant fossils from the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. (unpubl.).

WILLIAMS, H., TURNER, F.J., & GILBERT, C.M., 1958 - PETROGRAPHY - an introduction to the study of rocks in thin sections. San Francisco, Freeman & Co.

WOODWARD, H.P., 1915 - Coal resources of Western Australia. Geol. Surv. W. Aust. Bull. 64.

WOOLNOUGH, W.G., 1933 - Report on aerial survey operations in Australia during 1972. Canberra. Commonwealth Govt Printer

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L., 1975(a) - New and revised stratigraphic nomenclature, northeast Canning Basin, Western Australia. Geol. Surv. W. Aust. Ann. Rep. for 1974.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L. 1975(b) - Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1975/77 (unpubl.).

APPENDIX - MEASURED SECTIONS

Figure 11 shows the locations of the sections. The sections are shown as either 'measured' or 'estimated'. 'Measured' means that they were accurately measured on the ground using either the 'height to eyes' technique for predominantly vertical sections or the tape and compass method for horizontal ones. 'Estimated' means that the sections were compiled using a combination of outcrop information, 1:100 000 topographic maps for contour data, and aerial photographs for horizontal control. In most cases the 'estimated' sections were compiled to bring out a particular point that would not otherwise be obvious. Most of the sections are shown at the same scale to make correlation easier, although some additional more detailed sections are included.

LIST OF SECTIONS

Reference No.	Location	Status
1	Mount Piper - Poole Range	Measured
2	Poole Range	Measured
3	Mount Thorlan (part is large scale)	Estimated & Measured
4	Southern Poole Range	Estimated
4a	Southern Poole Range (large Scale)	Measured
5	Mount Hutton	Measured
6	Eastern St George Range	Measured
7	Eastern St George Range	Measured
8	Southeastern St George Range	Estimated
9	Eastern St George Range (type section, Wye Worry Member)	Measured
10	Central St George Range	Measured
11	Tullock Peak	Estimated
12	Central St George Range	Estimated & measured
13	Mount Tuckfield	Measured
13a	Carolyn Valley (large scale)	Measured
14	Millajiddee - Southwestern St George Range (reference section, Nura Nura)	Measured

Reference No.	Location	Status
15	Western St George Range (type section, Millajiddee Member)	Measured
16	Northwestern St George Range	Estimated
17	Western St George Range	Estimated
18	Lauris Range	Measured
19	McLarty Syncline	Measured
20	Mount Hardman	Measured
21	Shore Range	Measured
22	Lightjack Hill	Measured

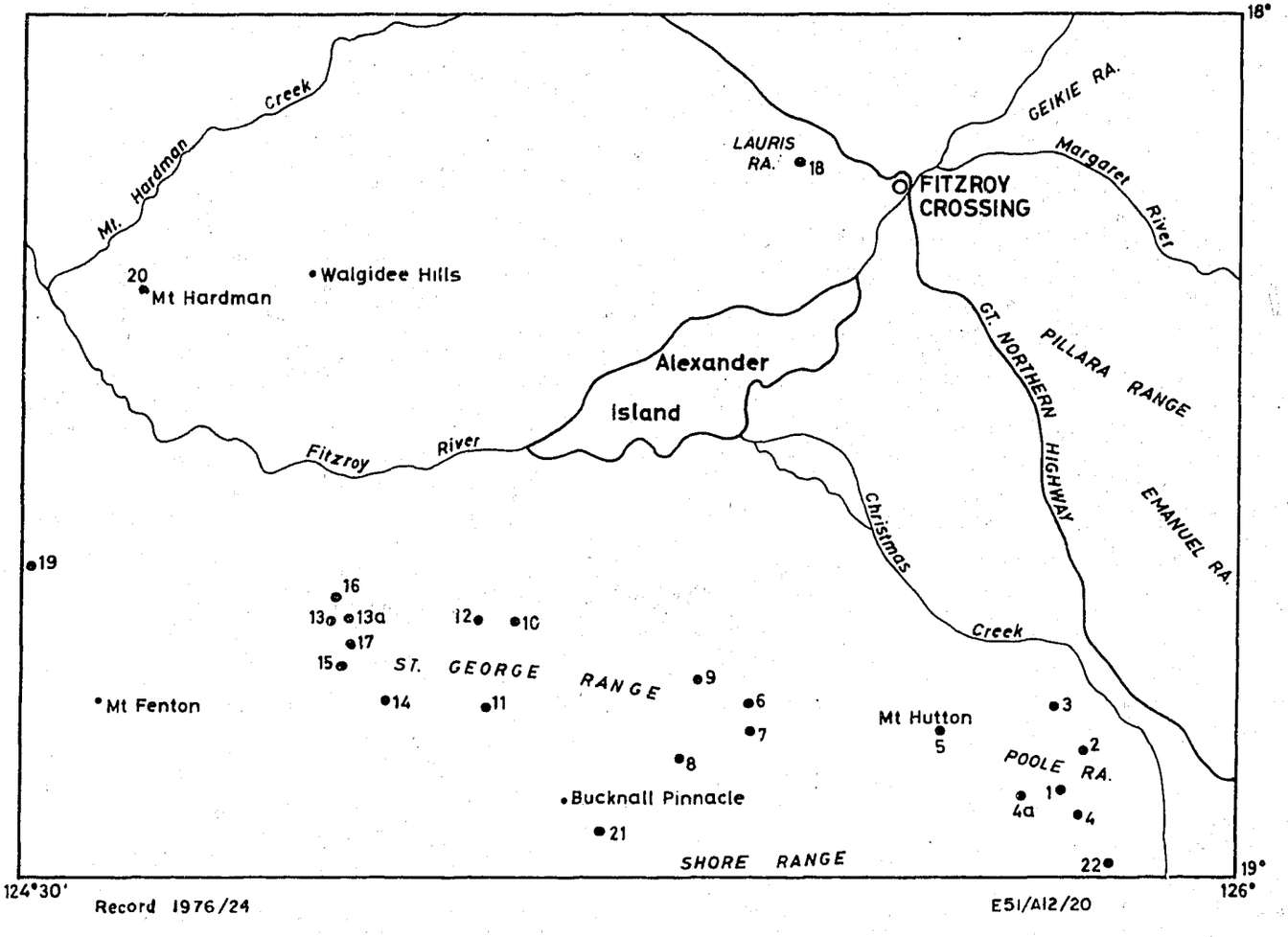
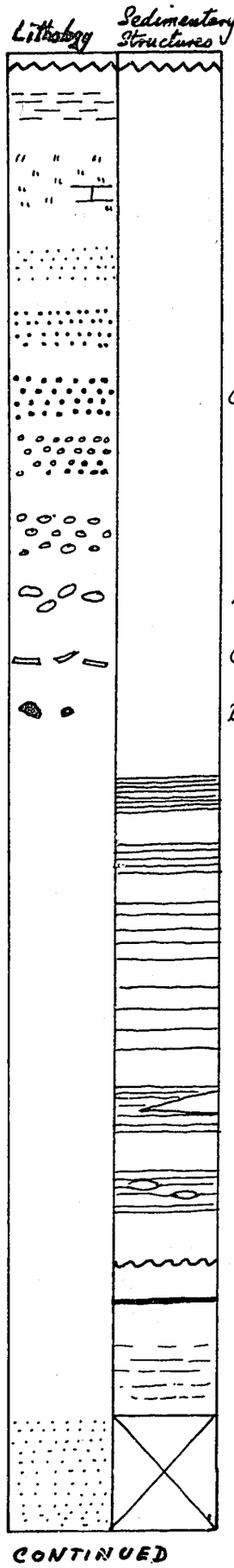


Fig.11. Noonkanbah Sheet area, showing location of sections described in Appendix. Scale; 1:1 000 000

SYMBOLS USED IN SECTIONS.



Limit of exposure

Shale

Siltstone - calcareous

Fine and very fine-grained sandstone

M Medium-grained sandstone - Micaceous (>10%)

F Coarse and very coarse-grained sandstone - Feldspathic (>10%)

Granule conglomerate

Pebble conglomerate

Boulder conglomerate

Clay-pellet conglomerate

Dropstones (sizes as above)

Laminated

Thin and very thin bedded

Medium bedded

Thick bedded

Wedge shaped bed

Lenticular beds

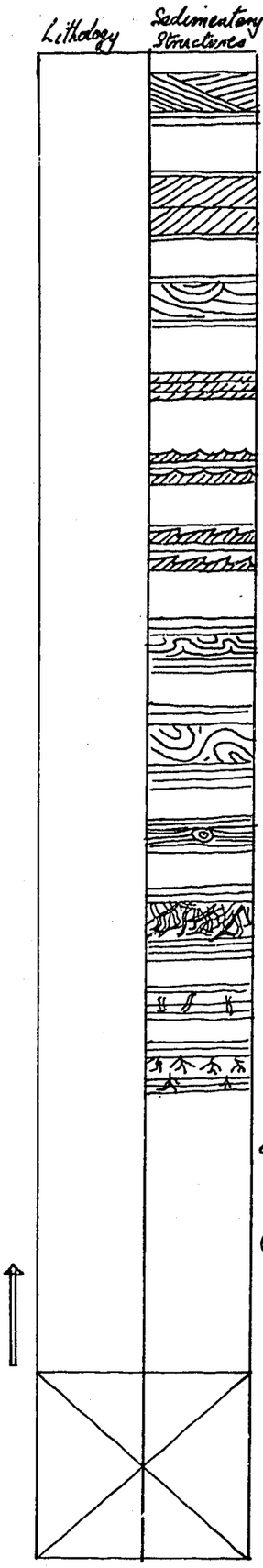
Erosional boundary

Sharp boundary

Bedding indistinct (sizes as above)

Bedding not seen but lithology interpreted from scree material.

CONTINUED



Simple cross-bedding

Planar cross-bedding

Trough cross-bedding

Large scale (greater than 5cm thick)

Small-scale cross-bedding (less than 5cm thick)

Small scale cross-bedding with symmetrical ripple marks on bedding plane

Small scale cross-bedding with asymmetrical ripple marks on bedding plane

Slump and flowage

Slump (minor sliding)

Concretion

Bioturbated

Burrows

Roots

Wood fragment fossils

Plant fossils

Marine macrofossils

Arrow indicates fining-upwards sequence. Length of arrow indicates thickness of sequence

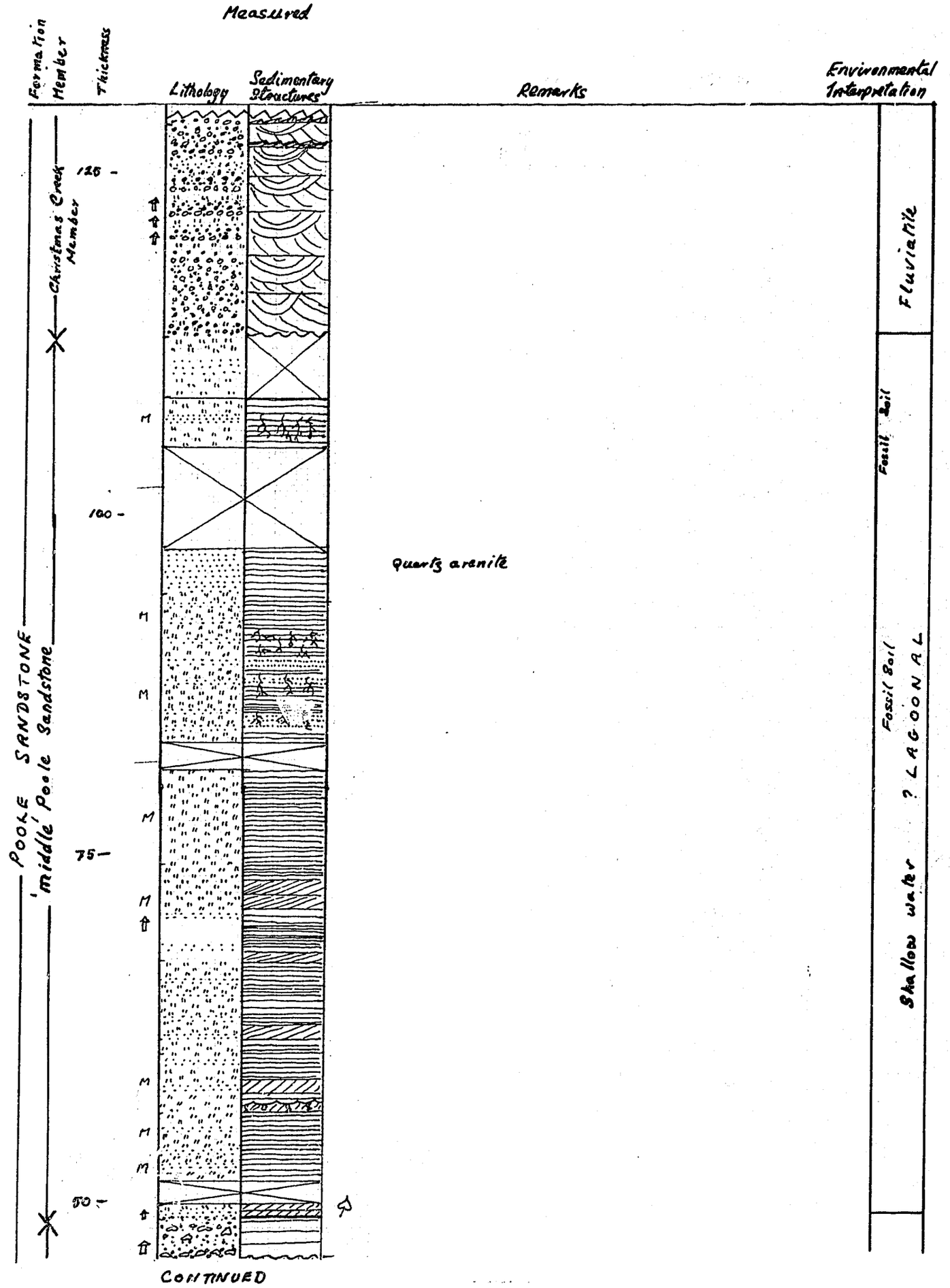
Section not exposed

SECTION No. 1

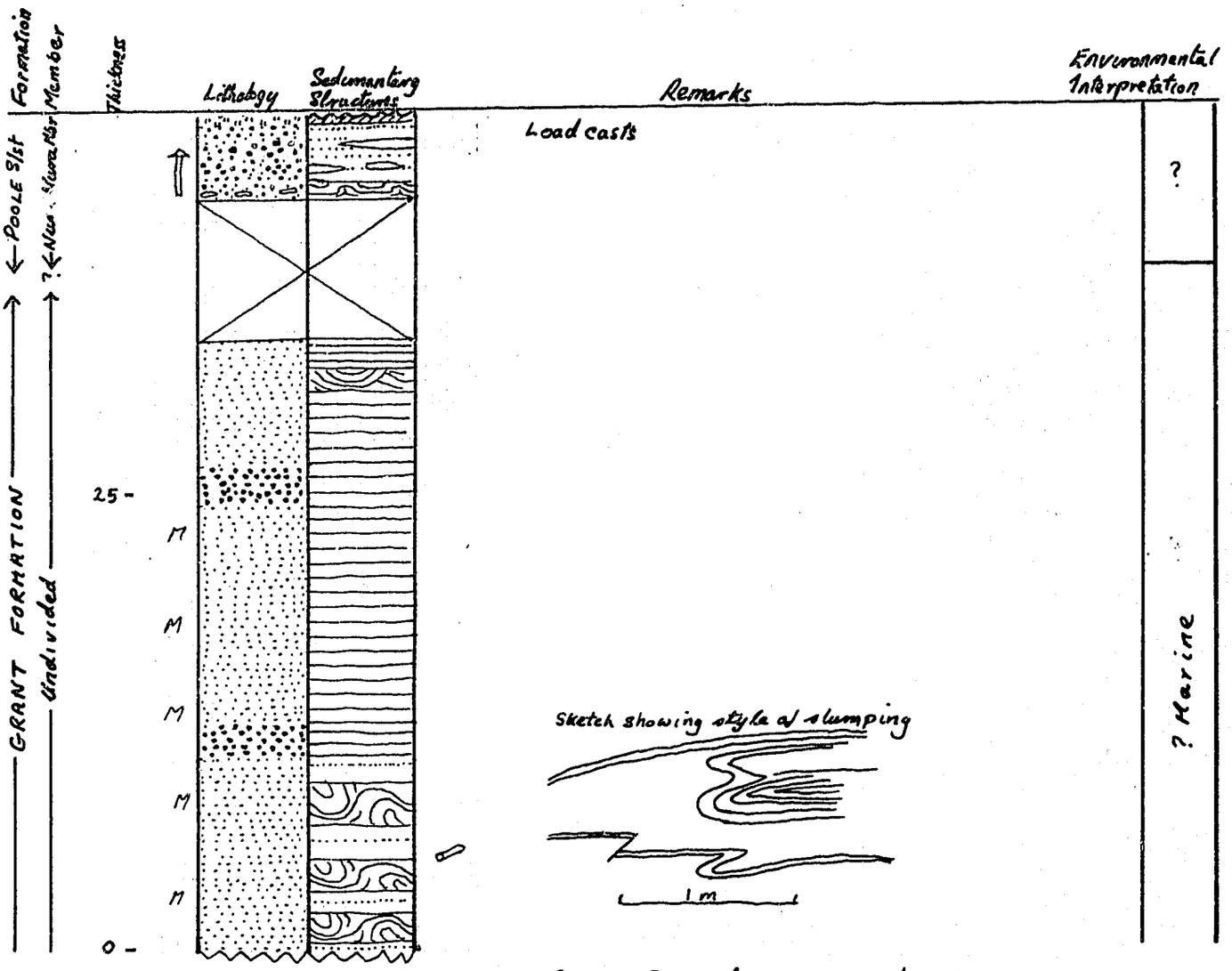
MOUNT PIPER - POOLE RANGE

18° 53' 38" S. 125° 47' 25" E.

Measured



SECTION No. 1 (cont.)



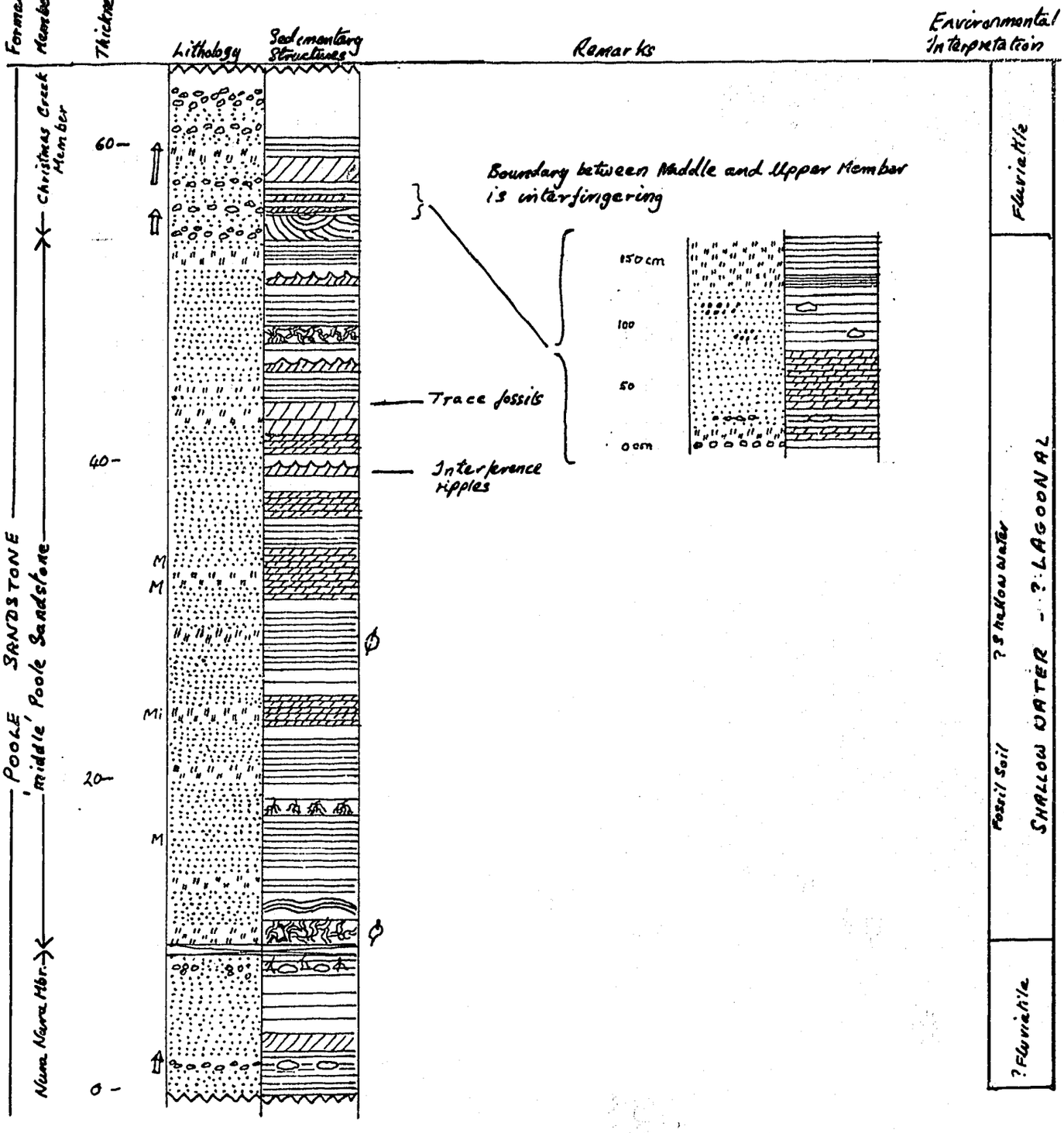
Approx. 35m of scree covered outcrop below.

SECTION No. 2

POOLE RANGE

18° 52' 08"S. 125° 48' 25"E.

Measured



Record 1976/24

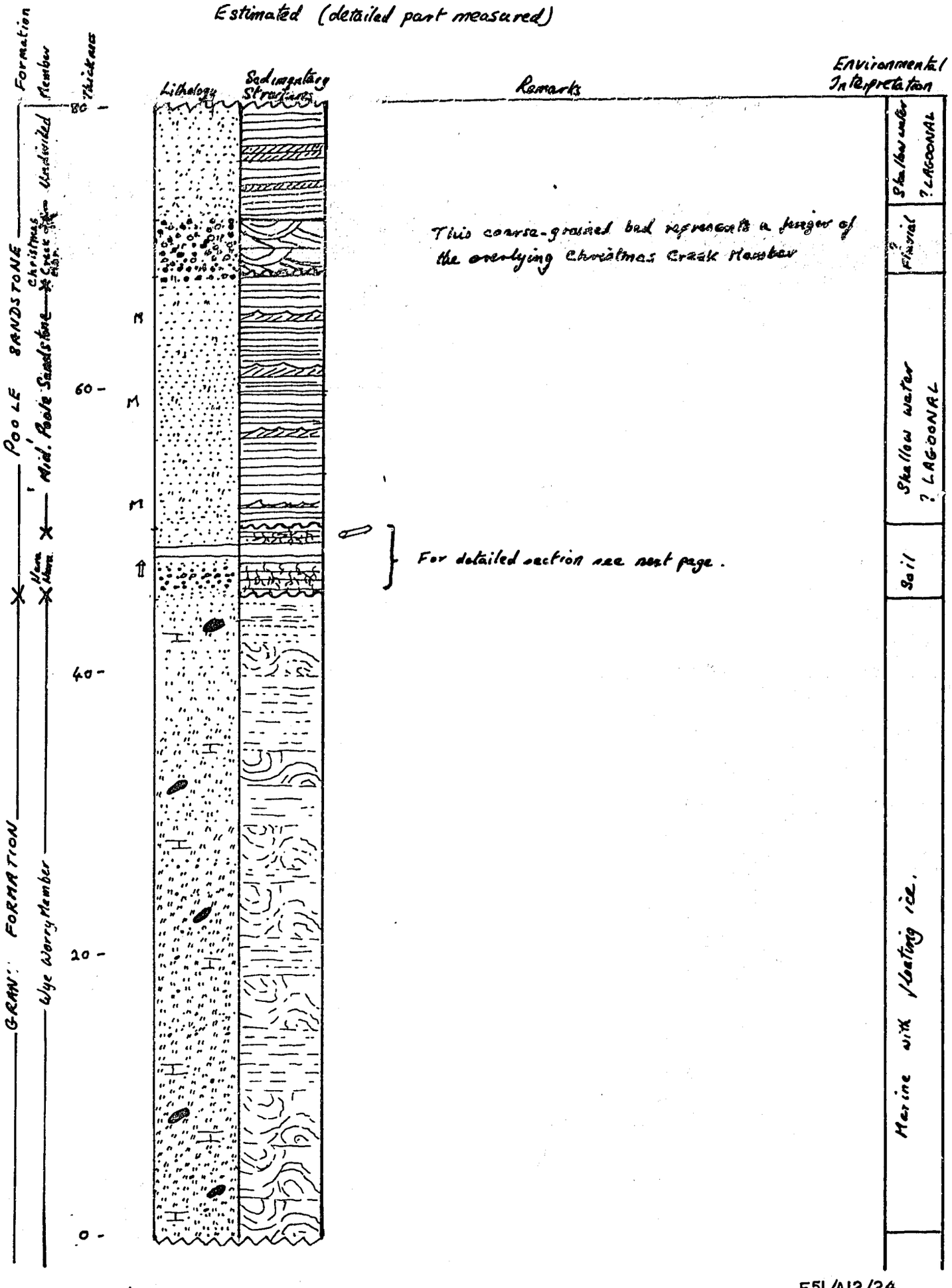
E51/A12/23

SECTION No. 3

MOUNT THORLAN

18°47'45"S. 125°46'35"E.

Estimated (detailed part measured)

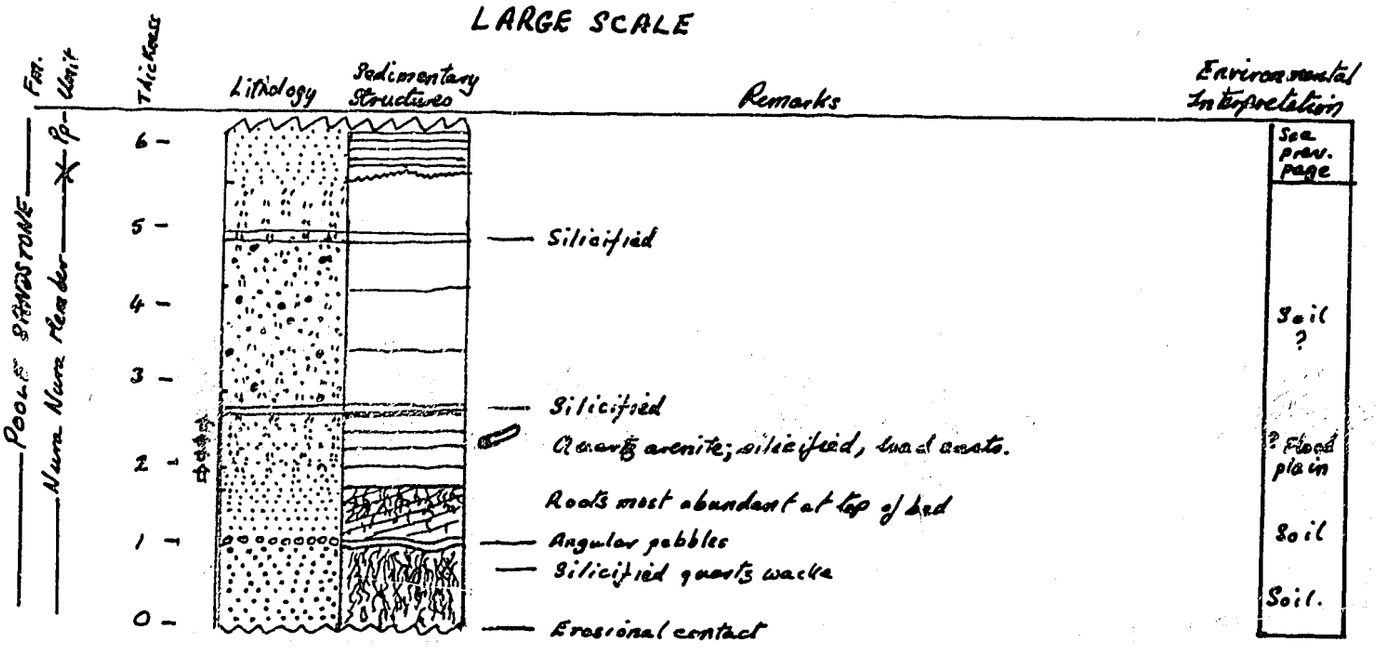


Record 1976/24

E51/A12/24

SECTION NO. 3 (cont.)

LARGE SCALE



Record 1976/24

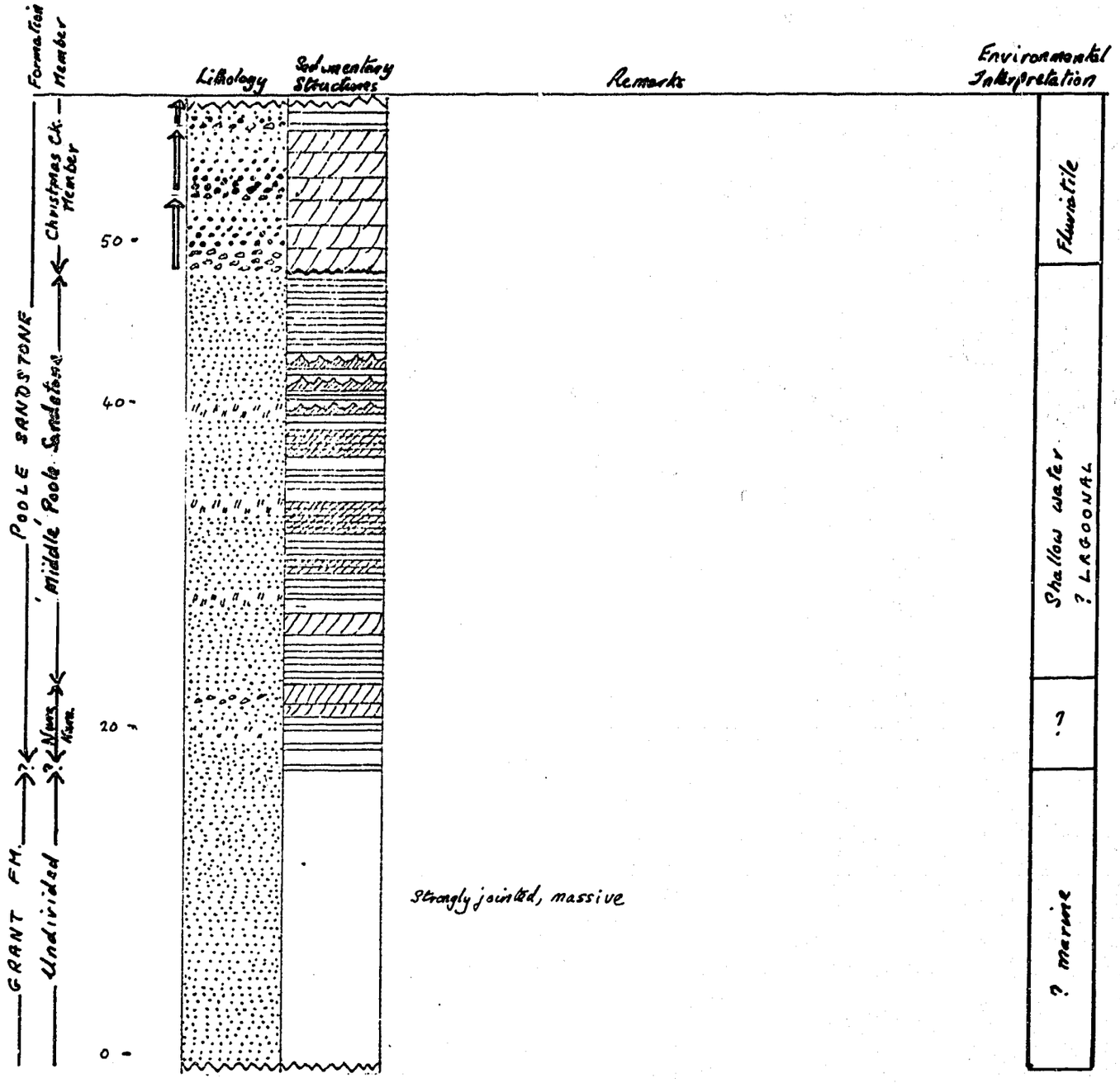
E51/A12/24

SECTION NO. 4

SOUTHERN POOLE RANGE

18°54'38"S. 125°46'30"E.

Estimated



Record 1976/24

E51/A12/25

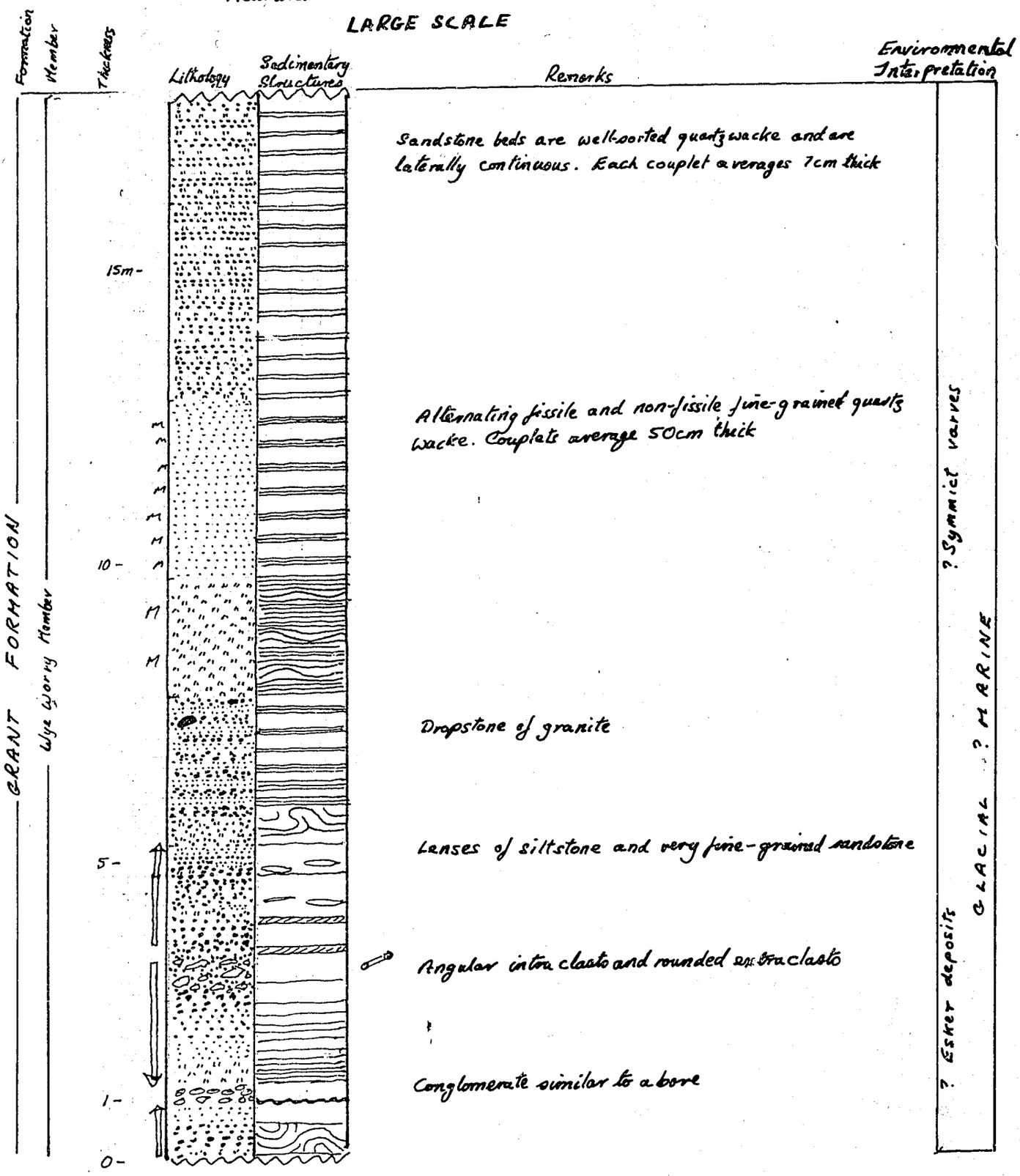
SECTION No 4a

SOUTHERN POOLE RANGE

18°53'37"S. 125°44'30"E.

Measured

LARGE SCALE



Record 1976/24

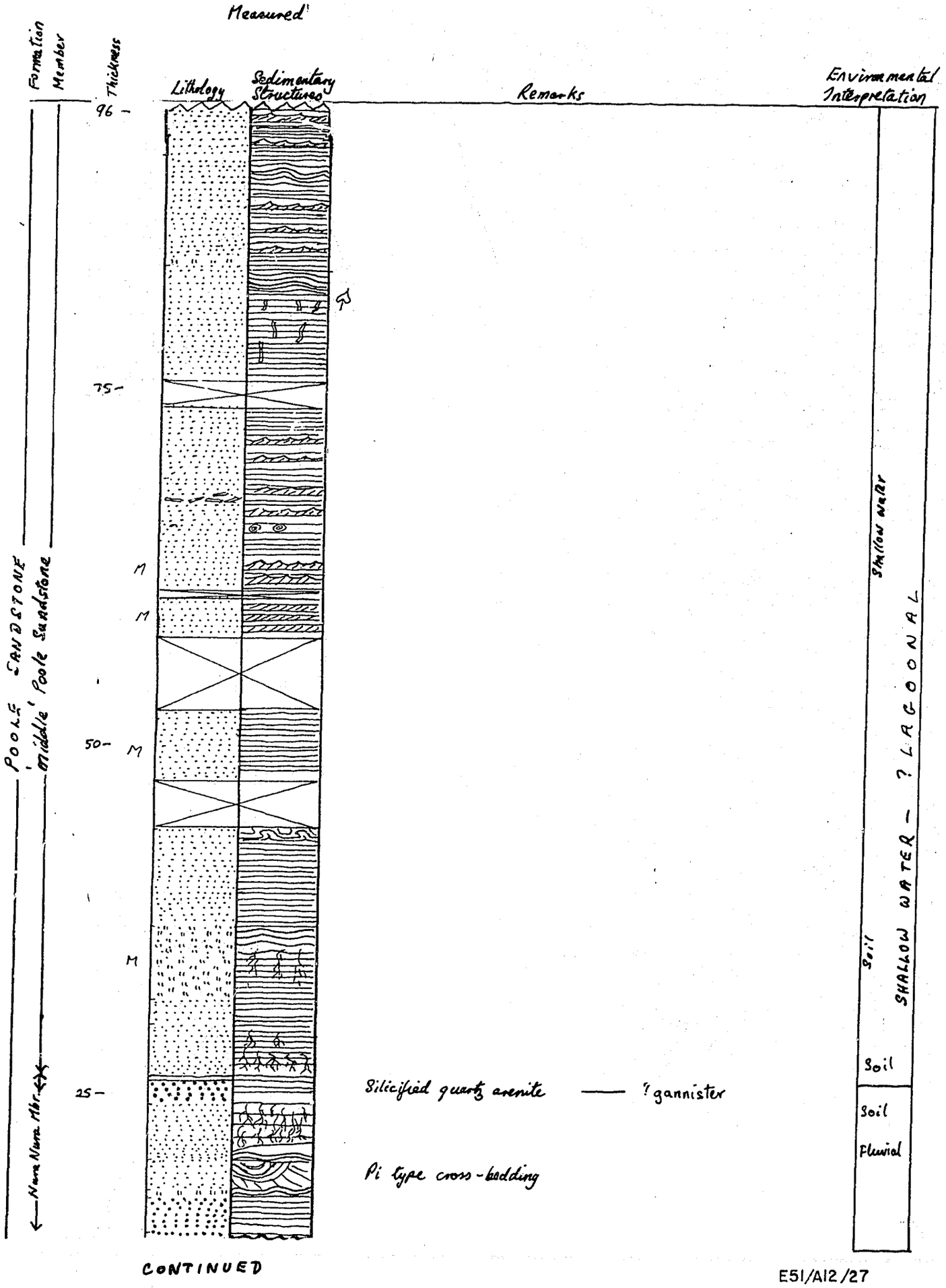
E51/A12/26

SECTION No.5

MOUNT HUTTON

18°49'33"S. 125°37'45"E.

Measured

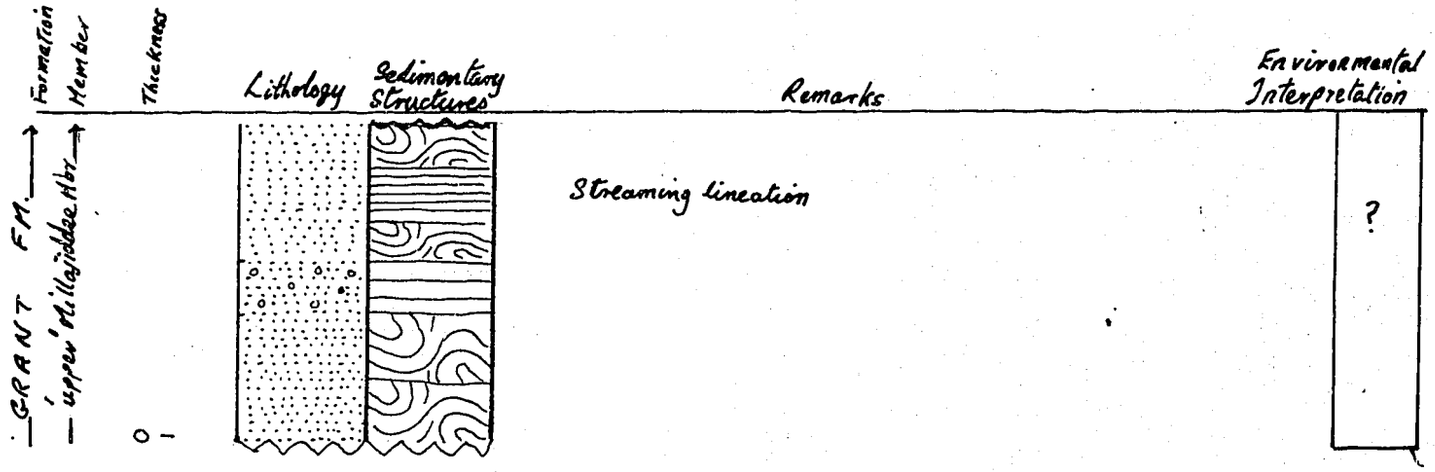


CONTINUED

E51/A12/27

Record 1976/24

SECTION No. 5 (cont)



Record 1976/24

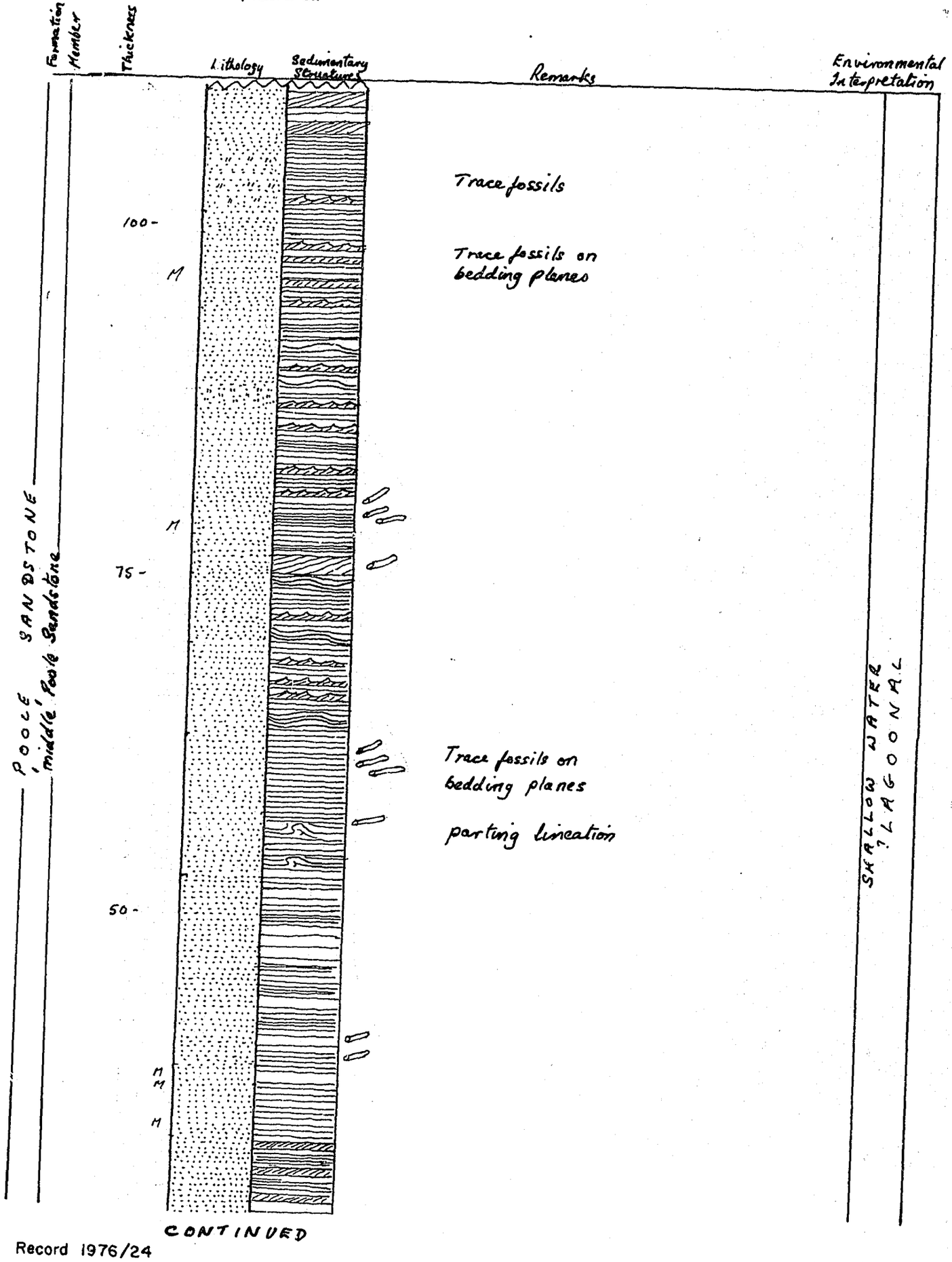
E51/A12/27

SECTION NO. 6

EASTERN ST GEORGE RANGE

18° 48' 00" S. 125° 23' 25" E.

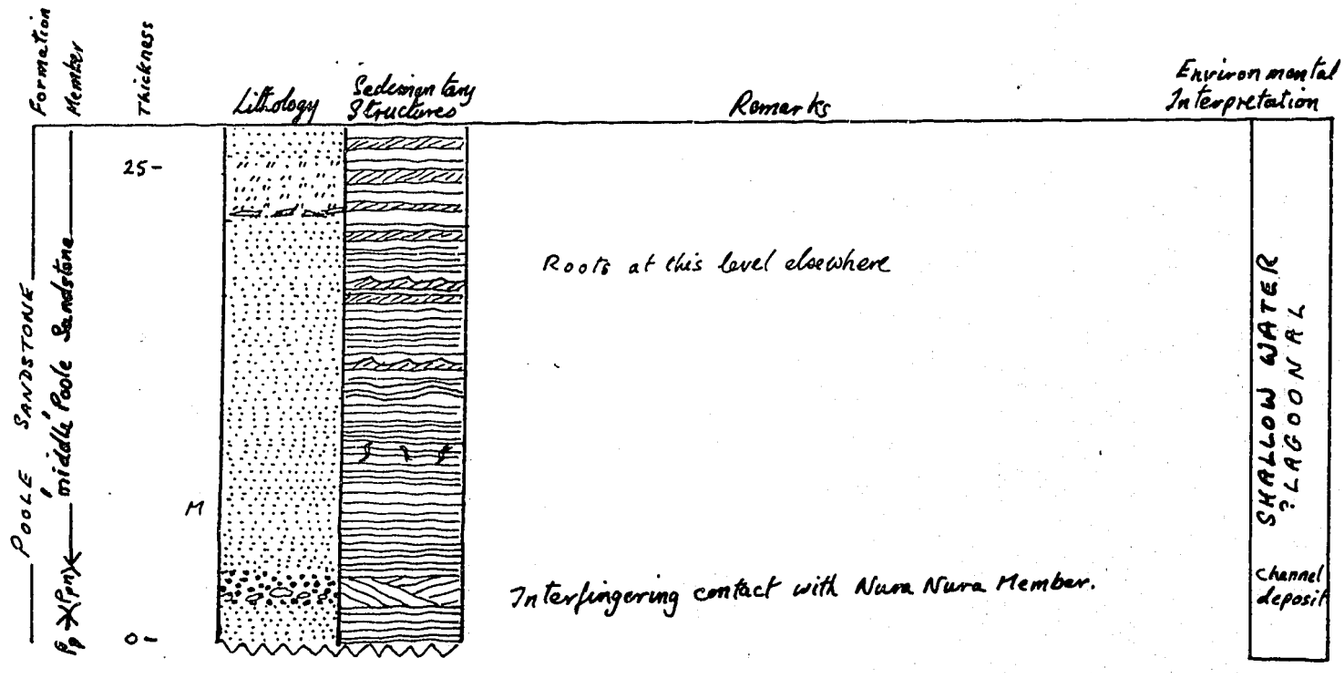
Measured



Record 1976/24

E51/A12/28

SECTION No.6 (cont.)



Record 1976/24

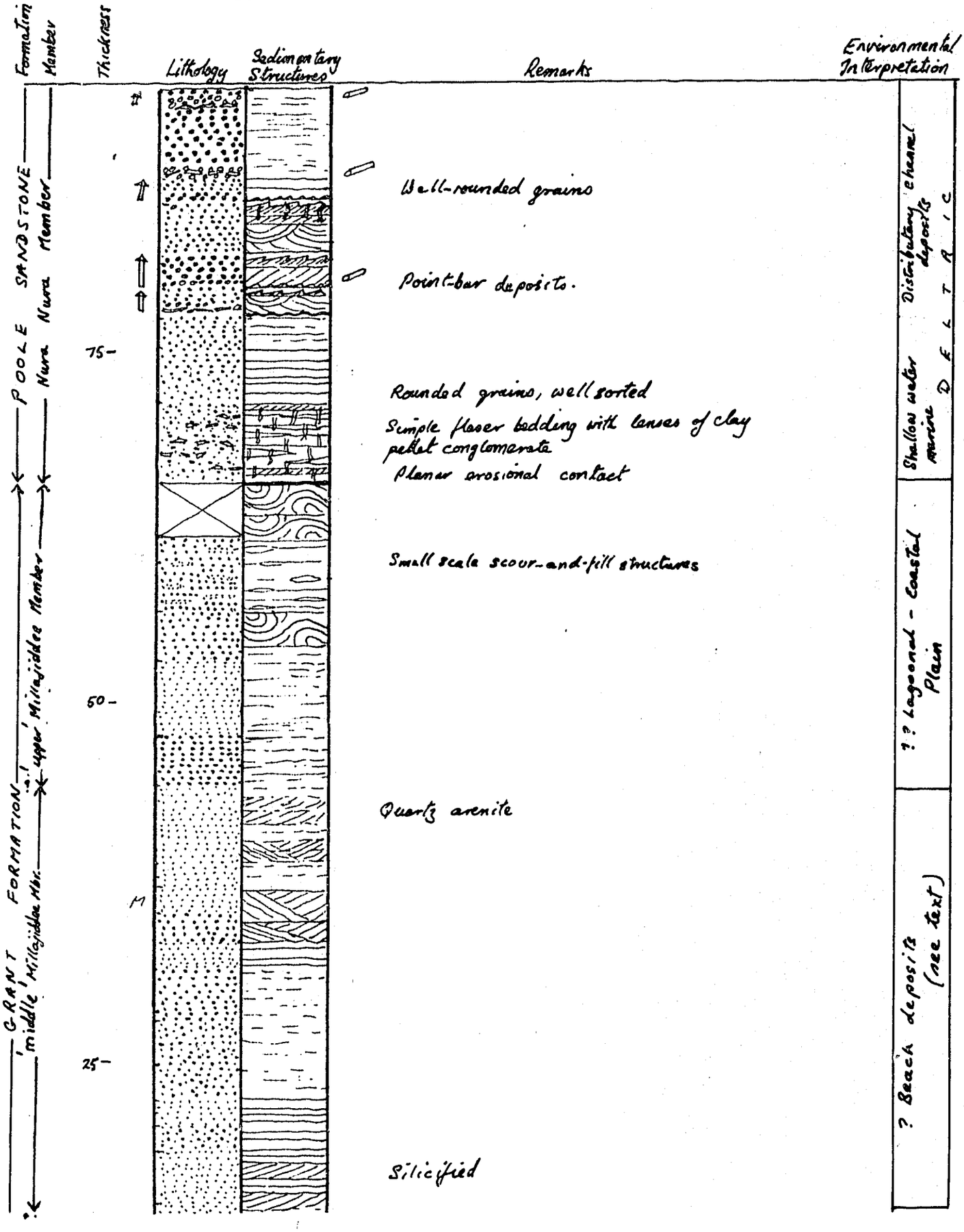
E51/A12/28

SECTION NO.7

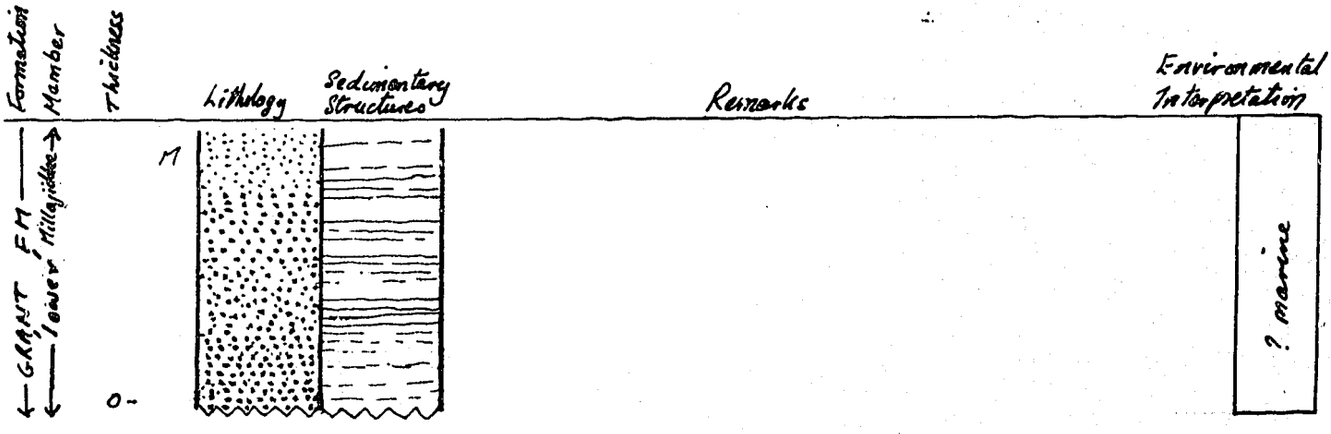
EASTERN ST GEORGE RANGE

18° 48' 45" S. 125° 23' 40" E.

Measured



CONTINUED



Record 1976/24

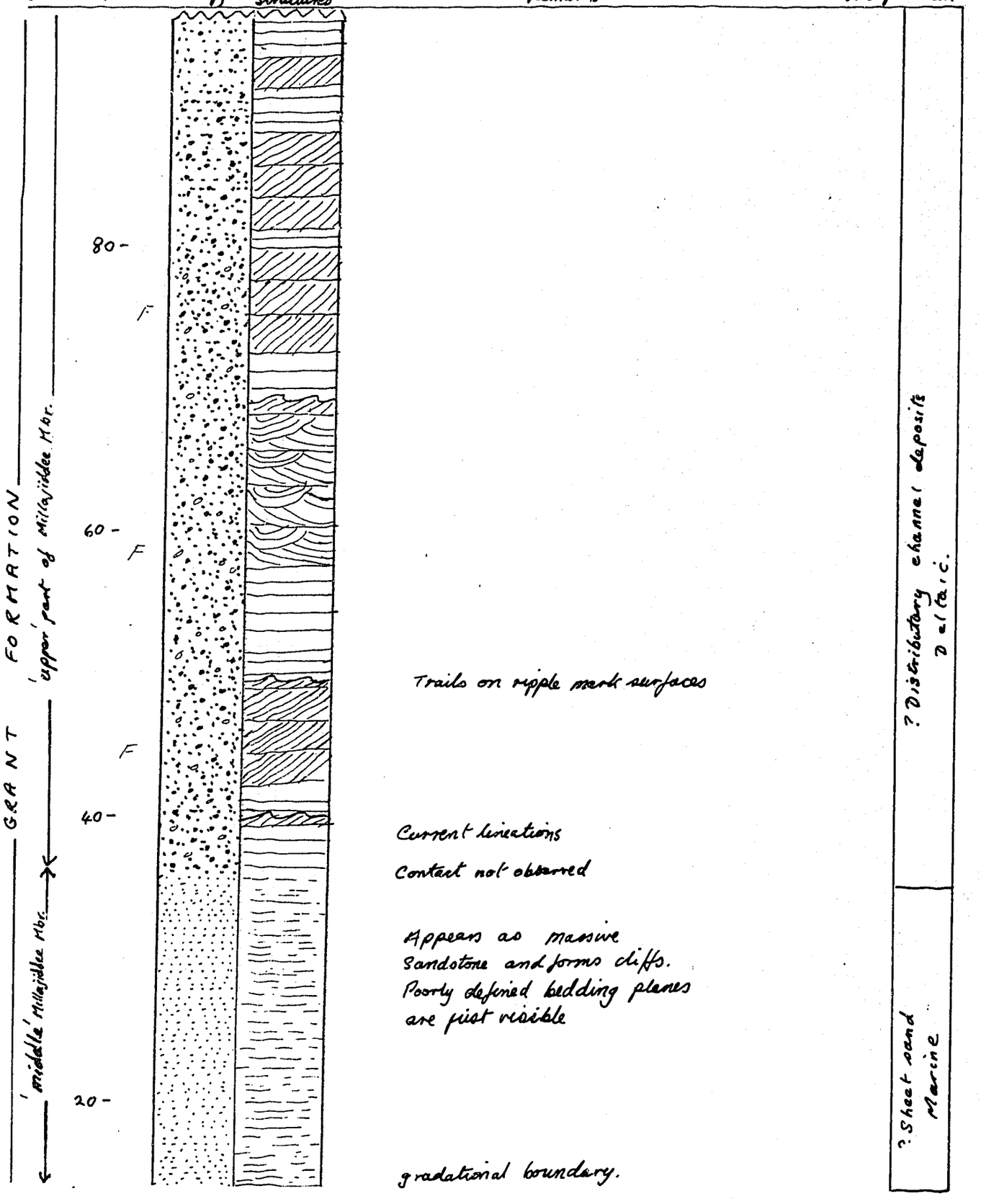
E51/A12/29

SECTION No. 8

SOUTHEASTERN ST GEORGE RANGE

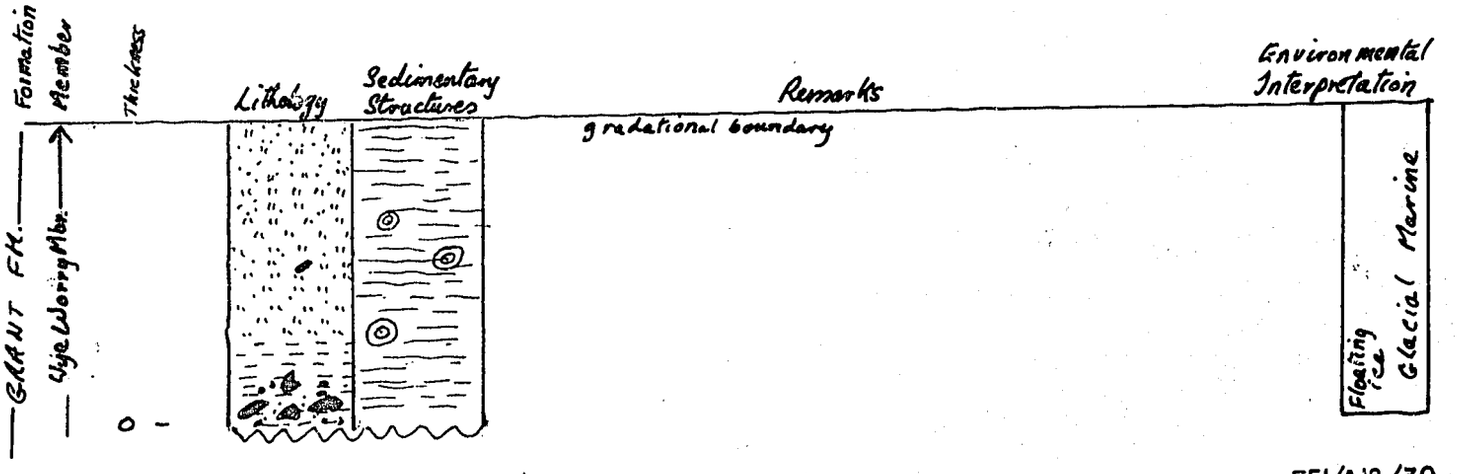
18°49'37"S. 125°18'30"E.

Estimated



CONTINUED

SECTION No. 8 (cont.)



Record 1976/24

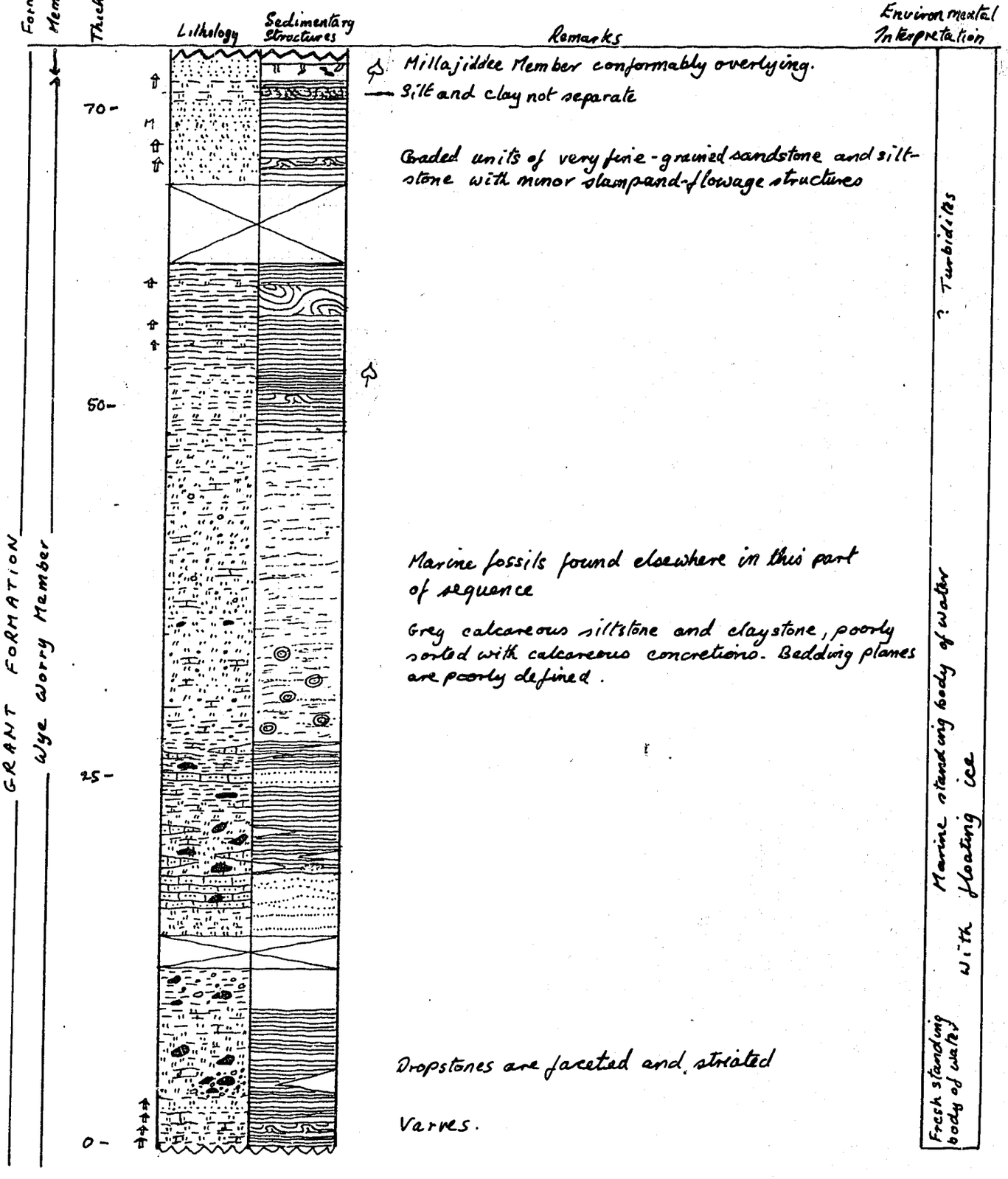
E51/A12/30

SECTION No. 9

EASTERN ST GEORGE RANGE

18° 46' 30" S. 125° 18' 50" E

Measured. Type section for Wye Worry Member

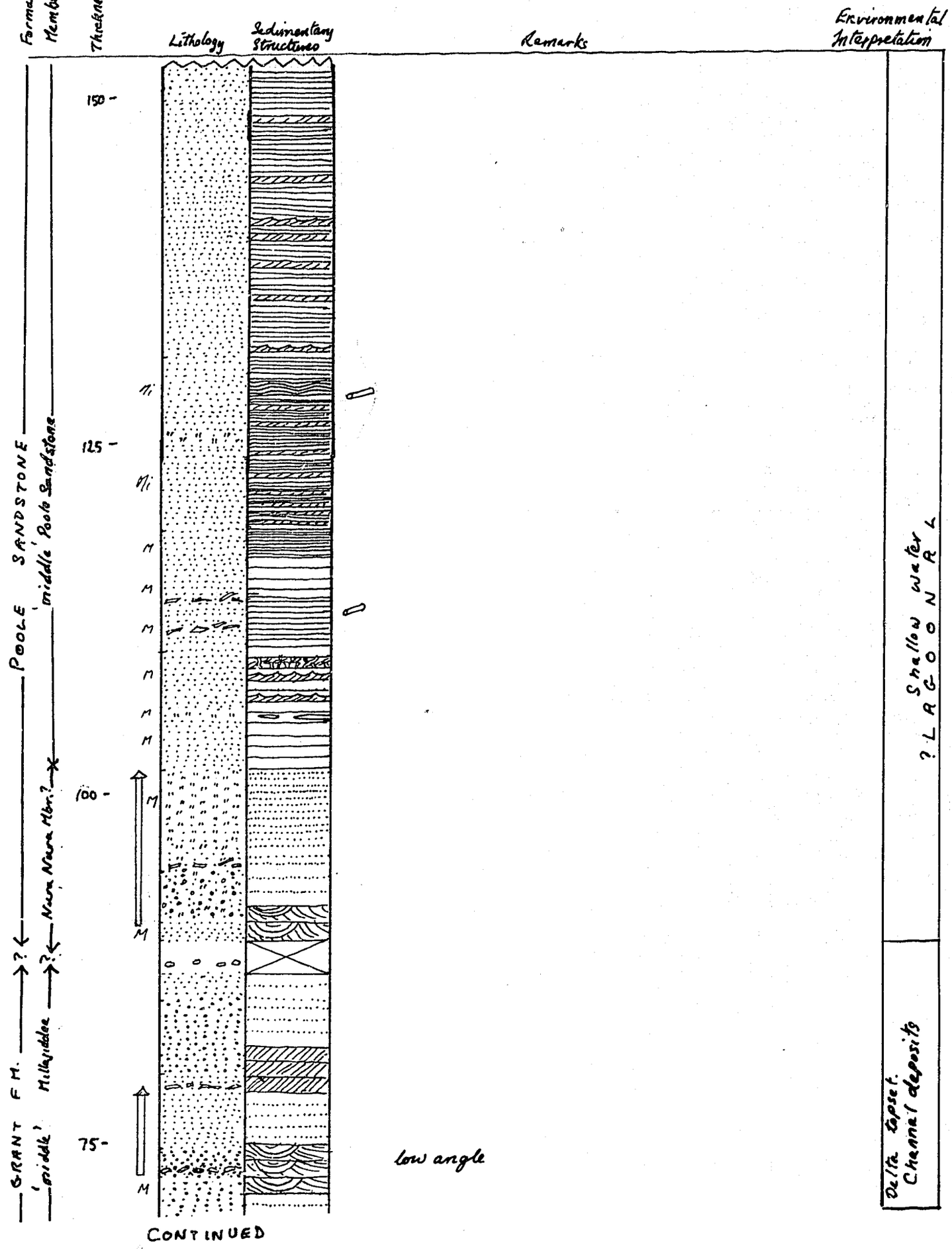


SECTION NO. 10

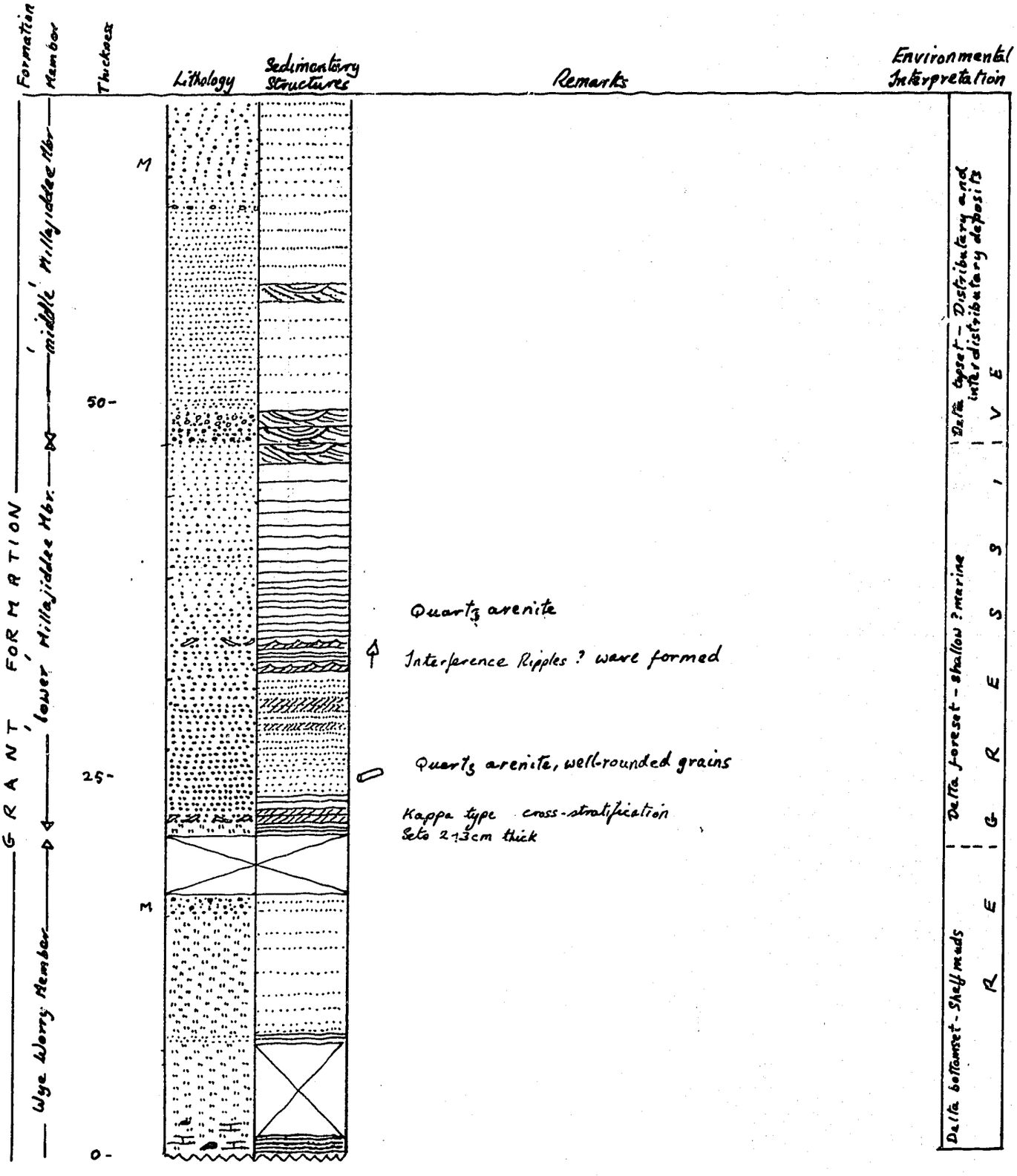
CENTRAL ST GEORGE RANGE

18°43'52"S. 125°07'52"E

Measured



SECTION No.10 (cont.)

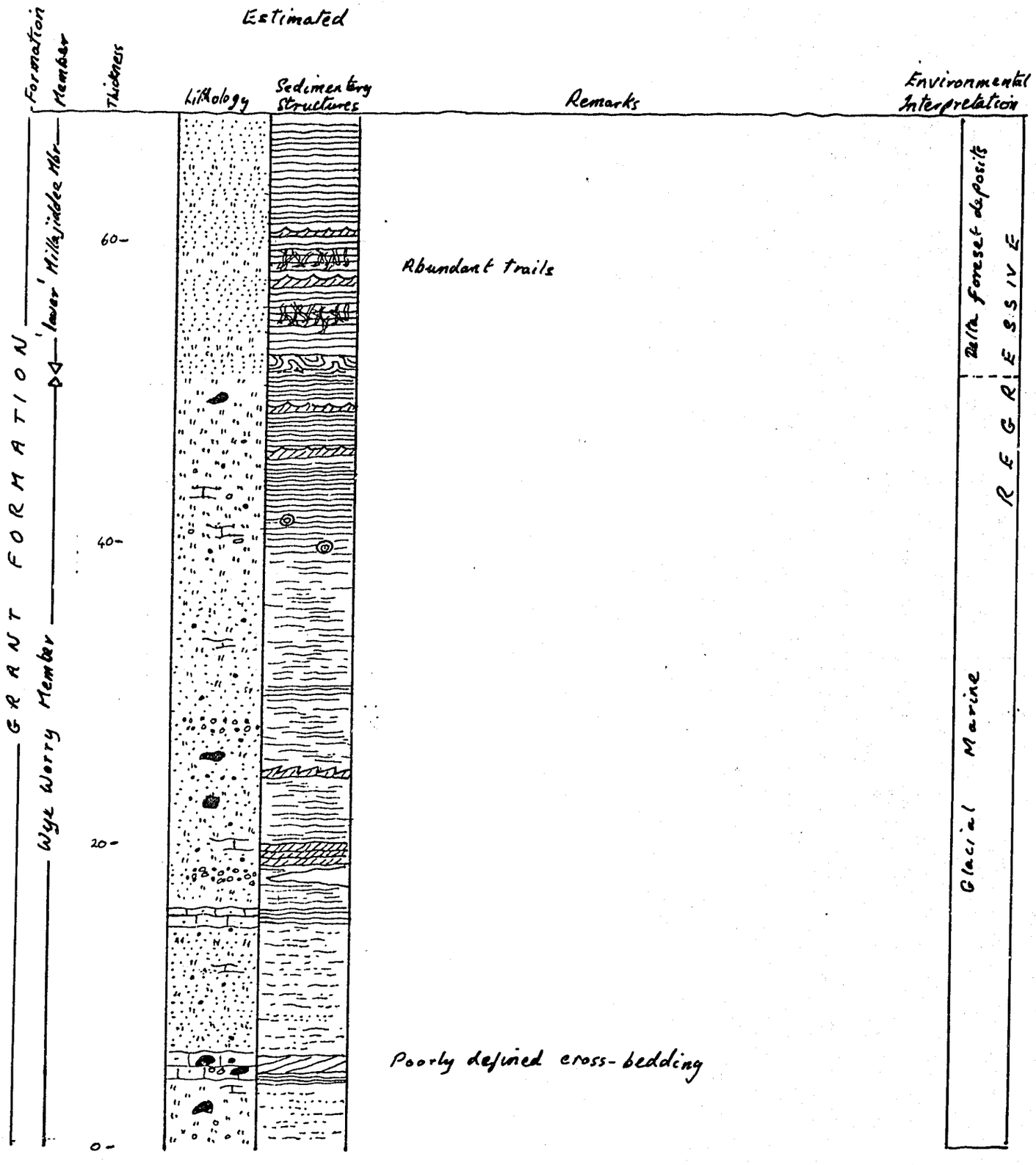


SECTION NO. 11

TULLOCK PEAK

18° 48' 00" S. 125° 07' 12" E.

Estimated



Record 1976/24

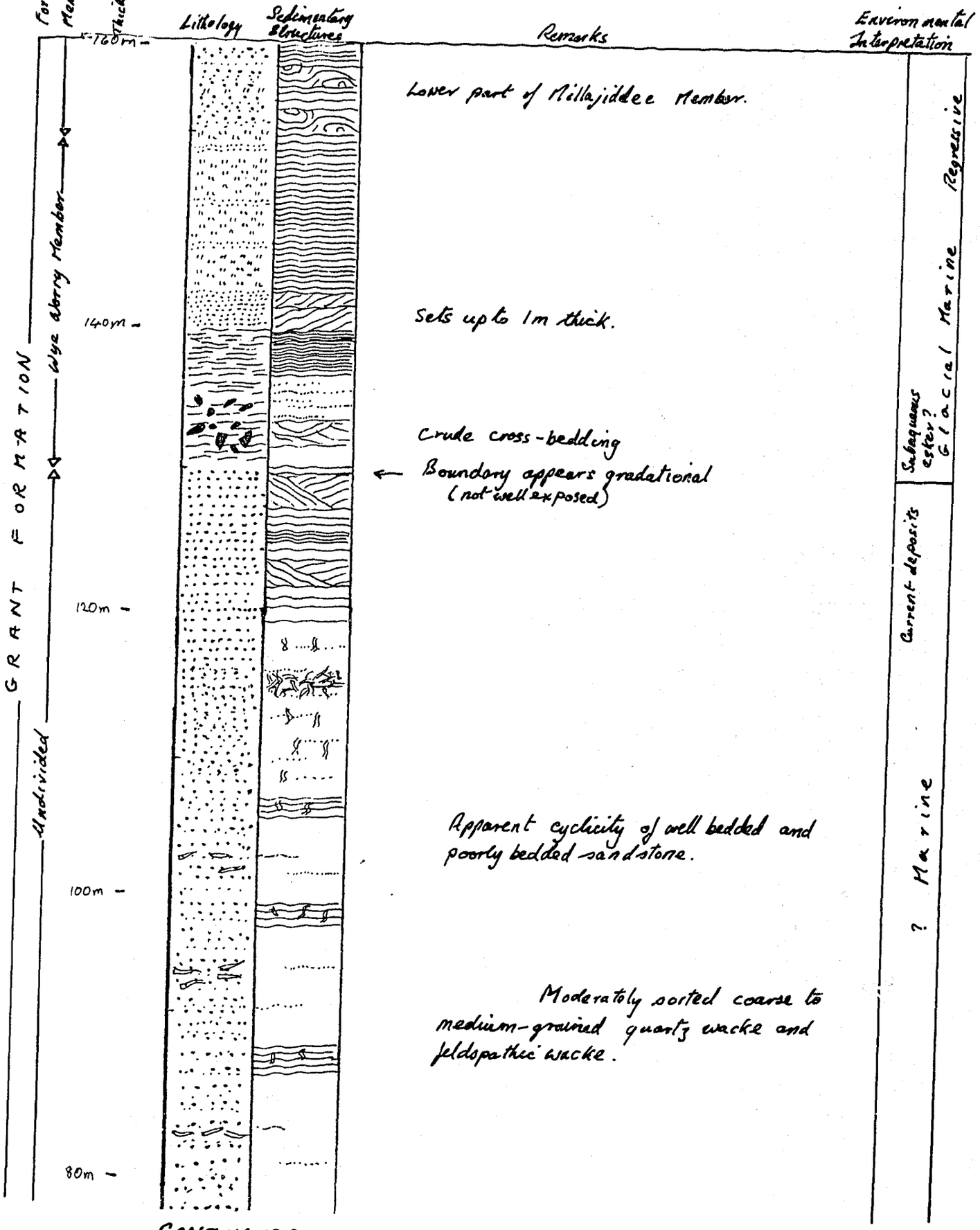
E51/A12/33

SECTION No. 12

CENTRAL GEORGE RANGE

18°43'25"S. 125°07'12"E

Measured from base of Wye Worry Member upwards; rest is estimated.

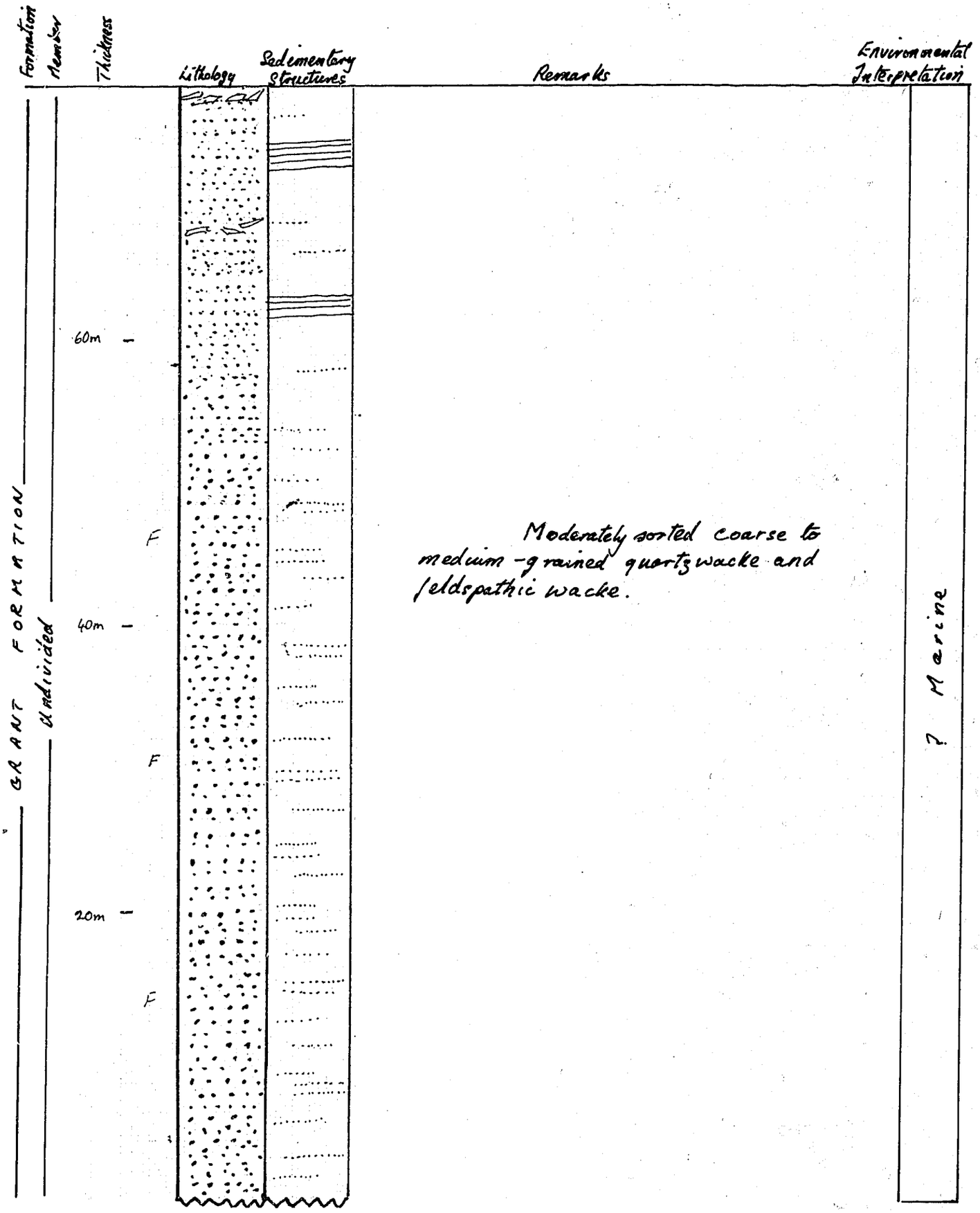


CONTINUED

Record 1976/24

E51/A12/34

SECTION NO. 12 (cont.)

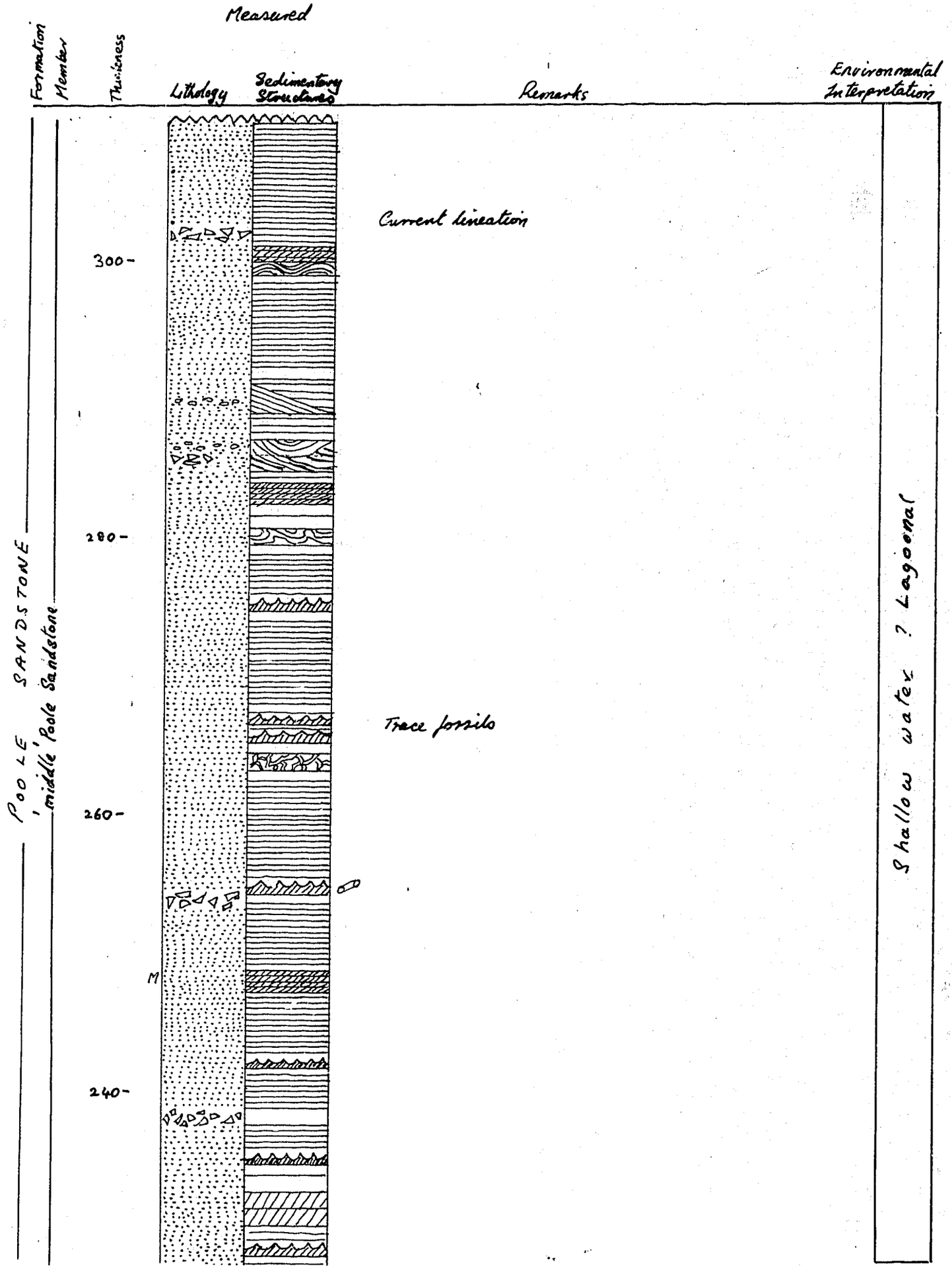


SECTION No. 13

MOUNT TUCKFIELD

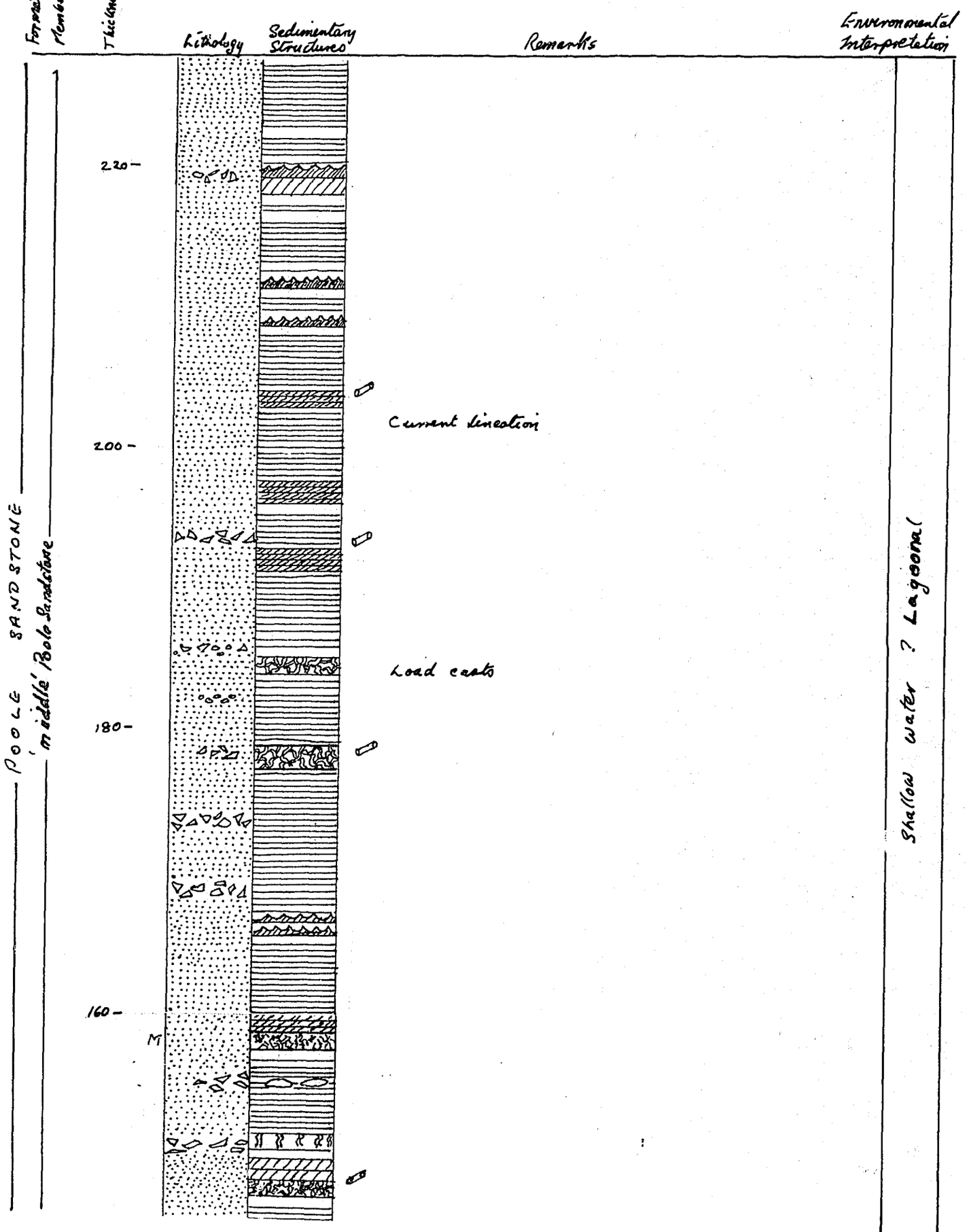
18° 42' 15"S. 124° 53' 35"E.

Measured



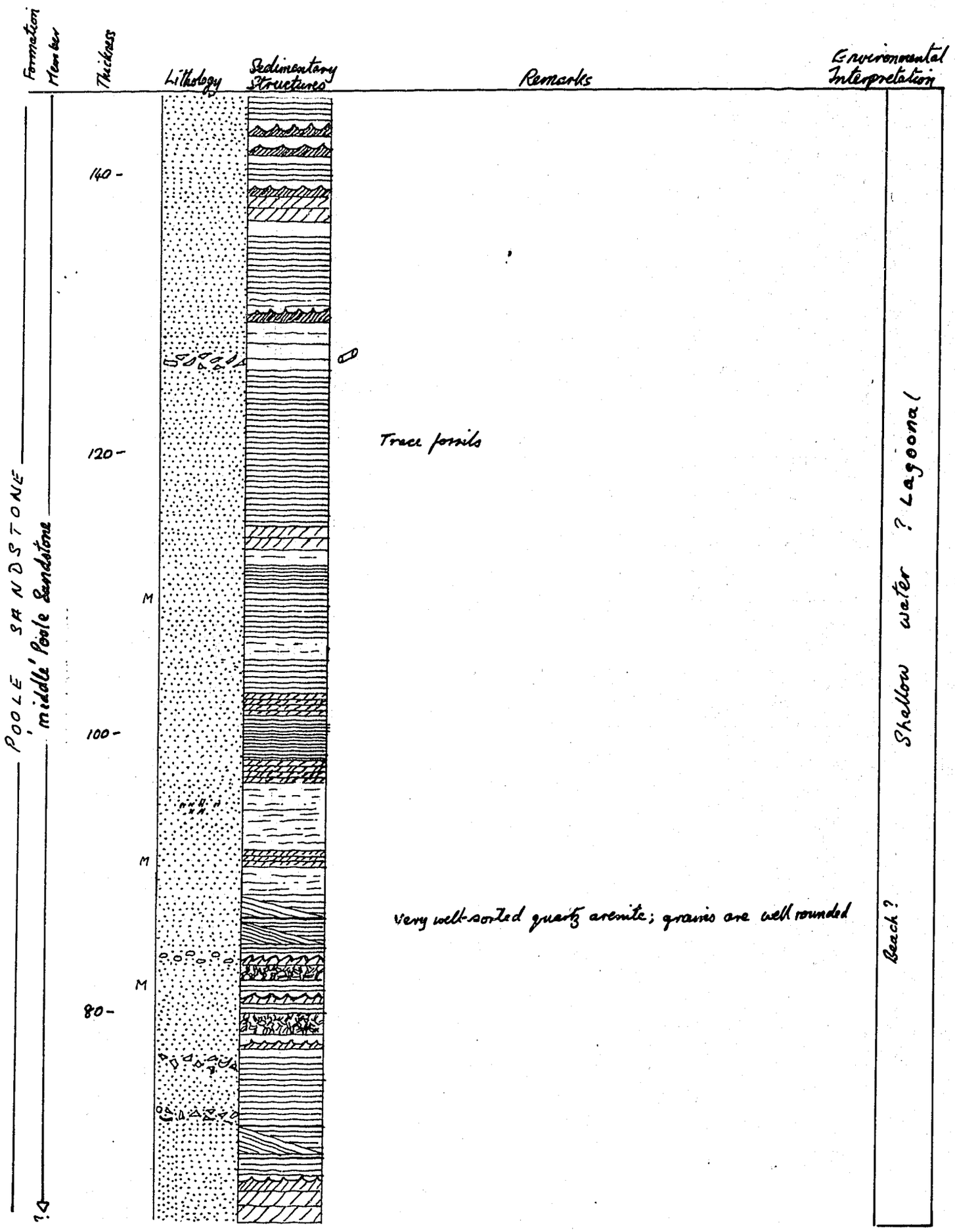
Continued

SECTION NO. 13 (cont.)



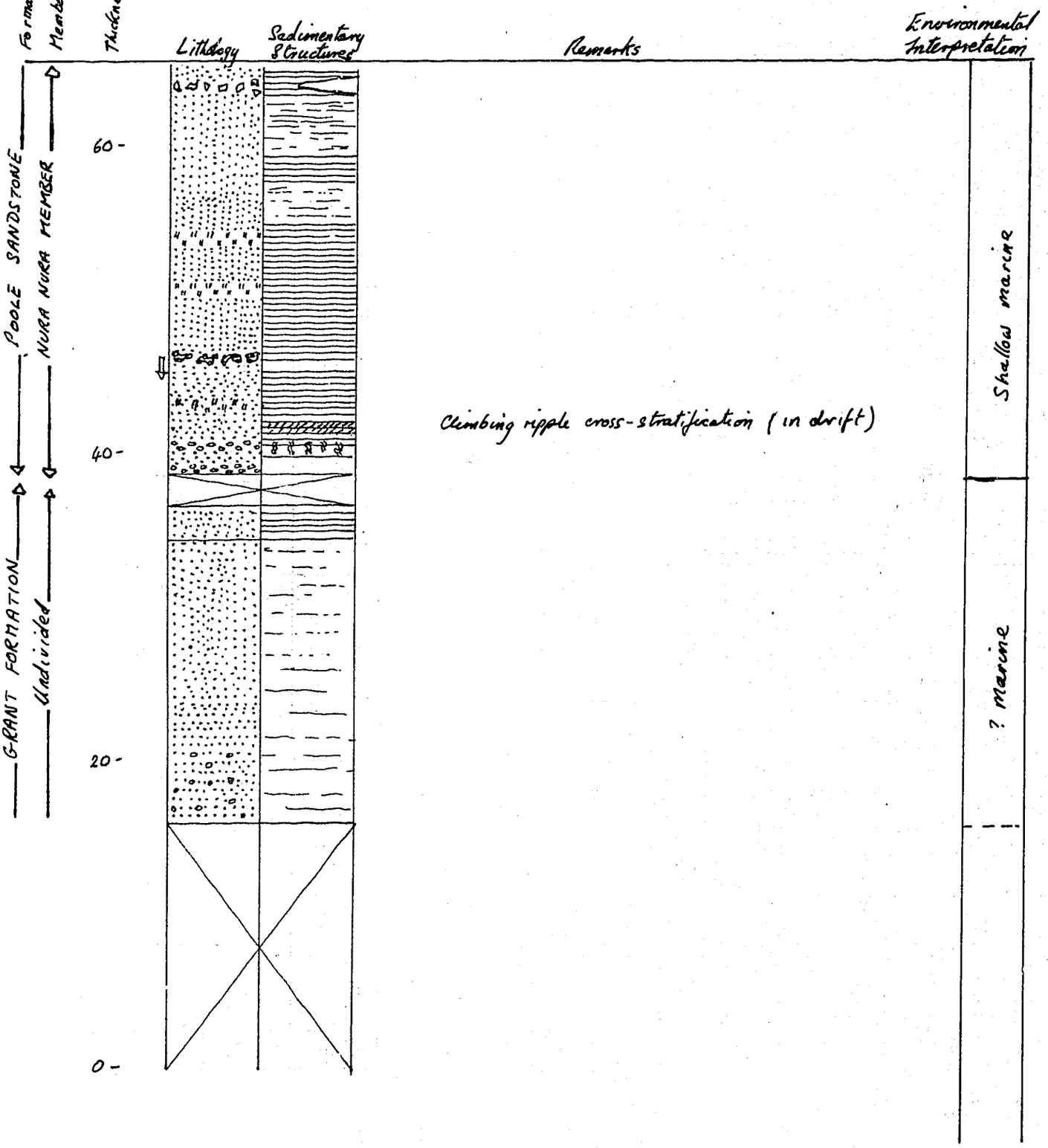
CONTINUED

SECTION No. 13 (cont.)



CONTINUED

SECTION NO. 13 (cont.)



Record 1976/24

E51/A12/35

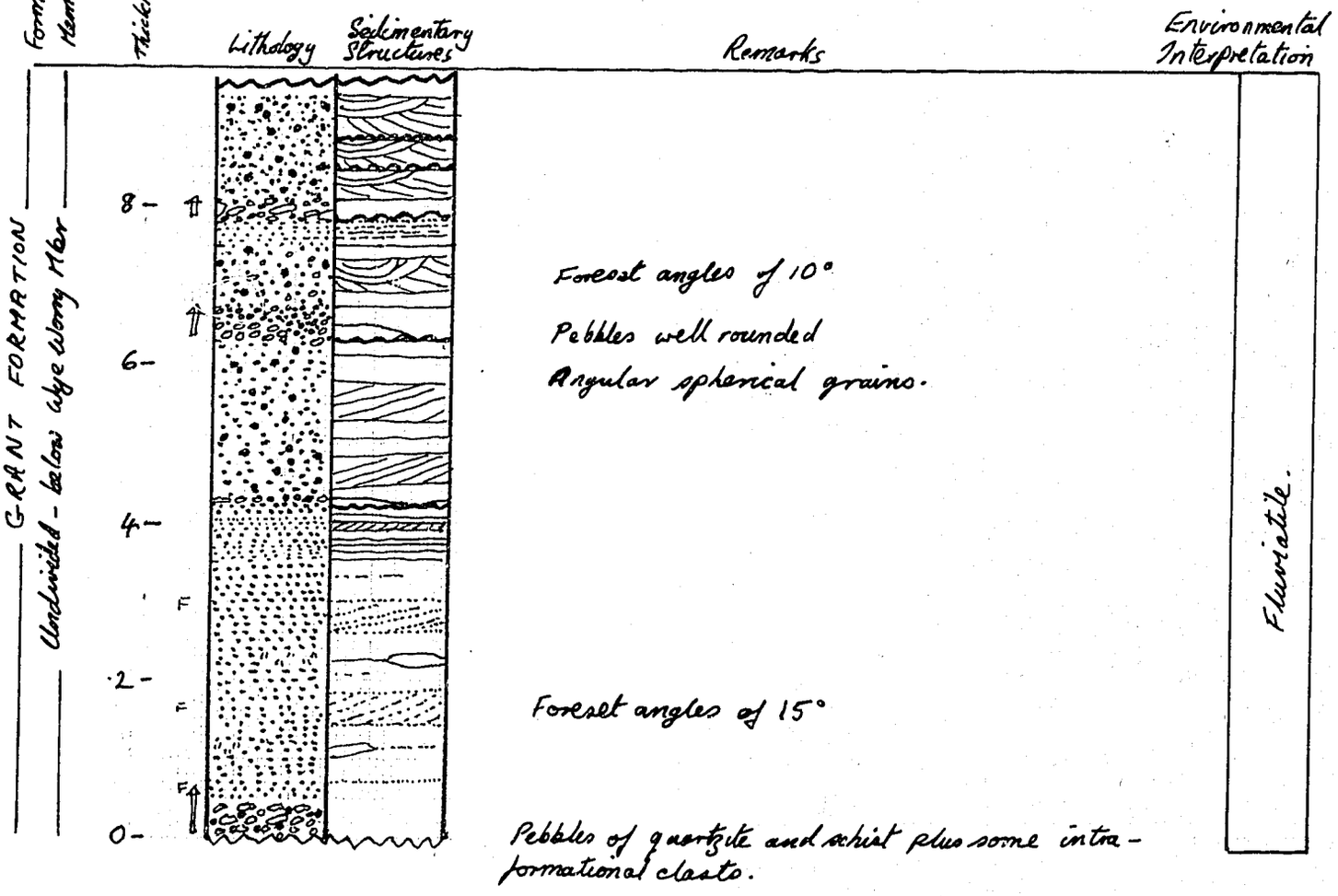
SECTION No. 13a

CAROLYN VALLEY

18° 43' 52" S. 124° 53' 45" E.

Measured.

LARGE SCALE

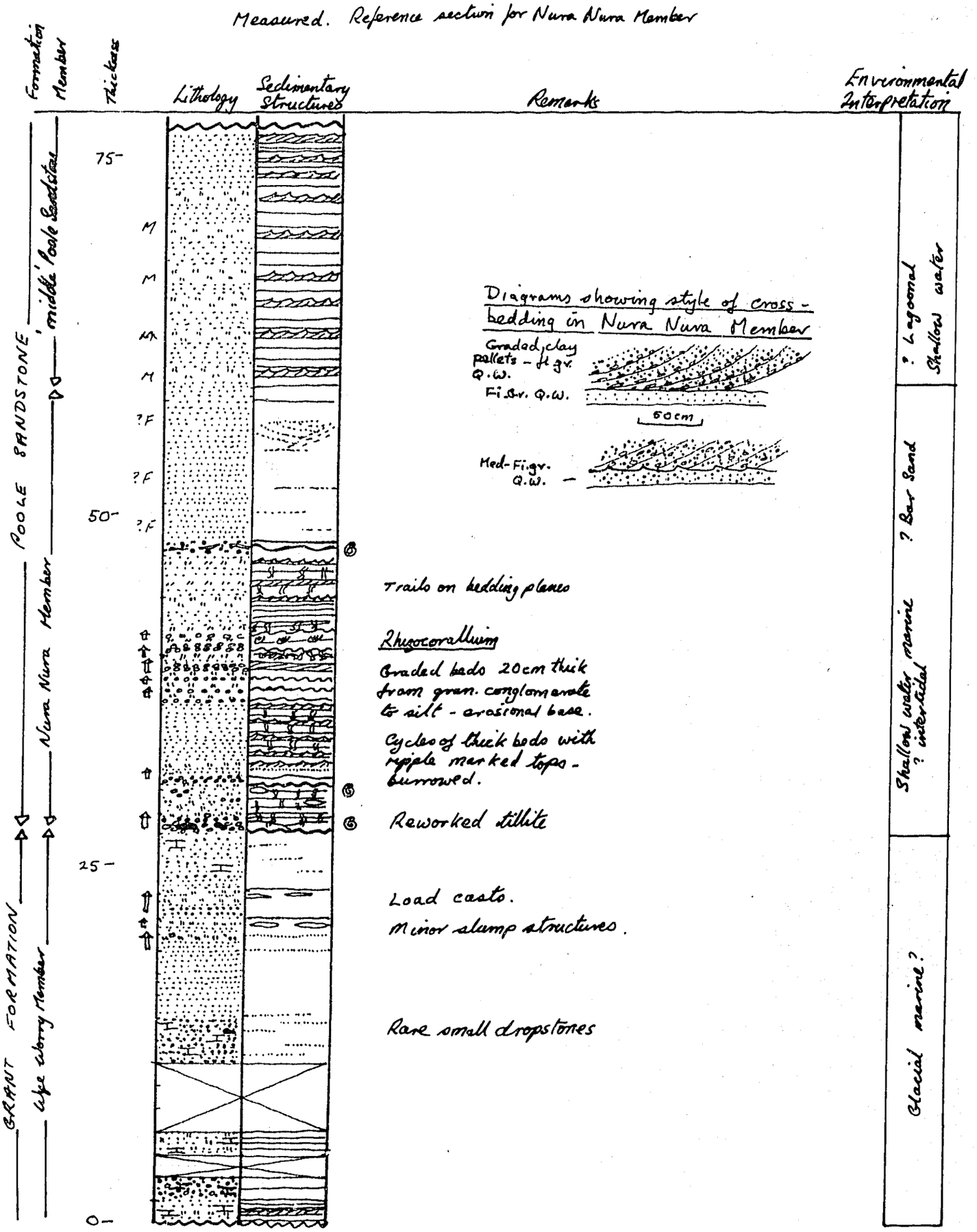


Record 1976/24

E51/A12/36

SECTION NO. 14

MILLAJIDDEE. S.W. ST GEORGE RA.
18°47'45"S. 124°57'33"E.
Measured. Reference section for Nura Nura Member

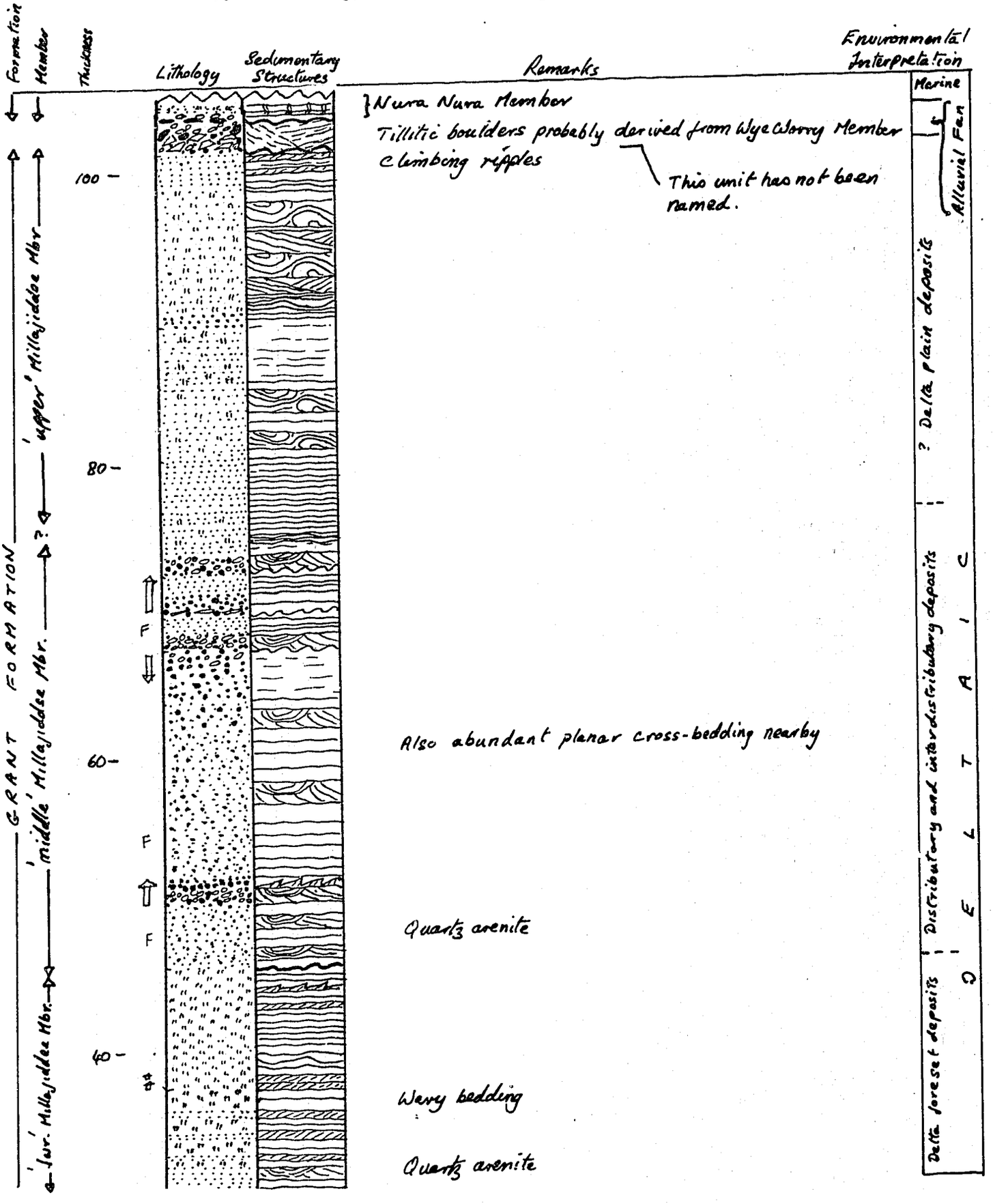


SECTION No. 15

WESTERN ST GEORGE RANGE

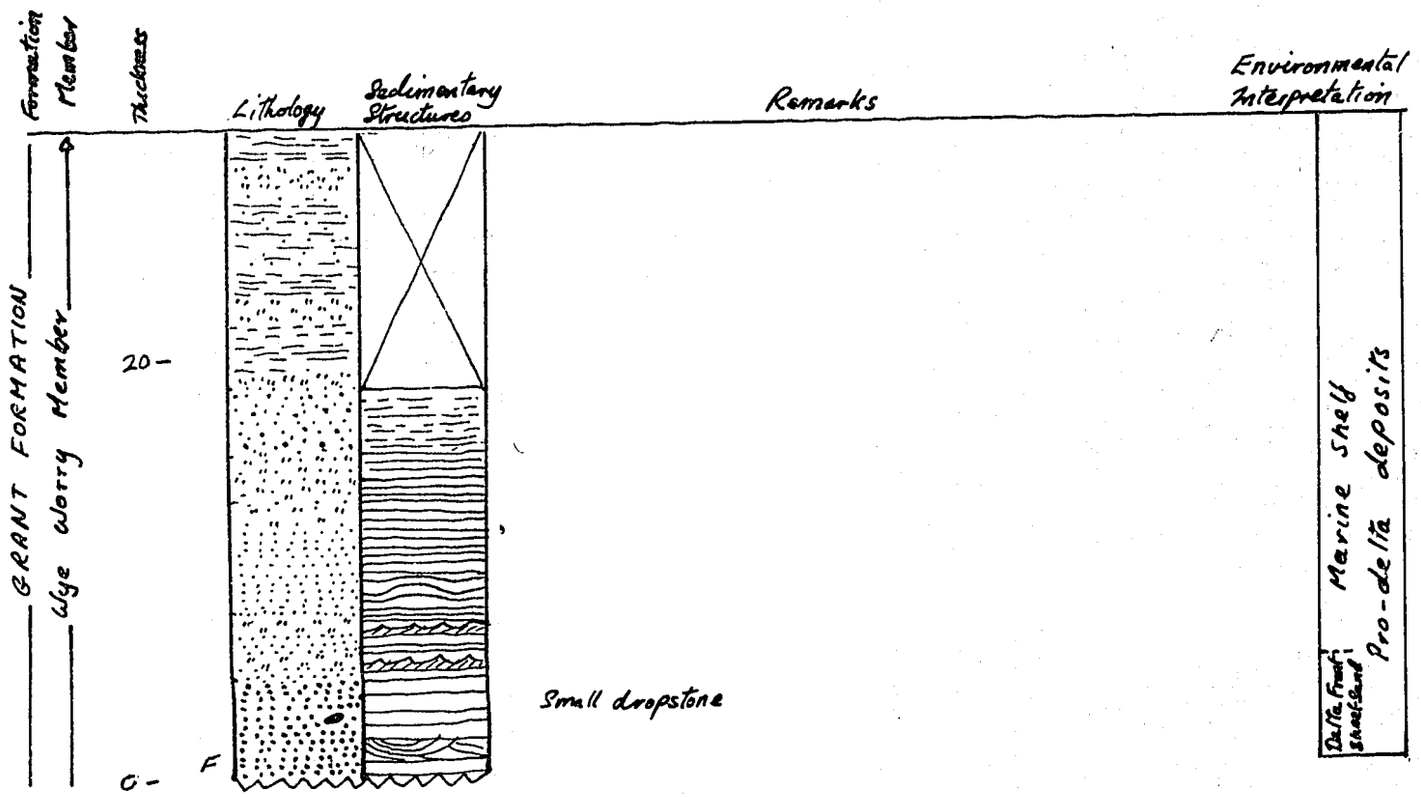
18°44'20"S. 124°55'52"E.

Measured. Type section for Millajiddee Member



CONTINUED

SECTION No. 15 (cont)



Record 1976/24

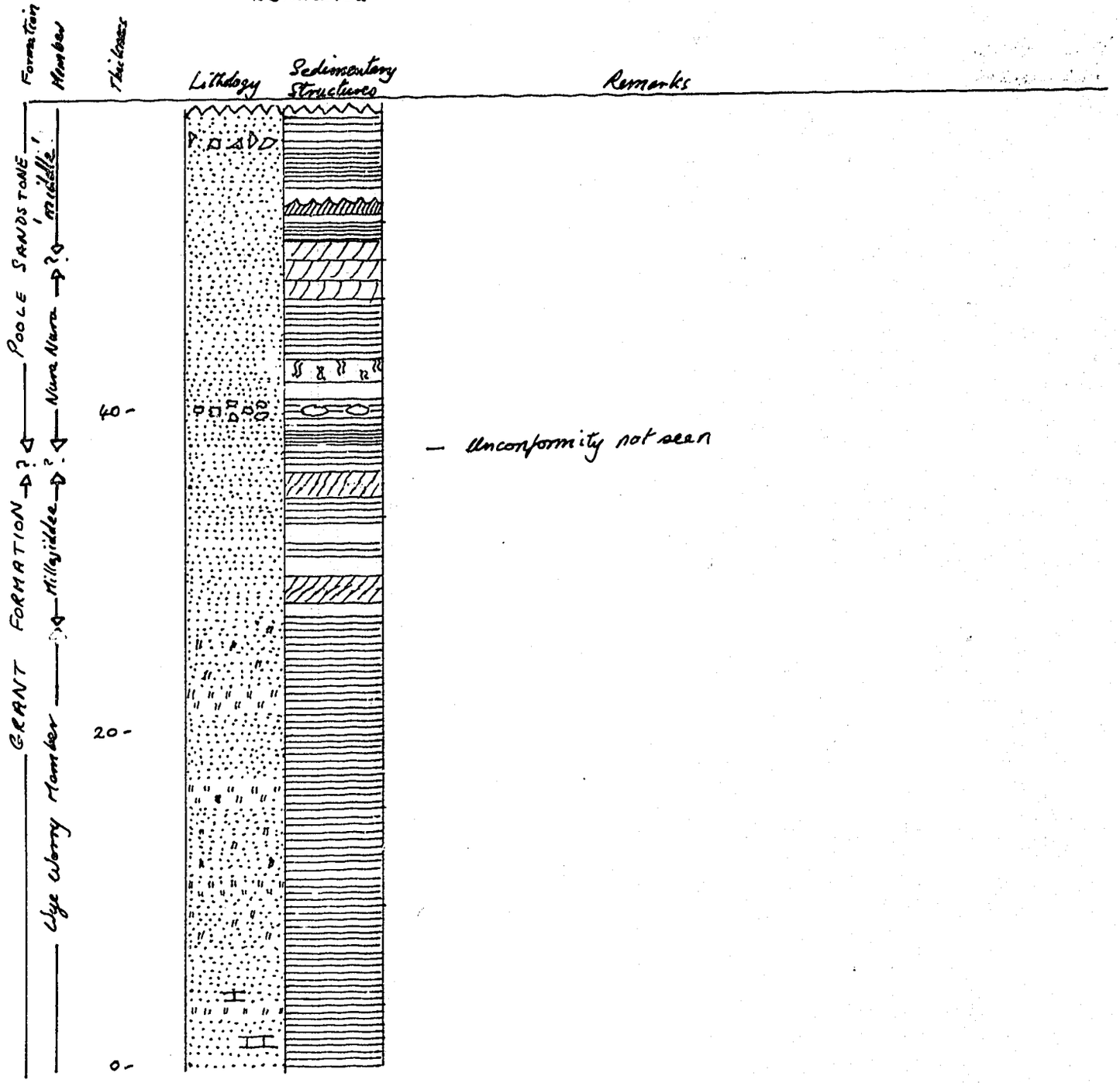
E51/A12/38

SECTION No. 16

NORTHWESTERN ST GEORGE RANGE

18°40'23"S. 124°52'50"E.

Estimated



Record 1976/24

E51/A12/39

SECTION NO. 17

WESTERN ST GEORGE RANGE

19°41'53" S. 129°54'30" E

Estimated

Formation | Member | Thickness | Lithology | Sedimentary Structures | Remarks | Environmental Interpretation

GRANT FORMATION

Undivided ? — Wye Worry Member — Millajiddee Member

60 –

40 –

20 –

0 –

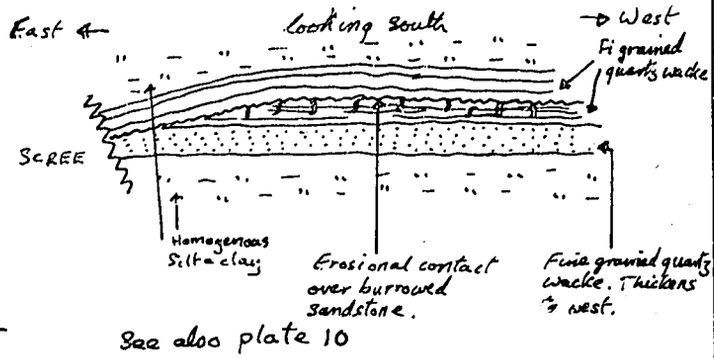
Millajiddee Member

Pro-delta.

Quiet water marine

Sandstone unit is coarser grained to east.

Diagram showing details of pinch-out of sandstone unit in Wye Worry Member.



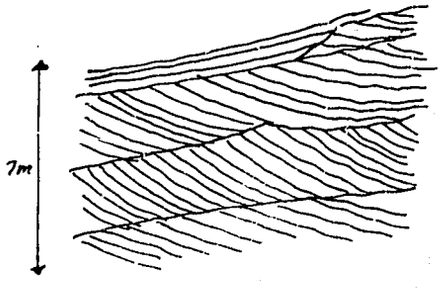
See also plate 10

Delta Front Sheet Sand

Quiet water ? marine

?

Diagram showing style of cross-bedding from nearby outcrop



Record 1976/24

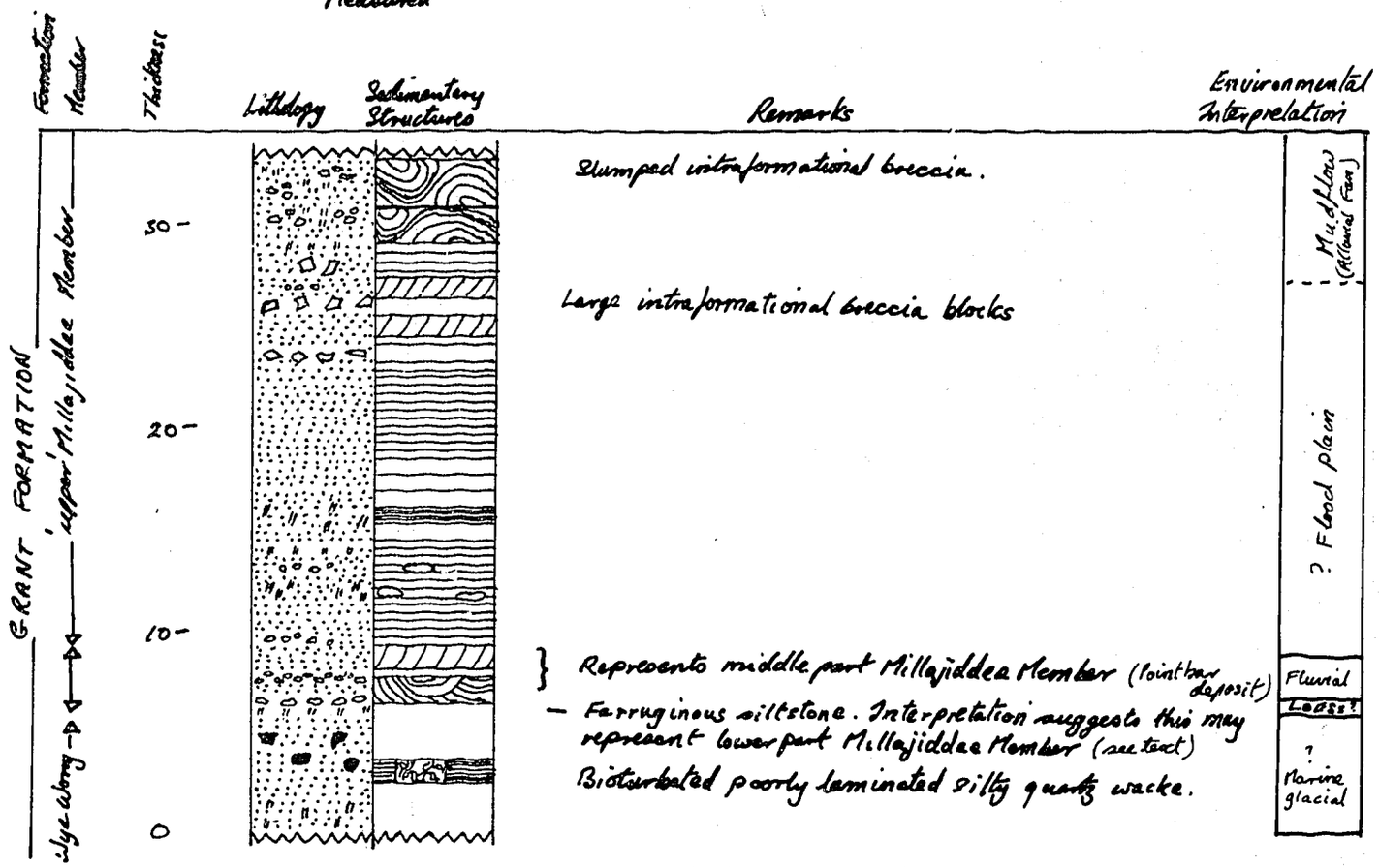
E51/A12/40

SECTION No 18

LAURIS RANGE

18°10'20"S. 125°25'30"E.

Measured



Record 1976/24

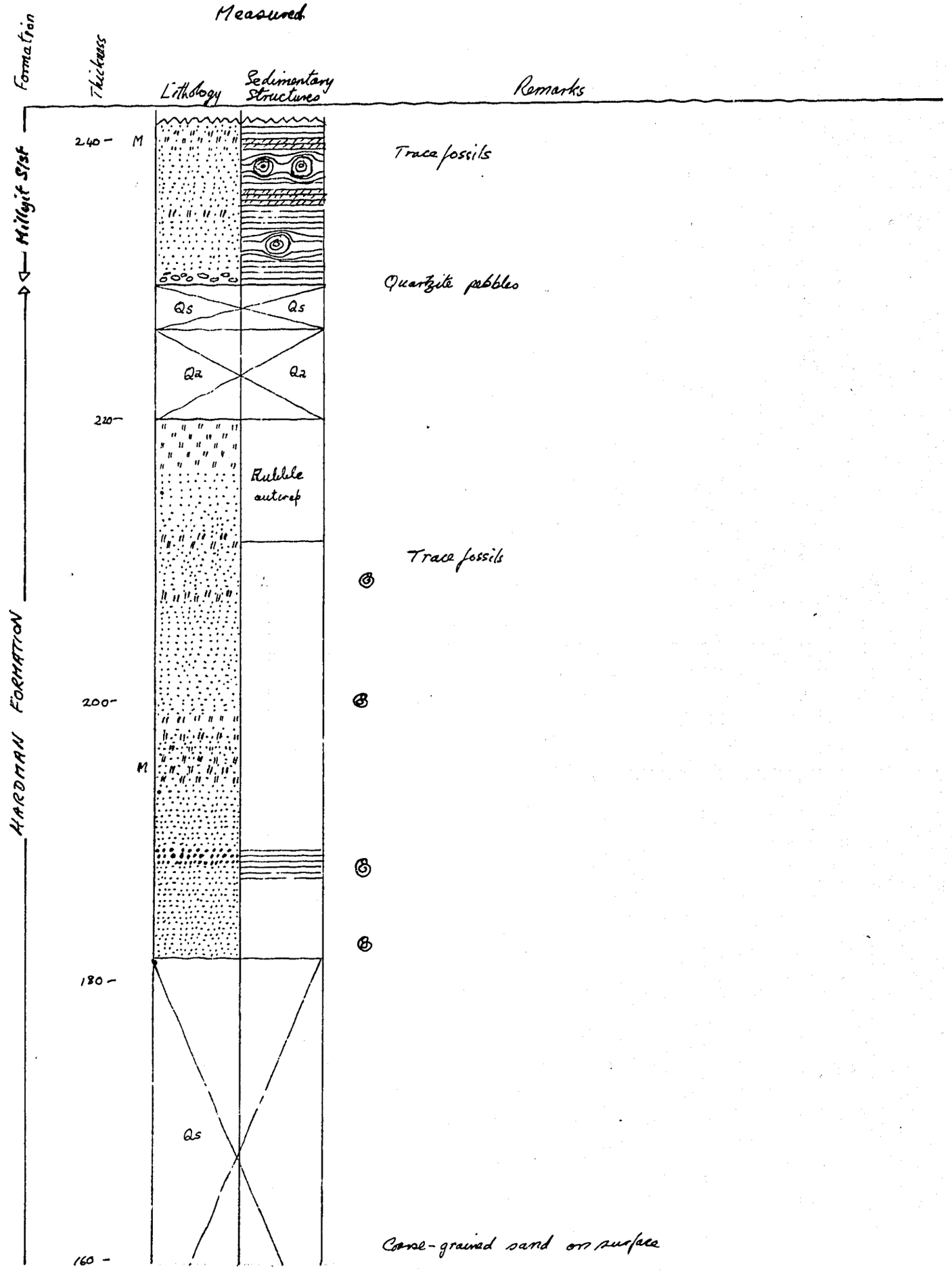
E51/A12/41

SECTION NO. 19

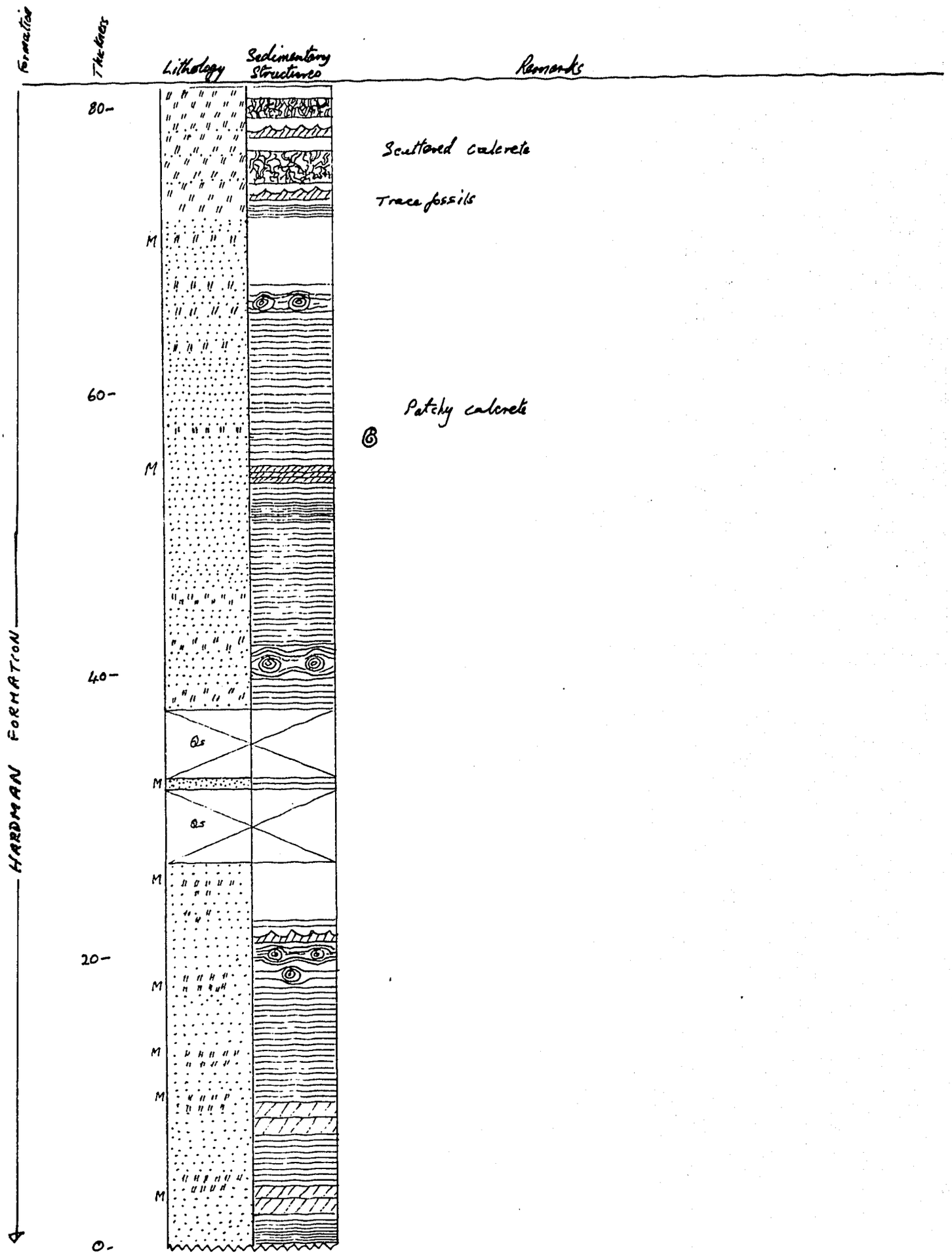
McLARTY SYNCLINE

18°39'00"S. 124°30'05"E.

Measured

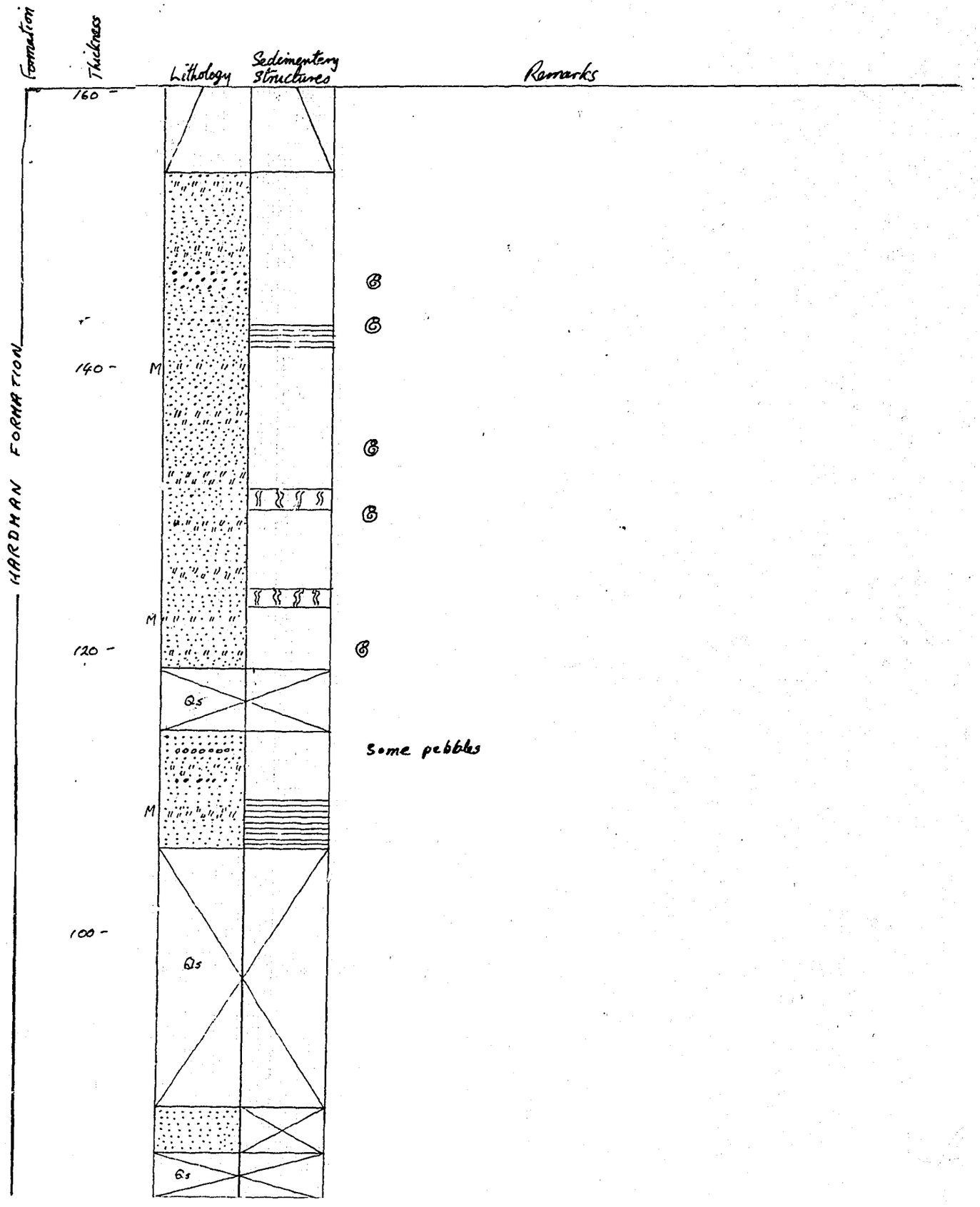


CONTINUED



Record 1976/24

E51/A12/42


Formation
Thickness
Lithology
Sedimentary structures
Remarks
HARDMAN FORMATION
160 -
140 -
120 -
100 -
M
M
M
Qs
Qs
Gs
Some pebbles

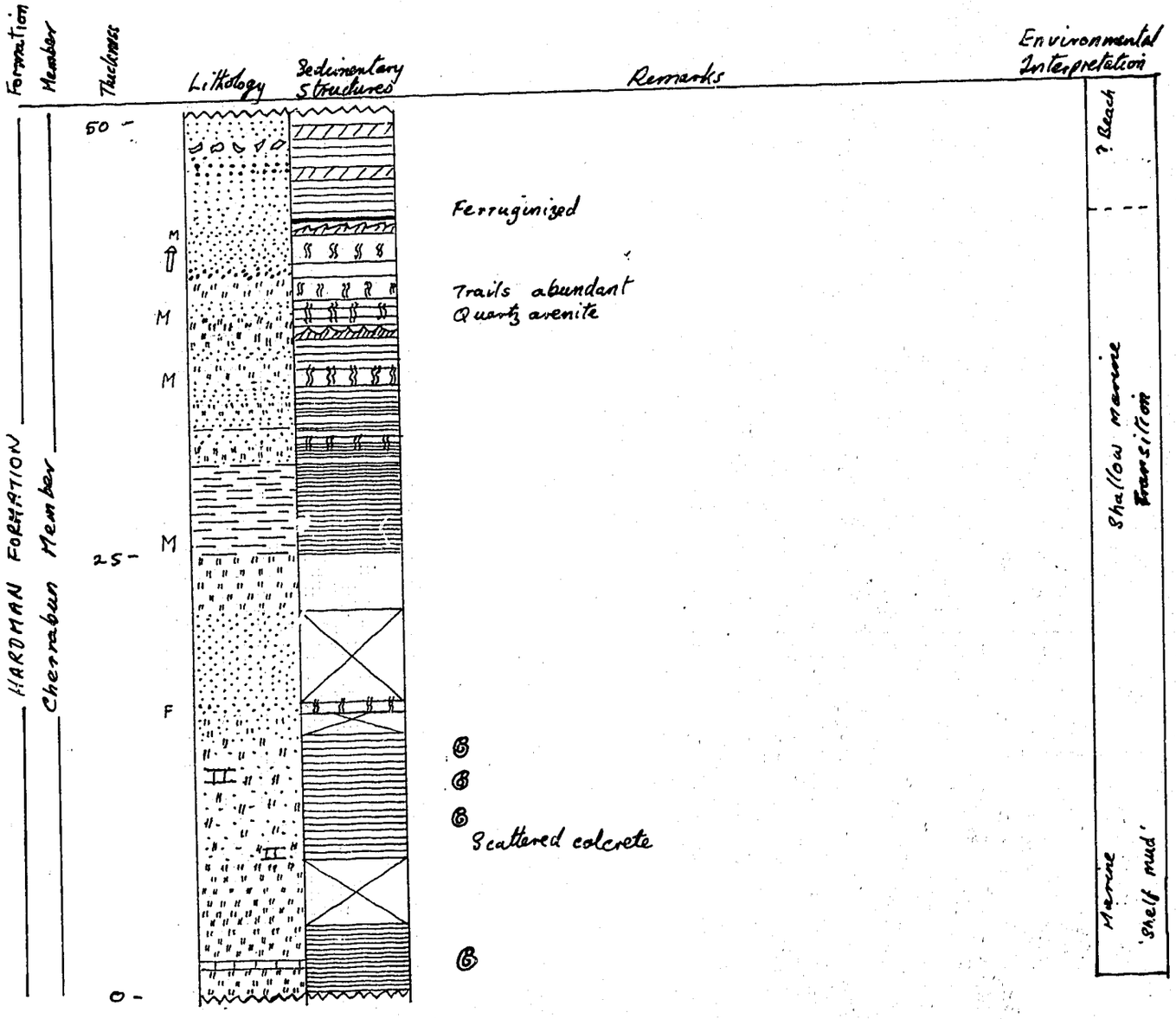
CONTINUED

SECTION No. 20

MOUNT HARDMAN

18°18' 45"S. 124°38'52" E.

Measured



E51/A12/43

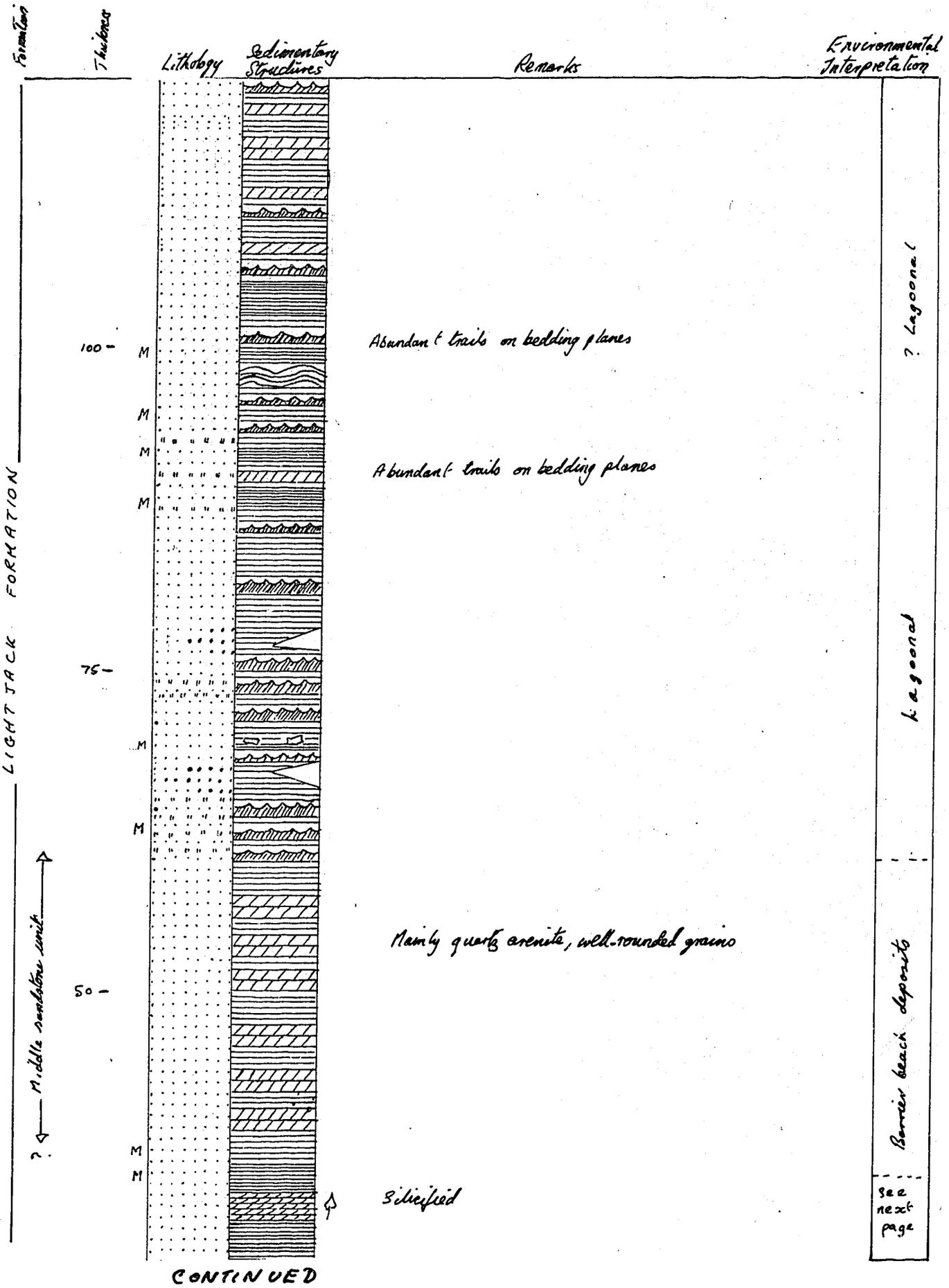
Record 1976/24

SECTION No 21

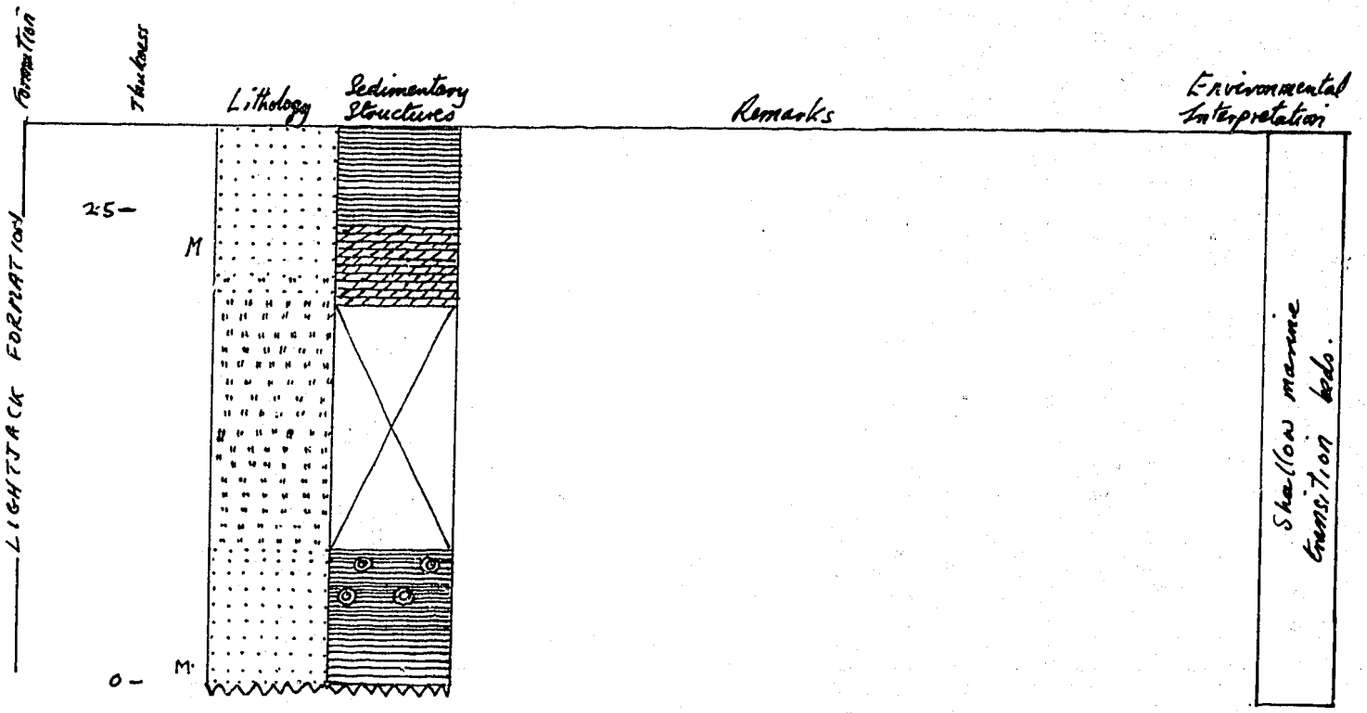
SHORE RANGE

18° 57' 20" S. 125° 01' 07"

Measured



SECTION No. 21 (cont.)



Record 1976/24

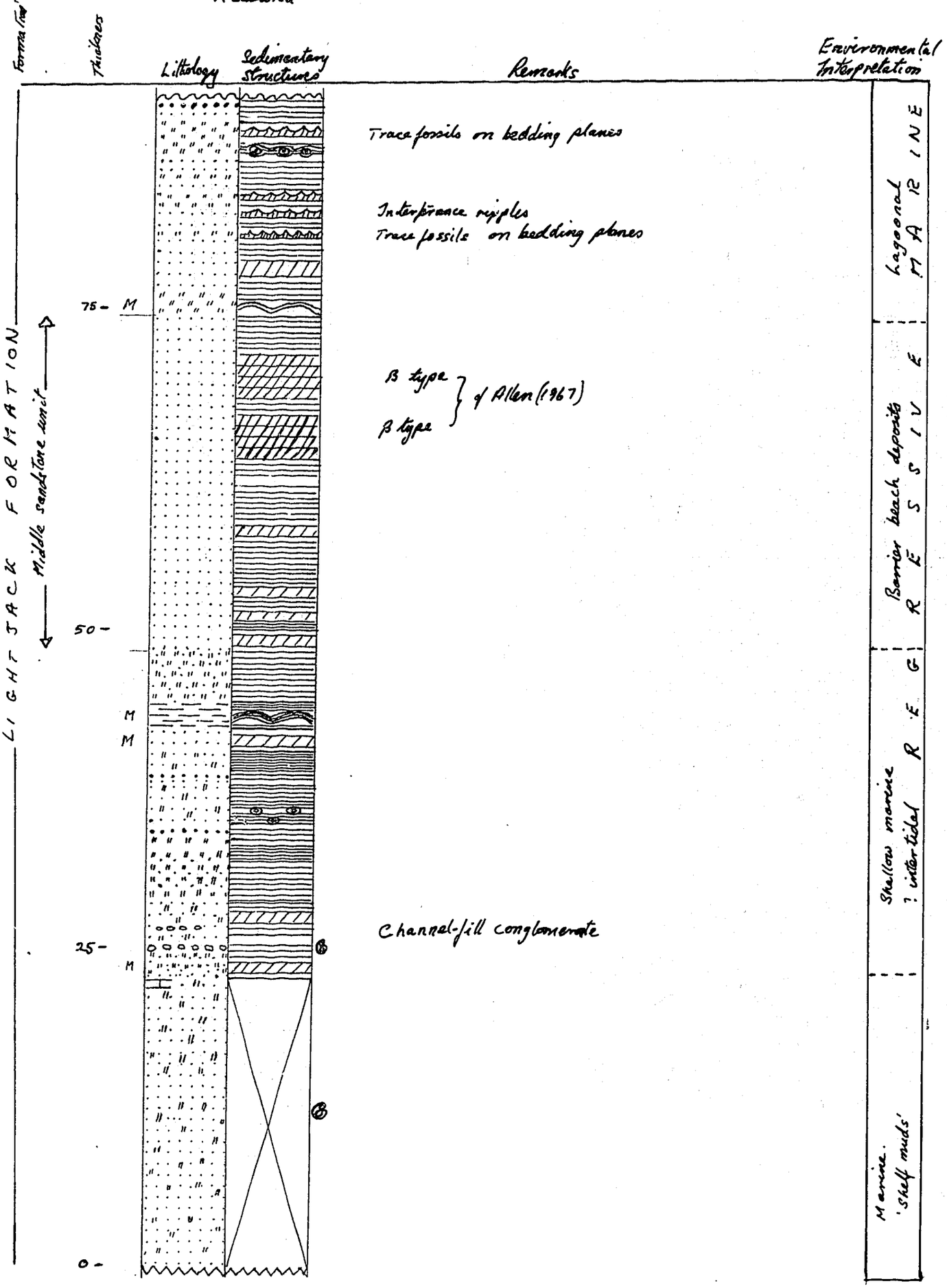
E51/A12/44.

SECTION No. 22

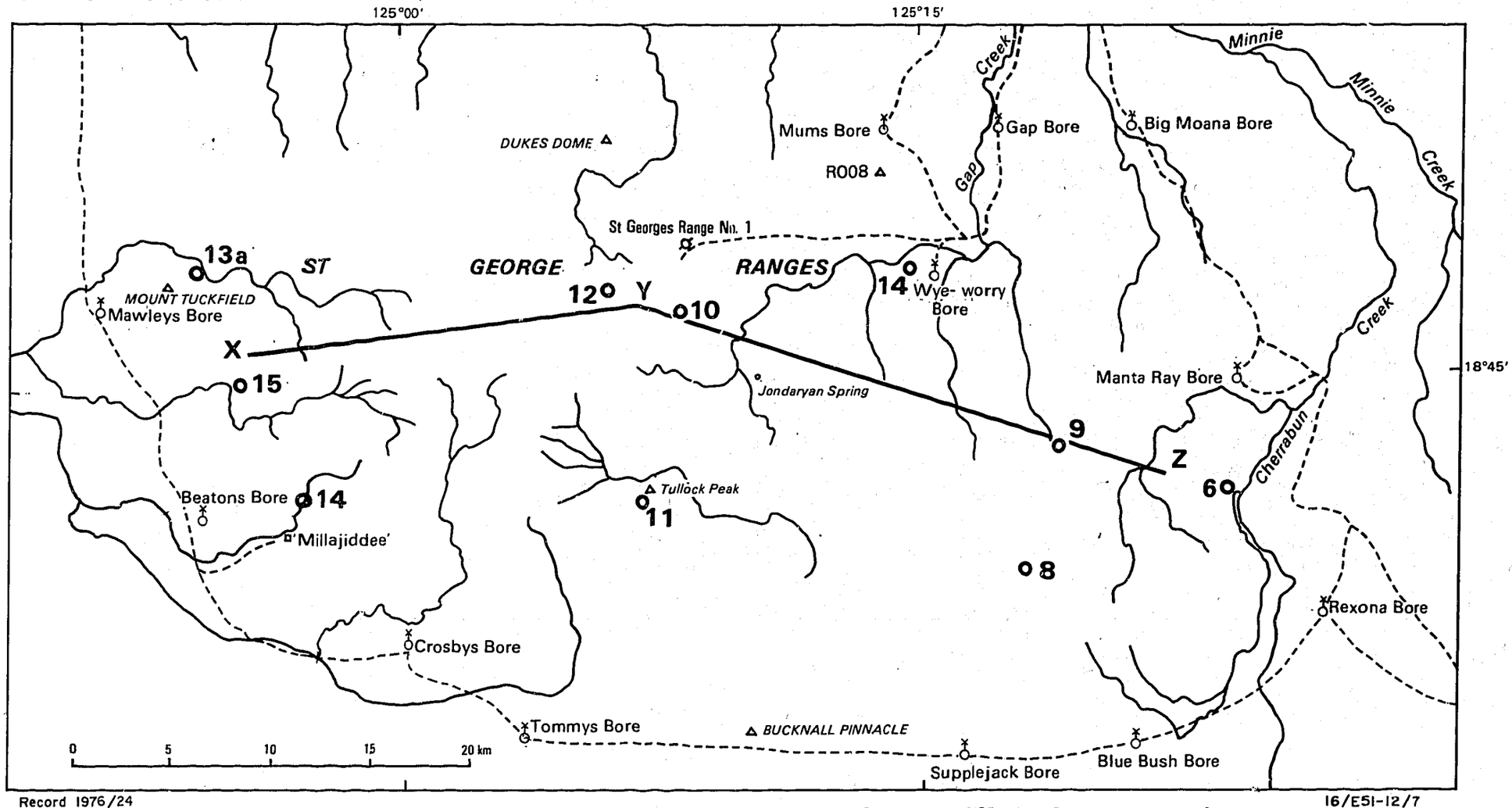
LIGHTJACK HILL

18°59'08"S. 125° 50' 38"E.

Measured

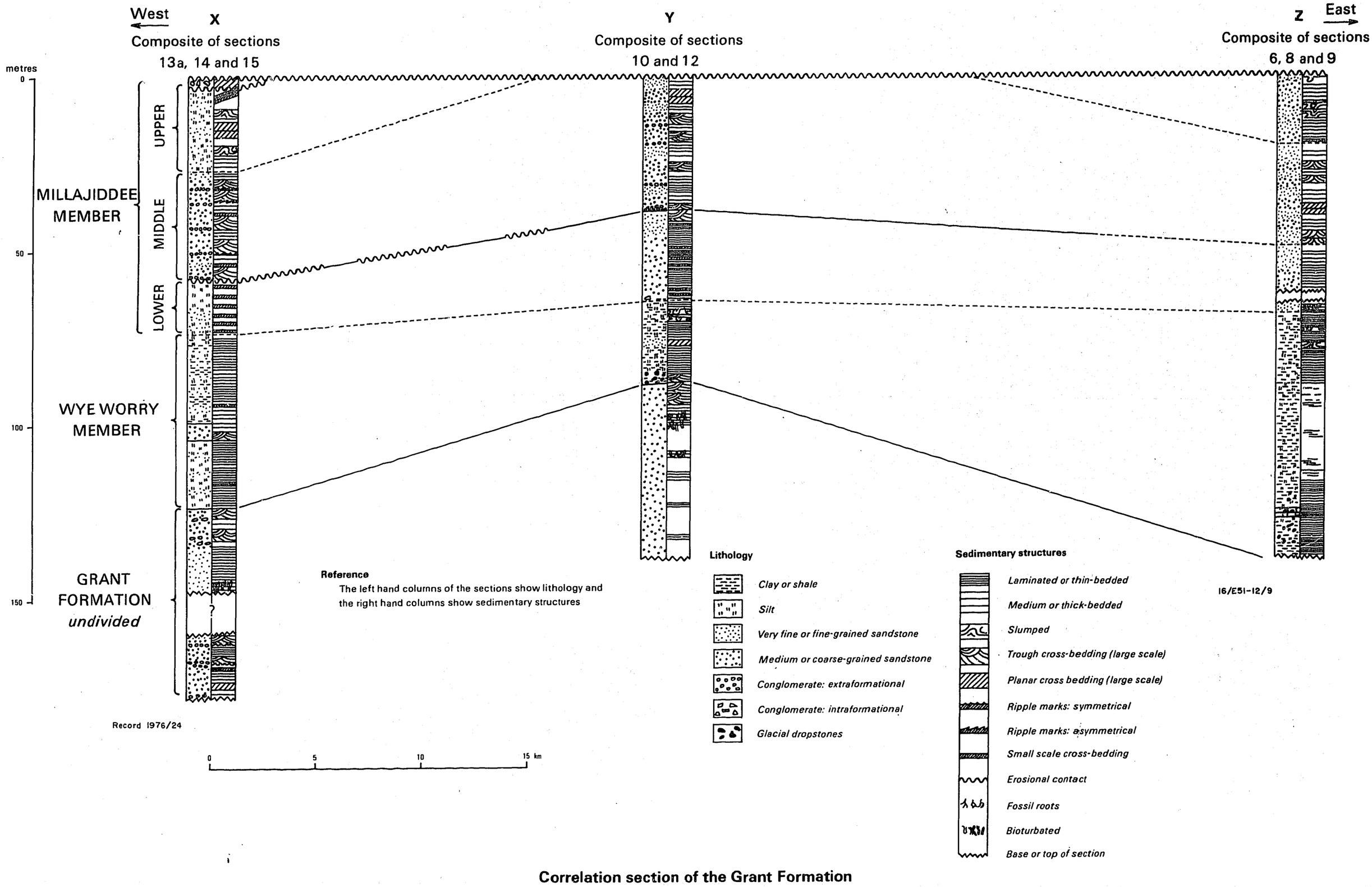


Enclosure No. 1



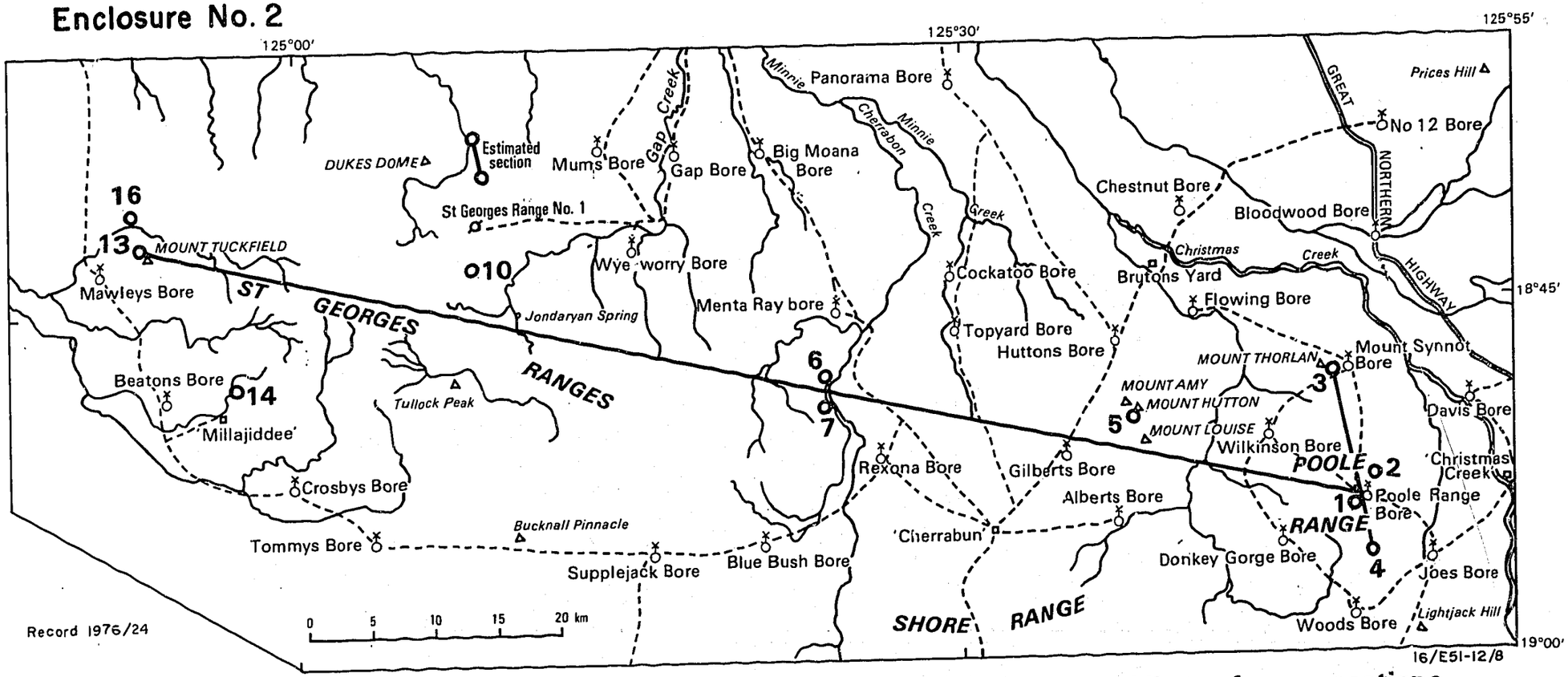
Location sketch: showing position of measured sections and line of cross-section

Enclosure No.1 (cont.)



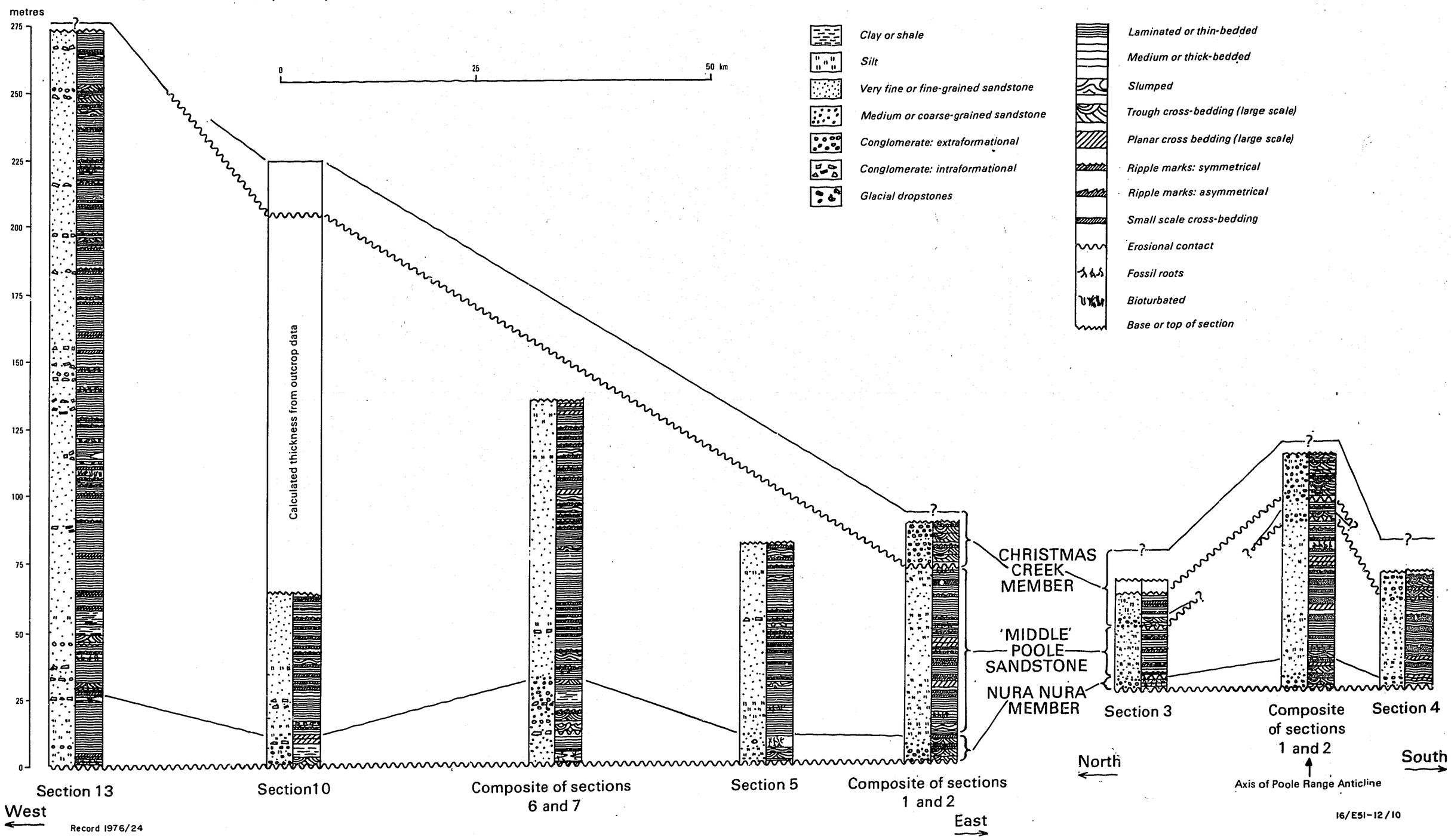
Correlation section of the Grant Formation

Enclosure No. 2



Location sketch: showing positions of measured sections of Poole Sandstone and lines of cross-sections

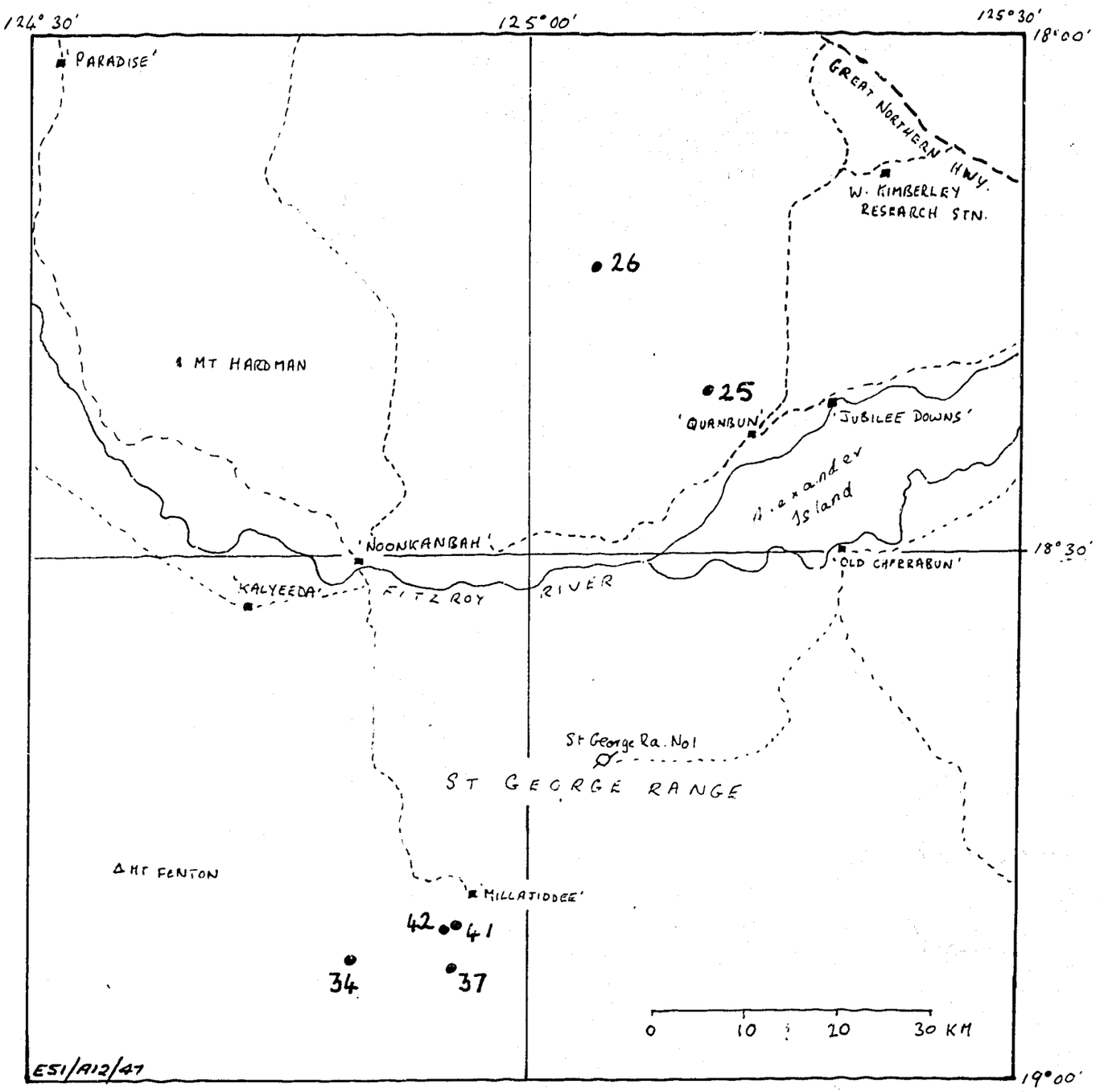
Enclosure No. 2 (cont.)



Record 1976/24

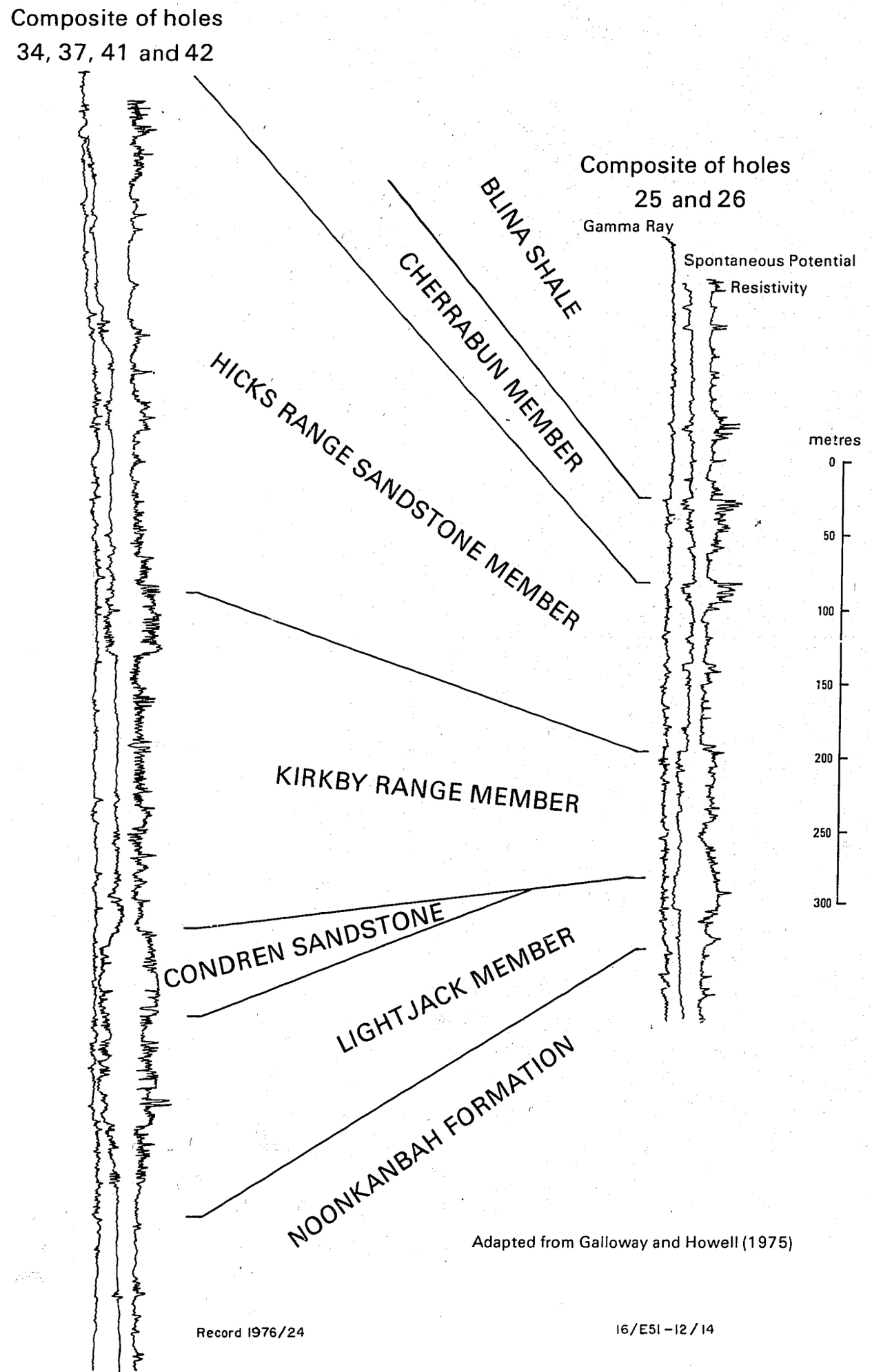
Correlation sections of the Poole Sandstone

ENCLOSURE No. 3



Location sketch showing Esso bore holes from which logs were compiled.

Enclosure No. 3 (cont.)



Adapted from Galloway and Howell (1975)

Record 1976/24

16/E51-12/14

Electric logs of the Liveringa Group

RECORD 1976/95

NOTES ON THE GEOLOGY OF THE SOUTHERN PART OF THE CANNING BASIN

by

R.R. Towner, R.W.A. Crowe*, A.N. Yeates

* Geological Survey of Western Australia

CONTENTS

		Page
	SUMMARY	
1.	INTRODUCTION	1
	Location and access	2
	Development	3
	Climate	3
	Flora	4
	Survey methods	4
2.	PREVIOUS INVESTIGATIONS	5
	Geological	5
	Geophysical	8
	Drilling	15
3.	STRATIGRAPHY	16
	Introduction	16
	Precambrian	17
	Pollock Hills Formation	17
	Mount Webb Adamellite	18
	Heavitree Quartzite	19
	Bitter Springs Formation	20
	Ellis Sandstone	22
	Maurice Formation	24
	Late Proterozoic or Cambrian?	25
	Undivided Palaeozoic	26
	Ordovician	27
	'Lower Formation'	27
	'Middle Formation'	28
	Goldwyer Formation	28
	?Late Ordovician to Early Devonian	29
	Carribuddy Formation	29
	Devonian	31
	Tandalgoo Red Beds	31
	Mellinjerie Limestone	33

	Page
Permian	34
Paterson Formation	34
Grant Formation	39
Poole Sandstone	43
Noonkanbah Formation	45
Triwhite Sandstone	48
Late Triassic? to Early Cretaceous	50
Callawa Formation	51
Cronin Sandstone	53
Cretaceous	55
Anketell Sandstone	55
Samuel Formation	58
Bejah Claystone	61
Undivided Mesozoic	62
Cretaceous to Tertiary	63
Lake George Beds	63
Lampe Beds	64
Cainozoic	66
Calcrete, chalcedony	66
Laterite	66
Lake deposits	67
Alluvium	68
Aeolian sand	68
4. PALAEODRAINAGES	69
5. STRUCTURAL GEOLOGY	71
6. GEOLOGICAL HISTORY	73
7. ECONOMIC GEOLOGY	77
Petroleum	77
Groundwater	78
Coal	82
Evaporites	82
Uranium	82
Constructional materials	82

Page

8. ACKNOWLEDGEMENTS 82

9. REFERENCES 83

APPENDICES 95

APPENDIX A
MEASURED SECTIONS

A1 Southwest Runton
A2 North Runton
A3 Ryan Buttes
A4 Helen Hill
A5 Southeast Paterson Range
A6 Triwhite Hills
A7 West-central Tabletop
A8 West-central Tabletop
A9 East-central Tabletop
A10 Cronin Hills
A11 Southeast Runton
A12 West-central Runton
A13 Kidson Bluff
A14 Southwest Ural
A15 North Runton
A16 Southeast Morris
A17 Dowling Hills
A18 Auger hole, Lake Auld

APPENDIX B
Petroleum Exploration Wells

B1 WAPET Sahara No 1
B2 WAPET Kidson No 1
B3 Aquitaine Wilson Cliffs No 1
B4 Aquitaine Contention Heights No 1

APPENDIX C

Permian fossils from the Tabletop 1:250 000 Sheet area, Western Australia by J.M. Dickins.

APPENDIX D

Early Cretaceous bivalves from Morris and Runton 1:250 000 Sheet areas, southern Canning Basin, Western Australia by S.K. Skwarko.

FIGURES

1. Location and Geological Setting
2. Sites visited during the survey
3. Interpretation of solid geology and diagrammatic relationship between outcropping Phanerozoic rock units.
4. Bouguer anomalies and Gravity Features in the south Canning Basin
5. Relationship between Grant and Paterson Formations
6. Geology of Well 26-27 area (TABLETOP)
7. Relationship of Mesozoic units in the south Canning Basin and north Officer Basin.
8. Palaeodrainages of the south Canning Basin
9. Provisional tectonic map and cross section of the south Canning Basin

PLATES

1. Graded sandstone and siltstone with dropstones
2. Striated pavement
3. Tillite, Paterson Formation
4. Striated boulder, Paterson Formation
5. Sandstone from upper part of Paterson Formation
6. Exposure of fine sandstone and siltstone, Grant Formation

7. Triwhite Sandstone
8. Ripple marks in Triwhite Sandstone
9. Trace fossils in Triwhite Sandstone
10. Massive pisolitic laterite
11. Sand dunes
12. Sand dunes
13. Fossil drainage channels
14. Percival Lakes

TABLES

1. Stratigraphy
2. Summary of petroleum potential for pre-Permian units
3. Condition of water wells along Canning Stock Route (July 1975)

SUMMARY

The semi-desert area within the WILSON, URAL, TABLETOP, SAHARA, PERCIVAL, RUNTON, MORRIS and RYAN 1:250 000 Sheet areas in the south Canning Basin were geologically mapped by the Bureau of Mineral Resources (BMR) and the Geological Survey of Western Australia (GSWA) in 1975. Large tracts of Cainozoic red aeolian sand, laterite, and evaporitic lacustrine sediments separate sparse outcrops of pre-Cainozoic rocks that form scattered low hills, ridges, mesas, buttes and undulating terrain. The latter consist of units of the Canning and Officer Basins, and, in the east, representatives of the basement Arunta Block and the Amadeus Basin.

In the south the Permian rocks that are exposed include glacio-lacustrine, fluvio-glacial and marine sediments (the Paterson and Grant Formations); these are overlain by mainly marine sediments in the north (Poole Sandstone, Noonkanbah Formation and Triwhite Sandstone). Thin Mesozoic sediments underlie virtually the entire area and include the fluvial Callawa Formation and Cronin Sandstone, the brackish-water Anketell Sandstone and its time-equivalent the marine Samuel Formation, and the marine Bejah Claystone. Continental deposition in the Late Cretaceous to Early Tertiary is represented by the fluvial Lampe Beds and the pedogenic Lake George Beds. Stratigraphic units recognized for the first time are described in detail, but subsurface units are only briefly described. Macrofossils collected during the surveys are described by J.M. Dickins and S.K. Skwarko.

1. INTRODUCTION

The information in this report derives from part of a program of regional reconnaissance geological mapping at a scale of 1:250 000 being carried out jointly by the Bureau of Mineral Resources and the Geological Survey of Western Australia, that is designed to map all the Phanerozoic rocks of the Canning Basin. The program began in 1972 and the following sheet areas have been mapped and reports written: Billiluna, Stansmore, Lucas, Webb, Mount Bannerman, Cornish, Helena, Crossland, Dummer (Yeates et al., 1975) and Noonkanbah (Crowe & Towner, 1976).

This report describes the Phanerozoic rocks mapped in 1975 in the Wilson, Ryan, Percival, Ural, Morris, Sahara, Tabletop, Runton and Rudall Sheet areas (designated in capital lettering throughout the text) and the Precambrian in the Wilson and Ryan Sheet areas. The adjoining rocks of the Pilbara Block were mapped by the Geological Survey of Western Australia (Williams et al., 1976). Explanatory Notes which briefly describe the geology of each 1:250 000 Sheet area are being published.

The mapping was carried out by A.N. Yeates, R.R. Towner (BMR) and R.W.A. Crowe (GSWA). M.J. Jackson (BMR) joined the party for three weeks as he had previously mapped adjacent areas to the south, and J.M. Dickins (BMR) spent two weeks collecting Permian faunas.

The exposed Phanerozoic rocks are described according to the classification of Gilbert (1958), and the outcropping Precambrian rock units are described as either sandstone or siltstone and are qualified by the usage of the terms quartzose, feldspathic and so on according to the classification of Pettijohn (1957). Grainsize is classified on the Wentworth scale, and the terms used for bedding thickness are those of Ingram (1954). The subsurface units are described according to the terms used in exploration company reports.

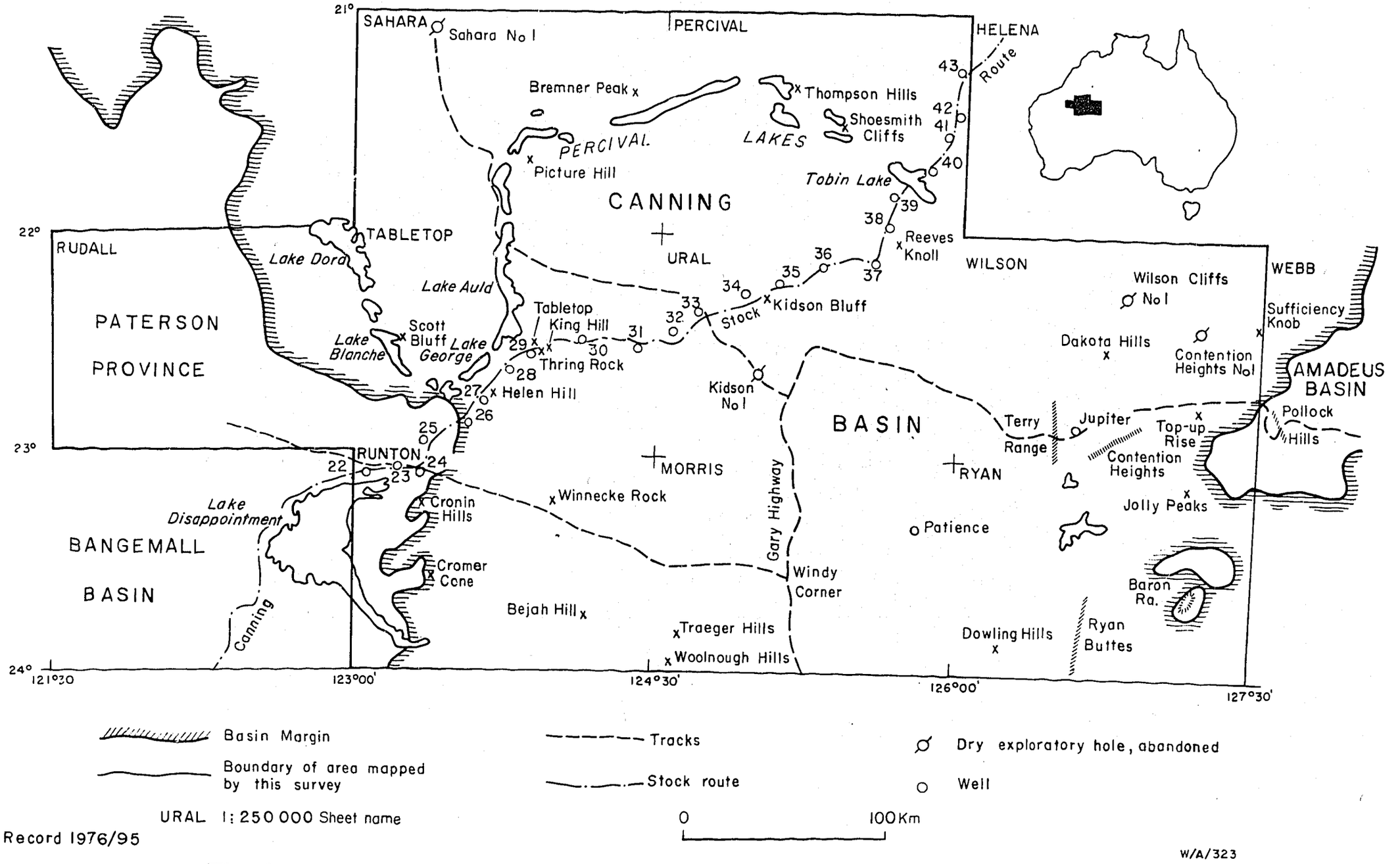
Location and access

The area lies in Western Australia between latitudes 21° and 24°S and longitudes 121°30' and 127°30' (Fig. 1).

Geologically the area is bounded in the west by the Precambrian sedimentary, metamorphic and igneous rocks of the Bangemall Basin and Paterson Province (Williams et al., 1976; Playford et al., 1975). To the east lie Archaean metamorphic and volcanic rocks of the Arunta Block (Blake, in press) and the Proterozoic-Phanerozoic sedimentary rocks of the Amadeus Basin (Wells et al., 1970).

Within the survey area, sedimentary rocks of both the Canning Basin (Forman et al., 1973) and Officer Basin (Lowry et al., 1972; Jackson & van de Graaff, in prep.) occur. An area of elevated basement, corresponding to the Warri Gravity Ridge, has been chosen as a convenient boundary between the two basins (Lowry et al., 1972; Playford et al., 1975). Consequently, most of RUNTON and the southwest portion of MORRIS lie within the Officer Basin, and the rest of the area in the Canning Basin.

Access to the area from the northwest is by a gravel road which branches southeast from the Great Northern Highway 230 km north of Port Hedland. This road runs southeast for 738 km across SAHARA, and TABLETOP to the site of WAPET Kidson No. 1 petroleum exploratory well (now abandoned) on URAL. Access from the south can be gained via the "Gary Highway" which branches off the "Gunbarrel Highway" about 9 km west of Mount Everard and joins the northwestern track near WAPET Kidson No. 1 well site. A poorly defined track branches off the "Gary Highway" on MORRIS and leads west to the Lake Disappointment area and onto the Great Northern Highway. Another track runs east from near WAPET Kidson No. 1 across URAL and WILSON to Papunya Native Settlement in the Northern Territory, where it joins a maintained gravel road which connects to Alice Springs. The now abandoned Canning



Record 1976/95

W/A/323

Fig 1 LOCATION AND GEOLOGICAL SETTING

Stock Route, which joins Wiluna to Halls Creek, crosses the area from northeast to southwest. The tracks are unmaintained, and are suitable only for 4-wheel-drive vehicles.

Some access to other parts of the area away from these tracks is facilitated by graded seismic lines which have become overgrown through disuse. To supply seismic and drilling parties within the area, several airstrips were made during 1964-66. Although these are also unmaintained, the airstrip 8 km southeast of WAPET Kidson No. 1 was still in fairly good order in 1975 and was used to position fuel and supplies for the mapping party.

There are no permanent settlements in the area and the nearest supply points are Giles Meteorological Station and Warburton Mission (about 450 km to the southeast), Alice Springs (over 950 km to the east), Balgo Mission, (about 350 km to the northeast), and Port Hedland (750 km to the west).

Development

The land is undeveloped except for a few water bores which have provided water for drilling companies that have operated in the area. In 1975 most of the water bores were caved-in except for one drilled by Geophysical Services International in 1973, 16 km north of WAPET Sahara No. 1 well. The water was potable and was used by the field party throughout the season. Several water wells along the Canning Stock Route were visited, but most were either caved in or polluted by dead animals.

Climate

The area has a desert climate with an annual rainfall of 200-300 mm, most of which falls from December to March with sporadic falls during the winter months. The average annual evaporation is 2750-3000 mm. The days are hot and the nights cool. In January, the average daily minimum and maximum temperatures are about 22°C and 38°C respectively; and in July, 5°C

and 22°C respectively (Australia, Bureau of Census and Statistics, 1970). The average frost-free period for the area is 300 days.

Flora

Most of the area is covered by hummock grassland in which the grass plants are organized into dense rounded clumps of the genera Triodia and Plectrachne, with irregularly scattered eucalypt trees and Acacia shrubs. Communities of small-stemmed succulent shrubs (samphire) or leaf-succulents (salt-bushes) are associated with lake beds and depressions. Groves of desert oaks (Casuarina decaisneana) are present in the Jupiter Well area (WILSON) and on western RYAN.

The area lies within the Eremaean Province and Desert Formation as defined by Gardener (1942) and shown on his Vegetation Formation Maps of Western Australia. More recently, Beard (1969) in a synoptic treatment of the desert areas of Western Australia has suggested a revision of the botanical districts of the Eremaea. Within the Eremaean Province, he recognized four botanical districts: the Carnegie and Canning Botanical Districts which occupy most of the area, and minor portions of the Mueller Botanical District (on WILSON) and Keartland Botanical District (in the southwest) (Beard & Webb, 1974).

Survey methods

The area was mapped using a helicopter, as ground access is impractical due to numerous longitudinal sand dunes. The base camp was established near WAPET Kidson No. 1 airstrip, as fuel for the helicopter, fixed-wing aircraft and motor vehicles was delivered by air.

Field work was planned using vertical airphotos to assist in the location of, and navigation between, the sparse outcrops. All airphotos used were at a scale of 1:80 000 (taken in 1973) except those of SAHARA and PERCIVAL which were at a scale of 1:50 000 (taken in 1953).

The 1:250 000 topographical maps of the Sheet areas, which show nearly all of the sand dunes and most other topographical features, were used for general navigation.

Observation sites were recorded on the airphotos their density is shown in Figure 2. Geological data were plotted on either the photographs or transparent overlays, and were later transposed to planimetric sheets reduced from 1:50 000 scale. The compilation sheets were photographically reduced to 1:250 000 scale and redrawn by a draftsman. Preliminary editions of these geological sheets will be available from the Bureau of Mineral Resources (Canberra) and the Geological Survey of Western Australia (Perth).

Marine macrofossils collected during the survey were studied by Dickins (Appendix C) and Skwarko (Appendix D).

During the survey, new units were recognized in the area for the first time, and the distribution of most of the others was considerably modified. A solid geology map of the area (Fig. 3) shows the distribution of the various units. This map differs substantially from the map of Veevers & Wells (1961).

2. PREVIOUS INVESTIGATIONS

Geological

Although many members of exploration and prospecting expeditions have described outcrops within the area, until 1954 no systematic attempt had been made to map the units and determine their succession.

Colonel Warburton (1875) was first to cross the desert, to which he gave the name Great Sandy Desert, to the north of the area. The first crossing from south to north was by L.A. Wells (1902) who travelled from Wiluna to the Fitzroy River,

passing by Separation Well (RUNTON) and Joanna Spring in 1896. In the following year Rudall journeyed near the salt lakes on TABLETOP and over a large part of SAHARA, while trying to locate the lost members of the Wells expedition (Feeken, et al., 1970).

The first crossing in the western part of the area was by Carnegie (1898) who crossed MORRIS and WILSON naming various rock holes and wells on his journey from Kalgoorlie via Godfrey Tank to Halls Creek in 1897.

In 1906-07, in order to help in the movement of cattle from the Kimberleys to Wiluna, Canning surveyed the stock route which now bears his name. Water wells along this stock route were made mainly by the deepening of native wells during Canning's well-sinking trip begun in 1908. A geologist, H.W.B. Talbot, who accompanied Canning for much of the latter journey, published an account of his geological observations and made an excellent assessment of the groundwater resources along the route (Talbot, 1910). Drovers began moving cattle along the Stock Route in 1911. Kidson (1921) recorded magnetic observations along the Stock Route in 1914.

L.J. Jones investigated the geology and water resources of the area. He made the first assessment of the petroleum potential of the area for Locke Oil Development Syndicate and Kimberley Petroleum Company. He also discovered Permian fossils northeast of Well 27 on TABLETOP (Jones, 1922).

The western margin of the Canning Basin in the area covered by this report was investigated geologically by T. Blatchford (1924).

One traverse by D.F. McKay during an aerial survey of the Canning Basin crossed over TABLETOP (McKay, 1934).

In 1940 and 1941, C. St J. Bremner flew over the southern part of the area as part of an aerial geological reconnaissance of the "Fitzroy Basin" by Caltex (Australia) Oil

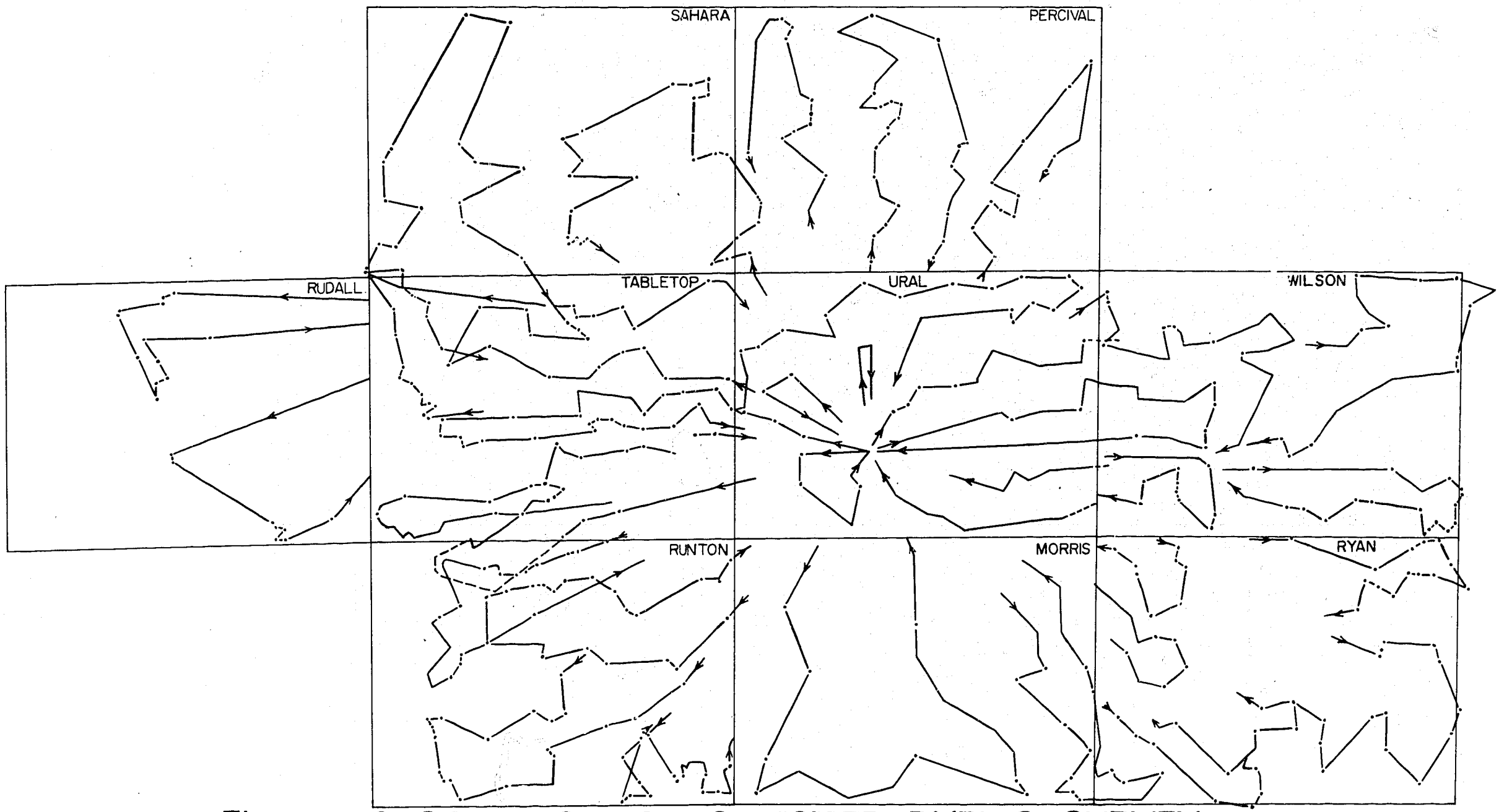
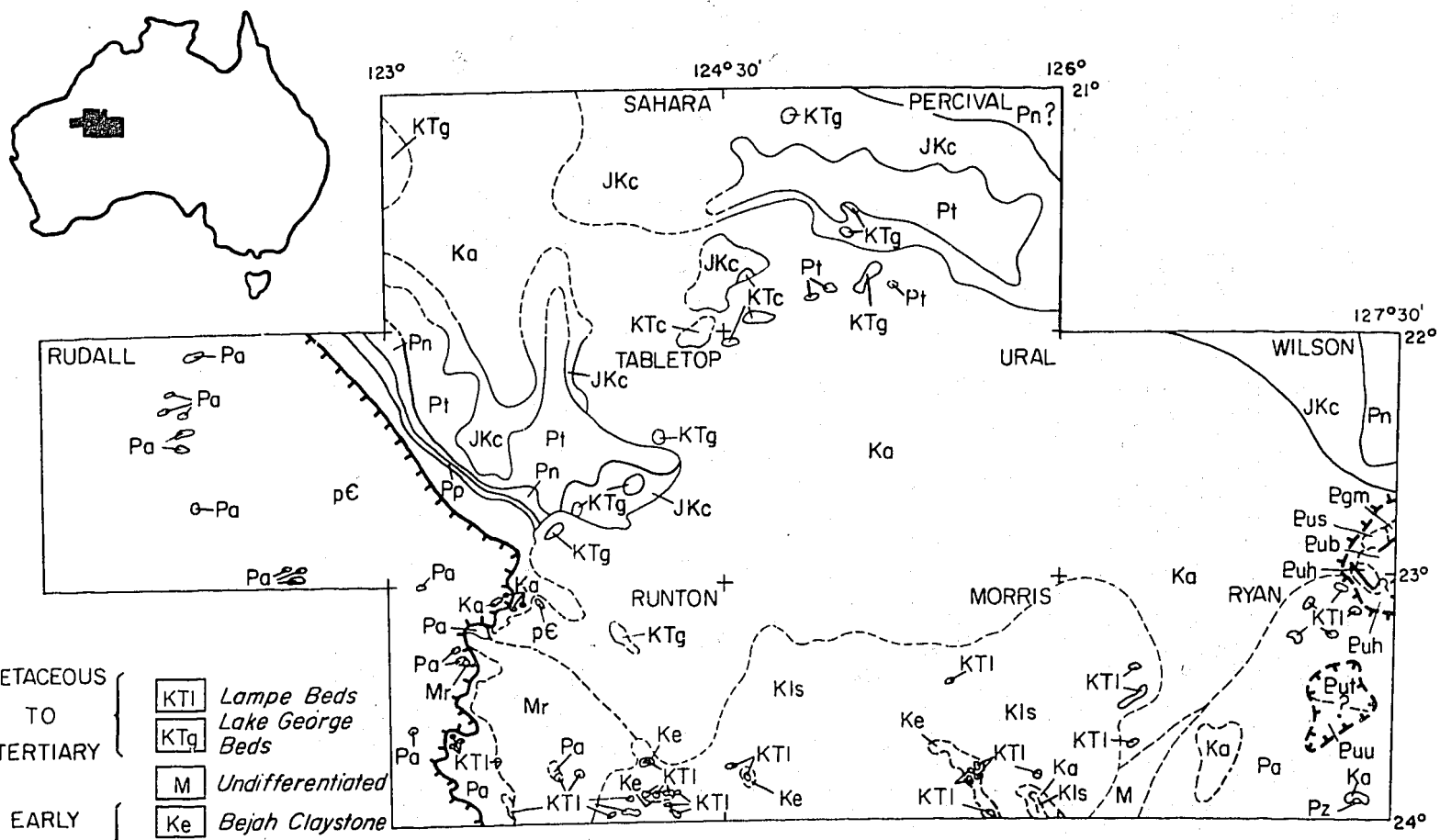
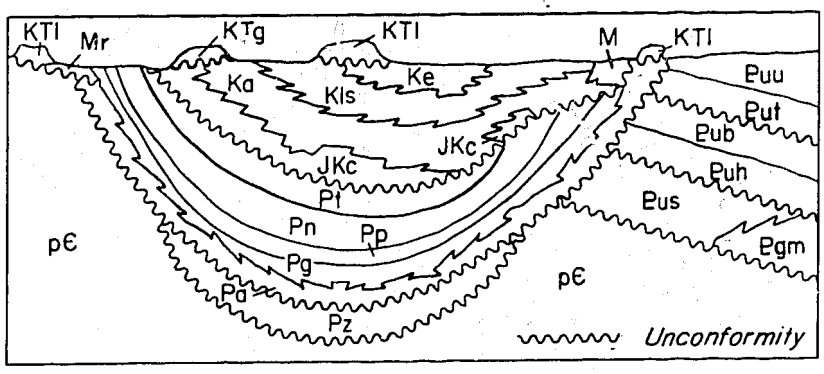


Fig 2 OBSERVATION SITES VISITED DURING SURVEY





? CRETACEOUS TO TERTIARY
- KTl — *Lampe Beds*
- KTg — *Lake George Beds*

MESOZOIC
- M — *Undifferentiated*

EARLY CRETACEOUS
- Ke — *Bejah Claystone*
- Kls — *Samuel Formation*

? CRETACEOUS
- Ka — *Anketell Formation*

JURASSIC OR CRETACEOUS
- JKc — *Callawa Formation*

L. TRIASSIC OR JURASSIC
- Mr — *Cronin Sandstone*

PALAEOZOIC

PERMIAN
- Pt — *Triwhite Sandstone*
- Pn — *Noonkanbah Formation*
- Pp — *Poole Sandstone*
- Pg — *Grant Formation*
- Pa — *Paterson Formation*

- Pz — *Undifferentiated*

Adelaidean
- Puu — *Maurice Formation*
- Put — *Ellis Sandstone*
- Pub — *Bitters Spring Formation*
- Puh — *Heavitree Quartzite*

Carpentarian
- Pgm — *Mount Webb Adamellite*
- Pus — *Pollocks Hill Formation*

PRECAMBRIAN
- pЄ — *Undifferentiated*

URAL — 1 : 250000 sheet area

W/A/324

Fig.3 Interpretation of solid geology and diagrammatic relationship between the outcropping Phanerozoic rock units in the southern part of the Canning Basin, Western Australia

Development Pty Ltd; he established that the Devonian limestone in the northern part of the basin does not crop out in the south. He photographed the Percival Lakes, and noted low rises of "sandstone and shale" in PERCIVAL and SAHARA. (Bremner, 1940, 1942).

Using aerial and ground surveys and a reassessment of previous surveys, F. Reeves described the geology and petroleum potential of the Canning Basin (Reeves, 1949). He found Permian fossils at Lake Blanche and near Well 26 on TABLETOP.

Using airphotos flown in 1953, Traves, Casey & Wells (1956) mapped the outcrops and erected a stratigraphy for the area along the southwestern margin of the Canning Basin. In 1957, J.J. Veevers (BMR) during a regional helicopter survey in the central part of the Canning Basin made geological observations and took gravity readings on WILSON, RYAN, URAL and TABLETOP (Veevers, 1957).

In 1956, Stinear, Wells (geologists) and Waterlander (geophysicist) of BMR mapped the southern part of the Canning Basin adjoining the Officer Basin and collected fossils from several localities (Veevers & Wells, 1961). From the results of this and other BMR surveys such as those of Guppy et al. (1952, 1958) and Casey & Wells (1964) outside the area, Veevers & Wells (1961) published an account on the geology of the entire Canning Basin with an accompanying geological map at a scale of 1 inch to 20 miles.

Other reports which refer to the area (McWhae et al., 1958; Playford et al., 1975) are based on compilations of previous work.

Geological reconnaissances were made by companies including West Australian Petroleum Pty Ltd (WAPET), Australian Aquitaine Petroleum Pty Ltd (Aquitaine), Alliance Petroleum (Alliance), and Union Oil Development Corporation (Union Oil); most of their information is unpublished. Parts of the area

(RUNTON and RYAN) were examined during geological survey of the Gibson Desert by Leslie (1961) for Frome Broken Hill Company Pty Ltd.

A.T. Wells (1963) visited localities in southern RYAN during his mapping of the Gibson Desert.

In 1965, during reconnaissance geological survey by Union Oil to evaluate the petroleum potential of the Gibson Desert, geological observations were carried out on RUNTON and RYAN (Mack & Herrmann, 1965).

The configuration of the laterite surface in the eastern part of the area was contoured photogrammetrically at 25-foot vertical intervals by Aquitaine. The results of this method of mapping, described by Creevey (1971), show that most of the geomorphological surface "anomalies" can be correlated with seismically defined subsurface structures.

The petrology of the halite-bearing Palaeozoic Carribuddy Formation was described by Glover (1973) who indicated a diagenetic origin for its red pigment.

Evans & Brown (1974) visited localities in northern WILSON and URAL including Redknap Mound and Kidson Bluff.

During the 1970s adjacent areas have been mapped by geological parties from BMR and GSWA; to the south the Officer Basin (Lowry et al., 1972; Jackson & van de Graaff, in prep.); in the northeast Canning Basin (Yeates et al., 1975); to the east the Webb Sheet area (Blake & Towner, 1974). During the 1975 survey, a crater thought to be of meteoritic origin, was located for the first time (Yeates et al., 1976).

Geophysical

The earliest geophysical investigations of the area were reconnaissance aeromagnetic and gravity surveys carried out by BMR.

In 1954, BMR flew an essentially reconnaissance aeromagnetic survey with ten widely spaced flight-lines over the northern part of the Canning Basin. Only two of these flight-lines reached into the area of this report - one onto WILSON, the other onto PERCIVAL (Quilty, 1960).

Gravity investigations were commenced in the Canning Basin by BMR in 1952, and by 1960 most of the basin had been covered (Flavelle & Goodspeed, 1962). However, the density of the gravity stations varies greatly owing to the remoteness of some areas; the stations were in general located near rock outcrops. Numerous gravity features were delineated, including an extensive gravity low called the "South Canning Regional Gravity Low" (Fig. 4).

In 1962, during a reconnaissance gravity survey by BMR, a single gravity traverse - flight B - was flown in a northeasterly direction across MORRIS and RYAN and thence eastwards across south WILSON to investigate the gravity low found by Flavelle & Goodspeed (1962). The results of this traverse suggested that the gravity low is divided by an east-trending gravity ridge in northern RYAN; the gravity low to the north was named the South Canning Regional Gravity Low and that to the south the Cobb Regional Gravity Low (Lonsdale & Flavelle, 1968).

Subsurface company investigations did not commence in the area until after the introduction of the Commonwealth Petroleum Search Subsidy Act in 1959 when subsidy became available for 50% of acceptable costs of approved geophysical operations and stratigraphic drilling. Before the cessation of the Commonwealth Petroleum Search Subsidy Act 1959-1969, in June 1974, - fifteen subsidized geophysical operations were carried out and four subsidized wells were drilled.

The first subsidized survey in the area was part of the South Canning Basin Aeromagnetic Survey and was flown in 1962-63 by Aero Services Limited for West Australian Petroleum Pty Ltd

(WAPET, 1966a). The survey was a regional reconnaissance airborne magnetometer survey covering all Sheet areas except RYAN. The objective of the survey was to delineate the depth and configuration of the South Canning Basin and to reveal other major structural features. The existence of the Kidson Sub-basin, a northwest-trending basin with a maximum thickness of between 9000 m and 10 500 m of sedimentary rocks, was confirmed by the survey.

WAPET drilled three shallow stratigraphic holes in the northwest of the area to examine the near-surface stratigraphy and to establish a water supply (WAPET, 1964) and then carried out a number of gravity and seismic surveys during 1963-64:

1. WAPET Sahara Reconnaissance Gravity Survey was carried out by helicopter in 1963 with the object of providing regional structural information to help in the geological interpretation of the area and to guide the planning of more detailed geophysical work. The results of the survey showed a gravity minimum trending northwest through the middle part of SAHARA (Fig. 4). The gravity values along this minimum have been interpreted as representing basement depths of approximately 4500 m below sea level in the northwest and more than 7500 m in the southeast. Many local residual gravity maxima were mapped, some of which may represent sedimentary structures at depth (WAPET, 1963a).

2. The Sahara Seismic Reconnaissance Survey was conducted to investigate the configuration and structure of the north-western part of the Kidson Sub-basin and to locate a favourable well site. Three subsurface horizons were mapped and several broad anticlinal features were located (WAPET, 1963b). This survey led to the drilling of WAPET Sahara No. 1 (WAPET, 1966b).

3. The Joanna Springs Gravity Survey was carried out in an area interpreted from aeromagnetic data as the "Joanna Springs Sub-basin" located on SAHARA and JOANNA SPRINGS. The survey was the northern continuation of the Sahara Gravity Survey, and its objective was to extend the regional gravity coverage over the

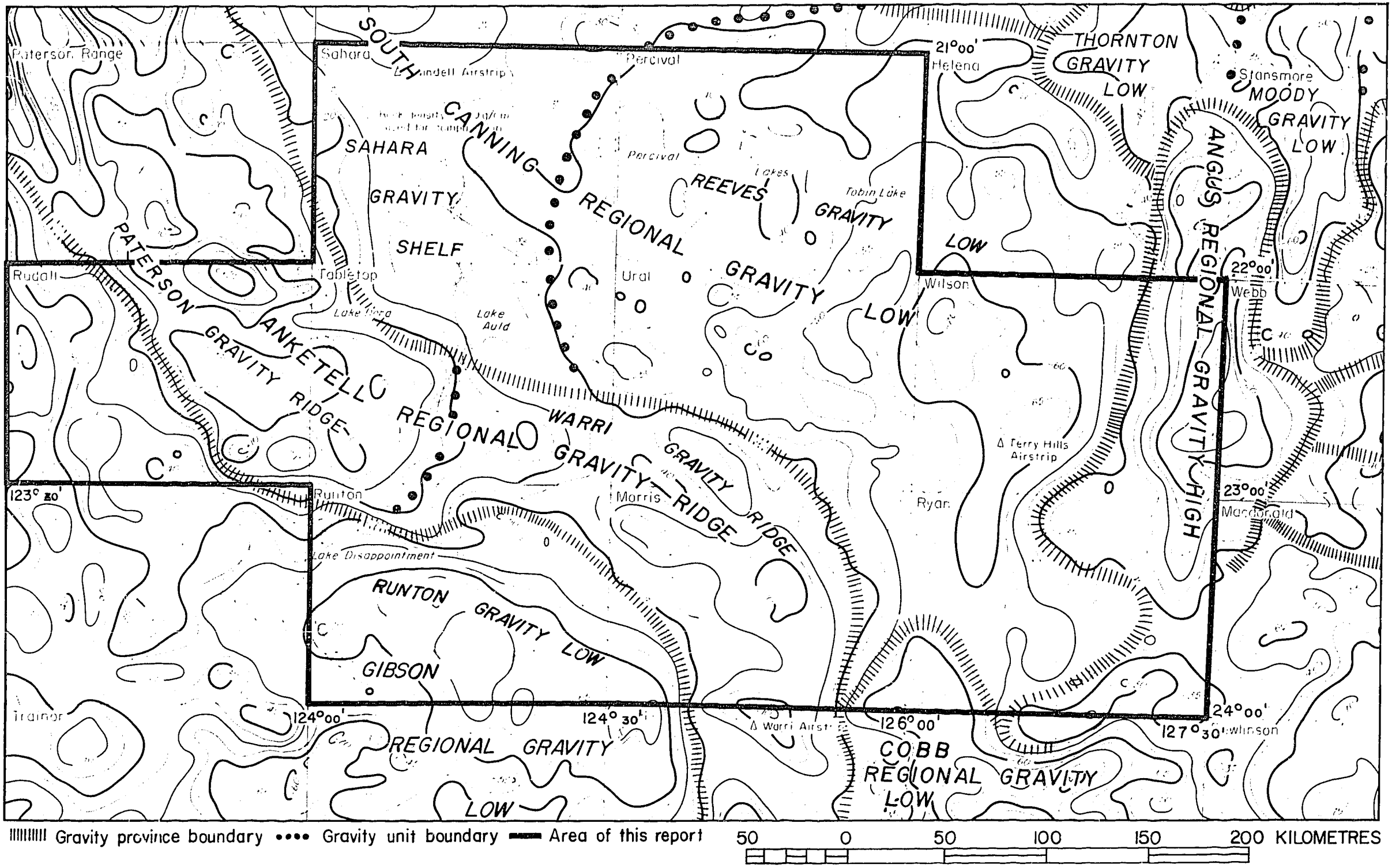


Fig 4 BOUGUER ANOMALIES AND GRAVITY FEATURES (from Darby & FRASER 1969)

Joanna Springs Sub-basin in the hope of finding gravity anomalies attributable to sedimentary structures. The dominant features observed in the results were: a large east-west positive gravity trend across northern JOANNA SPRINGS attributed to changes within the basement rocks; a broad gentle northwest negative trend which marks the axis of the Kidson Sub-basin, diagonally across the centre of SAHARA; and an east-west gravity positive at the junction of SAHARA and JOANNA SPRINGS which correlates roughly with some magnetic features as well as having expression in the sedimentary section (WAPET, 1963c).

In 1965, Aero Services Ltd conducted an aeromagnetic survey in the western part of the area for Aquitaine, involving parts of RYAN and WILSON. The purpose was to map the magnetic basement and to indicate the volume of potentially productive sediments in the area (AAP, 1965). Interpretation of the results indicate a deep trough in central WILSON and northern RYAN (the Kidson Sub-basin).

During mid-1965, Wongela Geophysical Pty Ltd conducted an aerial reconnaissance gravity for WAPET involving URAL, MORRIS and WILSON. The survey was carried out to determine the regional structure of the area and in particular to investigate structure in relation to a large gravity high feature with flanking gravity lows suggested as a result of a few gravity readings in the area by previous surveys (Flavelle & Goodspeed, 1962; Lonsdale & Flavelle, 1968). The results delineated an elongate sedimentary trough trending northwest and deepening to the east, which contains up to 4000 m of sediments. Southwest of this feature the sedimentary section thins towards a northwest-trending basement ridge. Numerous local gravity features were recognized but due to the lack of subsurface structural information the significance of these features was difficult to assess (WAPET, 1965a).

In the same year, the Southeast Kidson Seismograph Survey was carried out by WAPET in URAL. Data was generally good to fair, serving to define the possible axes of the Kidson Sub-basin and the structural and tectonic alignment which appears to be northwest. Several small anticlinal features were also delineated (WAPET, 1965b).

In 1967, a reconnaissance reflection/refraction seismic survey was carried out by Ray Geophysics Pty Ltd for French Petroleum (Australia) Pty Ltd with the purpose of establishing drill sites to help in the initial evaluation of the prospect (French Petroleum, 1967). Only a very minor portion of the survey occurred within the area of this report in far north SAHARA; most of it occurred in JOANNA SPRINGS and MCLARTY HILLS to the north, where two favourable geological structures were located.

In 1967, Compagnie Generale de Geophysique carried out a series of geophysical surveys on behalf of Aquitaine involving both WILSON and RYAN. The first of these, the Dakota Seismic and Gravity Survey (AAP, 1968) employed both reflection and refraction methods. The broad features of the Kidson Sub-basin in the area were delineated. Depth to basement was shown to decrease gently to the east, and the eastern limit of the basin was postulated to be palaeogeographic rather than tectonic.

The second Aquitaine survey, the Ryan Seismic and Gravity Survey (AAP, 1969a) was aimed to establish the shape and depth of the eastern end of the Kidson Sub-basin. The reflection and refraction results showed a thick geological section thinning towards the eastern edge of the basin, and in general confirmed and better defined the results obtained in the first survey. Simultaneously with this survey, Aquitaine carried out the first subsidized magnetotelluric survey in Australia - the Terry Range Magnetotelluric Survey (AAP, 1969b). The method professes to show sedimentary layers of different conductivity or resistivity properties, and the instruments measure the relative amplitude

of the telluric current and the magnetic fields inducing them within a broad frequency range. The results of this survey confirmed in general terms the shape of the eastern part of the Kidson Sub-basin.

The third Aquitaine survey, the Contention Heights Seismic Refraction and Gravity Survey, was carried out in 1969 with the objective of mapping the eastern edge of southeast Kidson Sub-basin and the delineation of any structures. The results were generally good with four reflection markers being recorded, one in Upper Proterozoic 'basement', one in the Ordovician, and two within the Devonian (top of the Carribuddy Formation, and top of the Mellinjerie Limestone). The 'Ordovician' marker pinches out eastwards against the basement and is overlapped by the 'Carribuddy' marker (AAP, 1969d).

To the south of this survey, the fourth Aquitaine survey was carried out - the Baron Range Seismic and Gravity Survey (AAP, 1969e). Its objectives were to map the eastern border of the southeastern Kidson Sub-basin, to correlate refractors with those in Aquitaine's Wilson Cliffs No. 1 well (WILSON), to delineate the geographic extent of Palaeozoic sediments, and to investigate the possibilities of pinch out. The seismic quality was good enough to show that basement rises to the east, that the Ordovician thins eastwards, and that the Carribuddy Formation totally covers the Ordovician and overlaps the limit of the pinch-out.

In 1968, under contract to BMR, Wongela Geophysical Pty Ltd completed a systematic helicopter gravity reconnaissance survey covering the southeastern part of the Canning Basin, thus permitting full delineation to be made of gravity features which were only partly defined from previous work. The results of this survey are given in Darby & Fraser (1969) and the gravity features delineated are shown in Figure 4.

During 1970, the Tabletop Seismic Survey involving TABLETOP, SAHARA and URAL investigated the structure of the

southern flank of the Kidson Sub-basin and the adjoining 'Tabletop Shelf' (WAPET, 1970a). Four horizons were mapped, within or near the top of the following formations: the Grant Formation, Tandalgoo Red Beds, Carribuddy Formation and Thangoo Limestone. Structures were defined in the vicinity of both WAPET Sahara No. 1 and WAPET Kidson No. 1 wells.

During 1971, three seismic surveys were carried out in and near the area. The first, the Lake Auld Seismic Survey, investigated the southern flank of the Kidson Sub-basin and the adjoining 'Tabletop Shelf'. Three horizons were mapped: the Tandalgoo Red Beds, the Carribuddy Formation, and the top of the Thangoo Limestone. The survey provided definition of the southwest flank of the Kidson Sub-basin and confirmed faulting indicated by gravity and aeromagnetic data (WAPET, 1971a).

The other two surveys, the Helena Seismic Survey (WAPET, 1970b) and the Crossland Platform Seismic Survey (WAPET, 1971b), were carried out mainly in the Sheet areas north of the area but involved parts of PERCIVAL and WILSON. The former survey produced generally poor-quality data with only two horizons mapped. The results of the latter survey allowed better definitions of the Crossland Platform. Three horizons were mapped.

In 1972, the Hickey Hills Seismic Survey (AAP, 1972) was carried out in the eastern part of the area. Data quality was fair and two traverses, one trending north and one northwest, demonstrated the northerly thickening of sediments into the Kidson Sub-basin by a series of terraces which are bounded by northwest-trending faults. Three unidentified horizons were mapped. Additional seismic work and some stratigraphic drilling were recommended.

In 1974, a report on the study of all the available gravity information in the Canning Basin, relating it to known geology including published information from surface surveys and boreholes logging up to the end of 1962, was released (Flavelle, 1974).

The results obtained from a comprehensive reconnaissance and detailed surface geological mapping program as well as reflection seismic survey utilizing the 'Vibroseis' technique carried out mainly to the northeast of the area are presented in a paper by Drew & Evans (1975).

Drilling

To help in the determination of the age and nature of the stratigraphic column and to evaluate the hydrocarbon potential of Permian and other sediments within the Kidson Sub-basin, four petroleum exploration wells were drilled, two by WAPET and two by Aquitaine.

WAPET Sahara No. 1 (Lat 21°04'40"S, Long 123°13'30"E) was designed to test the unknown stratigraphy of the western Kidson Sub-basin. The well penetrated Mesozoic, Permian and Devonian sediments before being abandoned at 2120.2 m in undated evaporites (WAPET, 1966b). The pre-Permian sequence had not been encountered elsewhere and three new formations were defined by Koop (1966a). A summary of the stratigraphy is given in Appendix B1.

WAPET Kidson No. 1 (Lat 22°37'00"S, Long 125°00'22"E) was programmed as a stratigraphic test of a structural terrace in the southern Kidson Sub-basin. The well penetrated to a total depth of 4431.5 m in a Early Ordovician sequence (WAPET, 1966c). A summary of the stratigraphy is given in Appendix B2.

Aquitaine Wilson Cliffs No. 1 was drilled in 1968 on an anticlinal feature in the eastern part of the basin (Lat 22°16'39"S, Long 126°46'55"E). Total depth was reached at 3722 m in Proterozoic sediments (AAP, 1969c). Appendix B3 gives a summary of the stratigraphy of the well.

Aquitaine Contention Heights No. 1 (Lat 22°25'36"S, Long 127°13'31"E) was drilled in 1973 near the southeastern margin of the basin to investigate the reservoir potential of the Ordovician

sequence. The well penetrated a Palaeozoic sequence similar to that encountered in Wilson Cliffs No. 1, and terminated at a depth of 1709.7 metres (AAP, 1974). Appendix B4 gives a summary of the stratigraphy of the well.

No significant hydrocarbon shows were recorded in any of the wells. The significance of the well information and the possible prospects and techniques for further exploration within the Kidson Sub-basin have been summarized at various stages by Koop (1966b) and Creevey (1971).

3. STRATIGRAPHY

Introduction

Major difficulties in elucidating the geology of the southern Canning Basin are the occurrence of extensive Cainozoic superficial deposits between widely scattered outcrops, the fact that most of the rocks exposed are quartz sandstones and are difficult to tell apart, and a paucity of useful marker beds. Deep and intensive weathering involving ferruginization, lateritization and silicification has affected most rocks in the region. The region has been subjected to subaerial denudation since the beginning of the Tertiary (or earlier), and the rocks most susceptible to weathering tend to form topographic depressions and to be concealed beneath superficial deposits.

The stratigraphy of the area is summarized in Table 1. The oldest rocks in the area are the Archaean and Early Proterozoic sediments intruded by granites which form the basement Arunta Block. Adelaidean sedimentary rocks of the Amadeus Basin sequence lie unconformably on basement. These rocks form the eastern margin of the Canning Basin. Basement to the western margin of the basin is made up of gneiss, schist and igneous rocks of the Rudall Metamorphic Complex, which is overlain by a moderately to strongly folded and faulted, mixed sedimentary succession

(the Yeena Group) of Early or Middle Proterozoic age, and are described in detail elsewhere (Williams et al., 1976).

The Precambrian units are overlain by marine and/or fluvial sediments of the Canning and Officer Basin sequences. Thin terrestrial and marine Mesozoic and Cainozoic sequences complete the stratigraphy.

Units older than the outcropping Permian Paterson Formation occur only in the subsurface, and the information on them is based mainly on data obtained from the wells drilled in the area: WAPET Sahara No. 1, WAPET Kidson No. 1, Aquitaine Wilson Cliffs No. 1, and Aquitaine Contention Heights No. 1. Interpretations of the environments of deposition of the subsurface units have not been attempted in this report.

PRECAMBRIAN

Pollock Hills Formation

The Pollock Hills Formation crops out as strike ridges, hills and undulating terrain in southeastern WILSON, and it extends eastwards onto WEBB. The type section is across part of the Pollock Hills from lat. 22°50'S, long. 127° 40'E to lat. 22°49'S, long. 127°38'E (WEBB).

Lithology

The unit consists mainly of quartz and feldspathic sandstone; acid lava is also exposed in low hills. The latter is porphyritic, hard, dense and jointed. A detailed description is given by Blake & Towner (1974). The sandstone is fine to medium-grained, medium to thin-bedded; lithic fragments are common.

On WEBB, the formation contains andesitic lava, tuffaceous siltstone and sandstone, conglomerate, lapilli tuff and agglomerate (Blake & Towner, 1974).

TABLE 1. STRATIGRAPHY OF AREA

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Quaternary	Qz	5	Red quartz sand, fine to medium-grained	Superficial deposit	Aeolian; thickness does not include height of dunes
	Qs	10?	Quartz sand, silt, minor gypsum	Superficial deposit	Alluvial and aeolian; in depressions
	Qa	10?	Silt, clay, sand, minor gravel	Superficial deposit	Alluvial outwash adjacent to some mesas
	Ql	100?	Clay, silt and brine-saturated red sand, gypsum	Superficial deposit	Evaporitic and fluvio-lacustrine
	Czk	50?	Calcrete, chalcedony	Superficial deposit	Alluvial and evaporitic in lines of ancient drainage; pedogenic in places; aquifer
	Czs	1-2	Sand, silt, ferruginous pisoliths, minor gravel, clay	Superficial deposit	Lateritic soil capping or flanking laterite plateaux

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
	Czl	5	Laterite, pisolitic or massive	Superficial deposit	Pedogenic; upper part off lateritic weathering profile; plateau-forming
	Czf	1	Ferricrete	Superficial deposit	Weathering product
	Czt	3	Silcrete	Superficial veneer	Weathered profile developed on highly quartzose rocks
Cretaceous to Tertiary	Lampe Beds KTl	2	Sandstone, fine to coarse; poorly sorted; pebble conglomerate; intensely silicified	Unconformable on Paterson and Samuel Formations, Heavitree Quartzite; top eroded	Fluviatile
	Lake George Beds KTg	5+	Sandstone, fine to very coarse; poorly sorted; granule conglomerate; massive; locally silicified, ferruginous	Unconformable but locally gradational on Anketell Sandstone and Callawa Formation; capped by laterite	Contains possible root moulds; interpreted as fluviatile and partly pedogenic
	Undivided M	10+	Sandstone, siltstone, conglomerate	Uncertain	Possibly equivalent to Callawa Formation. Crops out at Dowling Hills (RYAN)

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Early Cretaceous	Bejah Claystone Ke	10	Claystone, minor siltstone, thin laminae of very fine sandstone; massive to poorly bedded; porcellanite	Conformable on Samuel Formation; unconformable beneath Lampe Beds	Fossiliferous; shallow marine
	Samuel Formation Kls	30	Sandstone, very fine to fine laminated to thin-bedded; siltstone; coarse sandstone lenses bioturbated	Grades laterally into and lies on Anketell Sandstone; disconformable on Cronin Sandstone; Conformable beneath Bejah Claystone, unconformable beneath Lampe Beds	Fossiliferous; shallow marine. Kaolinized at surface
	Anketell Sandstone Ka	100	Sandstone, fine and siltstone interbedded with lenticular coarse sandstone, granule and pebble conglomerate; laminated to thin-bedded; cross-bedded; minor intraformational claystone conglomerate; some bioturbation	Conformable on Callawa Formation and Cronin Sandstone; unconformable on Permian and Precambrian rocks; laterally equivalent to Samuel Formation	Rhizocorallium burrows, wood fragments; paralic

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Late Triassic(?)	Cronin Sandstone Mr	100	Sandstone, fine to coarse, minor mudstone, pebble conglomerate; crossbedded; poorly sorted; bioturbated	Unconformable on Paterson Formation; conformable beneath Anketell Sandstone; disconformable beneath Samuel Formation	Plant fossils at Cronin Hills (RUNTON); fluvial: confined to Officer Basin only
to Early Cretaceous	Callawa Formation JKc	100	Sandstone, coarse to very-coarse; conglomerate; crossbedded; minor siltstone, fine sandstone; intensely ferruginized	Unconformable on Noonkanbah Formation and Triwhite Sandstone conformable beneath Anketell Sandstone	Distinctive dark photopattern; fluvial
			MAJOR UNCONFORMITY		
	Undivided Pz	30+	Silty sandstone, fine to coarse, thin-bedded; crossbedded; micaceous siltstone, laminated	Unconformably overlain by Anketell Sandstone	Confined to southeast Ryan Sheet area

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Early	Triwhite Sandstone Pt	77+	Sandstone, fine to medium, silty, micaceous, interbedded with siltstone, shale; laminated to medium-bedded; cross-bedded minor intraformational claystone conglomerate	Conformable on Noonkanbah Formation; unconformable beneath Callawa Formation, Anketell Sandstone and Lake George Beds	Fossiliferous; trace fossils: shallow marine
Permian	Noonkanbah Formation Pn	310+	Mudstone, poorly bedded and laminated; siltstone; shale, carbonaceous; sandstone, fine, silty, micaceous, feldspathic; laminated to thin-bedded	Conformable between Poole Sandstone and Triwhite Sandstone; unconformable beneath Callawa Formation and Anketell Sandstone	Fragmental plant remains, foraminifera, marine macrofossils; shallow marine
	Poole Sandstone	206	Sandstone, fine to medium, well sorted, thin-bedded, interbedded siltstone; minor intra-formational conglomerate, coarse sandstone; cross-bedded	Disconformable on Grant Formation; conformable beneath Noonkanbah Formation; unconformable beneath Anketell Sandstone	Fossiliferous; shallow marine
	Grant Formation	855	Sandstone, fine to medium, pebbly; laminated silt-stone and claystone, slightly calcareous, micaceous, carbonaceous, rare dropstones	Disconformable beneath Poole Sandstone; uncon-formable on Mellinjerie Limestone	Shallow-water glacial environment, some marine influence. Intersected in Aquitaine Wilson Cliffs No. 1, in WAPET Kidson No1 and Sahara No. 1

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
	Paterson Formation Pa	100+	Sandstone, fine to very coarse; conglomerate, poorly sorted; graded siltstone and claystone, laminated, with pebble and boulders; cross-bedded	Unconformable on Precambrian, undivided Palaeozoic, and Mellinjerie Limestone; Unconformable beneath Cronin Sandstone, Callawa Formation, Anketell Sandstone and Lampe Beds; laterally equivalent to parts of Grant Formation.	Rare plants; glacial continental, including fluvial and lacustrine deposits
			UNCONFORMITY		
Middle Devonian	Mellinjerie Limestone Dm	266	Dolomitic shale, dolomite, limestone. Minor fine to medium sandstone; minor anhydrite	Unconformable beneath Grant Formation; unconformable on Tandalgoo Red Beds	Subsurface only; intersected in Aquitaine Wilson Cliffs No. 1, Contention Heights No. 1, and WAPET Kidson No. 1, Sahara No. 1
Early Devonian	Tandalgoo Red Beds Dt	1400	Red-brown fine sandstone, with minor interbeds of siltstone, shale, limestone	Conformable between Mellinjerie Limestone and Carribuddy Formation	Subsurface only; intersected in Aquitaine Wilson Cliffs No. 1, Contention Heights No. 1 and WAPET Kidson No. 1

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Late Ordovician to Early Devonian	Carribuddy Formation Sc	2000	Dolomite, dolomitic siltstone, shale, halite, anhydrite; minor sandstone	Conformable beneath Tandalgoo Red Beds and disconformable on Goldwyer Formation	Subsurface only; intersected in Aquitaine Wilson Cliffs No. 1, Contention Heights No. 1, WAPET Kidson No. 1 and Sahara No. 1
Ordovician	O	1500	Sandstone, fine-grained; siltstone, shale, dolomite, limestone, minor evaporite	Conformable beneath Goldwyer Formation and unconformable on Precambrian sediments	Subsurface only; intersected in Aquitaine Wilson Cliffs No. 1, Contention Heights No. 1 and WAPET Kidson No. 1
			MAJOR UNCONFORMITY		
(?)Late Proterozoic or (?)Cambrian	Undivided B-C	220+	Ferruginous shale, micaceous siltstone; black, carbonaceous shale; minor sandstone, limestone	Unconformable on Archaean and Proterozoic rocks; overlain unconformably by Ordovician; relation with other Proterozoic units unknown	Subsurface only; intersected in Aquitaine Wilson Cliffs No. 1. May be equivalent to Amadeus Basin units to the east
	Maurice Formation Buu	900	Very fine to medium quartzose sandstone, cross-bedded; minor siltstone, micaceous, laminated	Conformable on Ellis Sandstone to east of Sheet area; top eroded, probably overlain by Paterson Formation unconformably	Topmost Proterozoic unit of the Amadeus Basin sequence. Occurs tightly folded in Baron Range (RYAN)

TABLE 1 (Contd)

Age	Rock Unit and Map Symbol	Approximate Maximum Thickness (m)	Lithology	Stratigraphic Relations	Remarks
Adelaidean	Ellis Sandstone Eut	500+	Fine to medium, feldspathic, quartzose sandstone, thin to medium-bedded, cross-bedded; minor siltstone	Conformable beneath Maurice Formation. Unconformable on Bitter Springs Formation to the east	Probably correlated with Erica Sandstone in the Granites-Tanami area
	Bitter Springs Formation Eub	100+	Fine sandstone, micaceous siltstone, dolomite, thin-bedded; minor limestone	Conformable on Heavitree Quartzite; top eroded	
	Heavitree Quartzite Euh	200+	Fine to medium quartz and feldspathic sandstone, thin-bedded, cross-bedded; minor siltstone, pebble conglomerate	Conformable beneath Bitter Springs Formation; base not exposed	Basal formation of Amadeus Basin sequence. Forms bold strike ridges
Carpentarian	Mount Webb Adamellite Egm	-	Hornblende-biotite adamellite	Intrudes Pollock Hills Formation	Photo-interpreted only
	Pollock Hills Formation Eps; Eps_a	25+	Feldspathic sandstone, fine to medium; siltstone, minor conglomerate. Porphyritic acid lava	Probably unconformable on Archaean and Proterozoic rocks; unconformably overlain by Heavitree Quartzite	Part of the Arunta Block sequence

Stratigraphic relations

The relation of the Pollock Hills Formation to any underlying and overlying unit is not known as no contacts are exposed in the area.

On WEBB the formation is intruded by the Mount Webb Adamellite, which may be comagmatic with the acid lava of the formation, and it is overlain unconformably by the Heavitree Quartzite. It is inferred to overlie Archaean metamorphic rocks (Blake & Towner, 1974).

Age

The age of the formation has been determined isotopically by the Rb-Sr method as 1526 ± 25 m.y. (Page et al., 1976).

Thickness

The maximum thickness of the formation is uncertain, as the base is not exposed: over 600 m was measured in the type section but it may be as thick as 1500 m.

Mount Webb Adamellite

During the 1975 field season, no outcrops of the Mount Webb Adamellite were visited in the field by members of the BMR/GSWA party, but photointerpretation and mapping by Blake (Blake & Towner, 1974) in 1973 has shown a small area of granitic rocks in southeast WILSON, where the adamellite apparently occurs as scattered groups of spherical boulders and tors surrounded by sand.

The Mount Webb Adamellite intrudes metamorphic rocks and the Pollock Hills Formation, and is cut by later basic dykes. It is overlain unconformably by Heavitree Quartzite (Blake & Towner, 1974).

The adamellite has been dated isotopically by the Rb-Sr method at 1526 ± 25 m.y., indicating that it may be comagmatic with the acid lava of the Pollock Hills Formation (Page et al., 1976).

Heavitree Quartzite

The Heavitree Quartzite was named and defined by Joklik (1955), Heavitree Gap at Alice Springs being the inferred type locality (Wells et al., 1970). It is the basal formation of the Amadeus Basin sequence and crops out in southeast WILSON and northeast RYAN, where it forms a series of strike ridges, low cuestas and hills.

Lithology

The main rocks are quartz sandstone, feldspathic sandstore and subordinate siltstone and conglomerate. Bedding is generally laminated to medium. Small-scale, low-angle, planar cross-bedding is present. The quartz sandstone is medium-grained and well sorted; it consists mainly of rounded grains and contains fine laminae of coarse to very coarse grains. Near Corroboree Valley (RYAN), the fine-grained, poorly-sorted quartz-feldspathic sandstone at the base of the section contains pebbles and cobbles of quartz.

Between the strike ridges of quartz sandstone are small exposures composed mainly of very thin-bedded to laminated, friable, fine-grained sandstone and siltstone.

Most of the quartz sandstone has a siliceous cement, and surface silicification is common.

At lat. 22°48'48"S, long. 127°30'06"E, a 20 m cliff exposure consists of coarse to very coarse-grained poorly-sorted sandstone, and beds of boulder and pebble conglomerate. The sequence is cross-bedded with sets of 5 m or more. This passes up into better-sorted, coarse to very coarse-grained lithic sandstone with cross-bedding sets 1 m thick, containing small-scale cross-laminations.

Stratigraphic relations

On WEBB, the Heavitree Quartzite unconformably overlies Archaean metamorphics, Pollock Hills Formation, and Mount Webb Adamellite (Blake & Towner, 1974). The basal contact of the Heavitree Quartzite is not exposed in the area, but a conformable contact with the overlying Bitter Springs Formation is assumed because of the presence of a conformable contact on WEBB. In south WILSON, the contact between the Heavitree Quartzite and Bitter Springs Formation is faulted. The formation is unconformably overlain by the Cretaceous-Tertiary Lampe Beds.

Thickness

No section of the Heavitree Quartzite was measured, but it is considered to be at least 200 m thick. In the Pollock Hills area on WEBB, over 500 m of Heavitree Quartzite is exposed.

Age

The Heavitree Quartzite is known to be younger than 1076 $\pm$ 50 m.y. (Marjoribanks & Black, 1974).

Environment of deposition

Wells et al. (1970, p.21) considered that 'The widespread distribution of the Heavitree Quartzite suggests deposition in a shallow marine epicontinental sea under relatively stable conditions', and that the coarse basal beds may indicate a littoral environment.

Bitter Springs Formation

The Bitter Springs Formation was originally named the Bitter Springs Limestone by Joklik (1955) and revised to Bitter Springs Formation by Wells et al. (1967). It crops out in far southeast WILSON and northeast RYAN as low mounds and hills.

Lithology

The rock types exposed are quartz sandstone, micaceous siltstone, dolomite and minor limestone. The quartz sandstone is fine to medium-grained, laminated to thin-bedded, moderately sorted and in places calcareous. The dolomite and limestone are generally capped with Cainozoic calcrete. The dolomite which is yellowish grey contains coarse rounded quartz grains.

On WEBB, limestone and dolomite are the predominant rock types and locally they appear to be stromatolitic; thin lenses and laminae of dark grey chert are associated with the carbonate rocks. Farther east, evaporitic minerals are present in the formation (Wells et al., 1970).

Stratigraphic relations

The contact of the Bitter Springs Formation with the overlying and underlying units is concealed by superficial deposits. The formation is conformable on the Heavitree Quartzite in the Pollock Hills area (WEBB). It is probably unconformably overlain by the possible Proterozoic-Cambrian sediments intersected in Aquitaine Wilson Cliffs No. 1 or by other Phanerozoic sediments of the Canning Basin.

Thickness

Although no sections were measured, the Bitter Springs Formation is considered to be 100 m or more thick. In the Western Australia side of the Amadeus Basin, the formation has a thickness of about 366 m (Playford et al., 1975).

Age

The Bitter Springs Formation is probably Adelaidean (Wells et al., 1970).

Environment of deposition

Wells et al. (1970) suggest that the formation was probably deposited in a relatively stable, highly saline, shallow-marine environment.

Ellis Sandstone

The name Ellis Sandstone was introduced by Wells et al. (1964) and the name has tentatively been assigned to outcrops which occur to the north of the Baron Range in central east RYAN. The outcrops form low hills and pinnacles.

Lithology

The predominant rock is a white, fine to medium-grained, quartz sandstone, laminated to thin-bedded, cross-laminated and cross-bedded. The sandstone contains mainly moderate to well-rounded grains but also some very well rounded to spherical grains of quartz and minor heavy minerals. A few beds of well-rounded coarse to very coarse-grained sandstone occur in several places.

Cross-bedding, common throughout the sequence, is mainly of the planar type with asymptotic bases and eroded tops. The sets range from small scale (3-5 cm) to large scale (3 m). Opposing dips of the foreset beds are present in adjacent sets of cross-bedding, giving rise to herringbone cross-bedding.

At one locality (lat. 23°10'00"S, long. 127°11'21"E) in a joint block 4 m high, the interbedding of planar stratified and cross-stratified sandstone is repeated 20 times.

Current wave ripple marks, and possible current lineations are present.

Stratigraphic relations

The contact between the Ellis Sandstone and other units is not exposed as it is covered by Cainozoic deposits. To the east, in the Amadeus Basin, the Ellis Sandstone probably lies unconformably above the Carnegie Formation or Board Formation, interfingers with the Sir Frederick Conglomerate, and is conformably overlain by the Maurice Formation (Wells et al., 1970). The Ellis Sandstone may be correlated with the Erica Sandstone of the Redcliff Pound Group in the Granites-Tanami area (Blake et al., 1973).

Thickness

No sections were measured, but the formation is estimated to be at least 50 m thick on RYAN.

Age

In 1964, Wells et al. assigned a Late Proterozoic or Early Palaeozoic age to the formation. However, later work showed that the Ellis Sandstone interfingers with Sir Frederick Conglomerate and is equivalent in part to the Late Proterozoic Winnall Beds (Wells et al., 1970). The Ellis Sandstone is considered to be Late Proterozoic (Adelaidean) in age.

Environment of deposition

Wells et al. (1970, p 41) consider that "... the complex interfingering of the Sir Frederick Conglomerate with the Ellis Sandstone suggests deposition close to the provenance area in alternating continental and transitional environments. The conglomerates were probably mainly fluvial and the interfingering sand mainly littoral".

Maurice Formation

Wells et al. (1964) introduced the name Maurice Formation for the sequence of sandstone and siltstone which conformably overlies the Ellis Sandstone in the western part of the Amadeus Basin. The formation crops out in the Baron Range and hills nearby in the central east part of RYAN.

Lithology

At the base of the Baron Range, fine to medium-grained, thin to medium-bedded, grey-green quartz sandstone, which occurs as strike ridges, is interbedded with laminated, fissile, micaceous, very fine-grained sandstone and siltstone. This is overlain by cream to pale grey, highly silicified fine to very fine-grained sandstone containing 5% clay pellets (weathered feldspar). This sequence is distinctly thin bedded to very thick bedded with no visible internal lamination. This highly silicified sequence is interbedded in places with pale brown, coarse-grained sandstone and siltstone. Bedding dips range from 35° to vertical.

Stratigraphic relations

In the Amadeus Basin, the Maurice Formation is conformable on the Ellis Sandstone and is unconformably overlain by the Permian Buck Formation.

Thickness

No sections were measured, but the formation is estimated from dip reading and airphoto to be at least 900 m thick. It is estimated to be at least 1800 m thick in the Maurice Hills (Wells et al., 1970, p. 39).

Age

Wells et al. (1964) tentatively assigned a Late Proterozoic or Early Palaeozoic age to the Maurice Formation. However,

later work has shown that this formation is equivalent in part to the Late Proterozoic Winnall Beds (Wells et al., 1970), and is therefore considered to be Late Proterozoic and the topmost Proterozoic unit of the Amadeus Basin.

Environment of deposition

Wells et al. (1970, p. 41) suggest that the Maurice Formation was probably deposited in alternating fluvial and shallow-marine environments.

LATE PROTEROZOIC? OR CAMBRIAN?

Sedimentary rocks of possible late Proterozoic or early Palaeozoic age were intersected at the base of Aquitaine Wilson Cliffs No. 1 (AAP, 1969c). The sequence intersected has been informally named by the company as the 'Carbonaceous Shale Beds' and 'Ferruginous Shale Beds'.

The "Carbonaceous Shale Beds" are almost entirely black, silty, non-calcareous, carbonaceous, micaceous, pyritic and partly silicified shale. Interbedded with the shale are grey to white siltstone, and minor carbonates occur near the base of the beds. Bedding ranges from laminated to massive. The beds are strongly jointed, the fractures being filled with pyrite, quartz and calcite. The dipmeter log indicates that these beds dip at 22° WSW.

The thickness of the beds penetrated in the well is 143.9 m. No age can be determined but the beds are possibly Late Proterozoic.

The 'Ferruginous Shale Beds' consist of interbedded, multicoloured silty shale and siltstone; they are ferruginous, micaceous, and slightly calcareous, and contain minor pyrite. The siltstone grades in part to fine-grained sandstone. The sediments are well laminated and contain small faults with micro-

displacements; the faults are filled with quartz and carbonate. Dipmeter readings in the well show that the beds dip at 6° NW. The total thickness of section penetrated in the well is 75 m.

The age of these beds is unknown; the overlying formation contains marine macrofossils and microfossils of Early to Middle Ordovician age.

The dipmeter readings in the well indicate a strong angular unconformity at the boundary between the 'Carbonaceous Shale Beds' and the overlying 'Ferruginous Shale Beds'.

UNDIVIDED PALAEOZOIC

Outcrops of cross-stratified sandstone and minor siltstone occur at a prominent mesa/breakaway 30 m high in south-east RYAN at lat 23°55'18"S, long 127°20'42"E. The base of the sequence is not exposed and the top of the sequence is unconformably overlain by the Cretaceous Anketell Sandstone. Since this sequence is not as friable and soft as the Mesozoic sediments observed elsewhere in the southern Canning Basin, the exposure has been mapped as Undivided Palaeozoic.

Lithology

Near the base of the hill are outcrops of fine to coarse, friable, micaceous sandstone, moderately sorted and cross-bedded throughout. The cross-sets are less than 10 cm thick and are mostly planar, with a maximum dip of 15° on foresets. Overlying this is a sequence of interbedded cross-bedded and non-cross-bedded sandstone. The non-crossbedded sandstone ranges in thickness up to 5 cm and contains large siltstone clasts up to 20 cm long. In the cross-bedded sequence, opposing dip directions on the foresets occurs. This sequence is capped by 30 cm of deeply weathered micaceous siltstone.

The top 5 m of the section contains fine to coarse-grained, thin to medium, parallel-bedded sandstone which grades upwards into laminated siltstone and fine-grained sandstone at the top. Cross-bedding is poorly developed and some beds wedge out along strike.

Thickness

At least 30 m is exposed.

Environment of deposition

As only one outcrop of this unit was visited, it is difficult to suggest an environment of deposition. The opposing direction of the cross-bedded sand separated by planar laminated sand is consistent with a shallow-water environment in which opposing current directions are common; possibly a tidal environment.

ORDOVICIAN

Ordovician sediments have been intersected in three of the four wells drilled in the area: WAPET Kidson No. 1, Aquitaine Contention Heights No. 1 and Aquitaine Wilson Cliffs No. 1; the last well has the most complete section.

The Ordovician sequence has been divided into three units; the basal and middle units have been informally named the 'Lower Formation' and 'Middle Formation' respectively in company reports (AAP, 1969c; 1974) and the upper unit is placed in the Goldwyer Formation.

'Lower Formation'

The 'Lower Formation' is almost entirely quartz sandstone with minor shale and shaley siltstone. The sandstone is white to grey, is fine-grained, and contains angular to sub-rounded grains. The siltstone and shale are grey to black and

form scattered interbeds throughout. The formation has a maximum thickness of 540.1 m in Aquitaine Wilson Cliffs No. 1 well and is at least 45.7 m thick in Aquitaine Contention Heights No. 1 well.

Marine fossils including graptolites, brachiopods, and molluscs, indicate a Middle Ordovician age (Arenigian to Llandeilian-Llanvirnian age). The 'Lower Formation' has been tentatively correlated with the 'Nambeet Formation' (Playford et al., 1975).

'Middle Formation'

The 'Middle Formation' consists of predominantly white, fine-grained, slightly calcareous sandstone with minor glauconite and pyrite, and, towards the base, grey argillaceous limestone and dolomite. Grey to black shale forms rare interbeds. In Aquitaine Contention Heights No. 1 well the formation contains mainly medium to coarse-grained, poorly sorted sandstone with interbeds of siltstone and very little carbonate cement (AAP, 1974).

Marine fossils including echinoderms, pelecypods, brachiopods, and trilobites are present, particularly in the carbonate beds. Microfossils from the cores indicate a Middle Ordovician age (Llandeilian-Llanvirnian) for the formation. The 'Middle Formation' may correlate with the Willara Formation (Playford et al., 1975).

Goldwyer Formation

The Goldwyer Formation (Elliott, 1961) is a sequence of shale, limestone, dolomite and siltstone which overlies the Willara Formation and is conformably overlain by the Nita Formation. It is named after Goldwyer No. 1 well and the type section is in Thangoo No. 1A well between 848 m and 1060 m. Both these wells are located outside the area, to the northwest. The formation has a wide distribution in the subsurface of the southern Canning Basin being intersected in WAPET Kidson No. 1 well and both of the Aquitaine wells, Wilson Cliffs No. 1 and Contention Heights No. 1.

Lithology

The formation consists of interbedded grey, calcareous siltstone and shale with thin beds and lenses of limestone. The limestone is finely crystalline and slightly dolomitic, and contains rare crystals of pyrite and gypsum. In Aquitaine Contention Heights No. 1 well, a fine to medium-grained grey sandstone occurs in the middle of the formation.

Age

Fossils include brachiopods, trilobites and graptolites which date the Goldwyer Formation as Mid-Ordovician (Llanvirnian, possibly Llandeilian).

Thickness

Sections of Goldwyer Formation penetrated in the wells include at least 133.5 m in WAPET Kidson No. 1; 314.6 m in Aquitaine Wilson Cliffs No. 1 and 237.7 m in Aquitaine Contention Heights No. 1.

?LATE ORDOVICIAN TO EARLY DEVONIAN

Carribuddy Formation

The Carribuddy Formation (Koop, 1966a) is named after Carribuddy Springs, 16 km northeast of WAPET Sahara No. 1 well, in which the type section is located between 1727 m and 2120 m (total depth of well). The formation is widespread over the south Canning Basin and has been intersected in Aquitaine Contention Heights No. 1, Aquitaine Wilson Cliffs No. 1, and WAPET Kidson No. 1.

Lithology

The formation was first informally subdivided into two units A and B in WAPET Sahara No. 1 (Koop, 1966a), and later into

five units A, B, C, D, and E in WAPET Kidson No. 1 (WAPET, 1966c), Unit A being the top and Unit E the bottom of the sequence:

Unit A: mainly dolomite with minor interbedded siltstone and shale with rare sandstone beds.

Unit B: predominantly halite with minor siltstone.

Unit C: mainly grey, calcareous claystone with a little siltstone. Minor interbeds of halite near the top and bottom.

Unit D: red-brown claystone with quartz and dolomite with halite interbeds.

Unit E: mainly interbedded and gradational red-brown claystone and argillaceous dolomite with thin beds of halite and anhydrite. In Aquitaine Contention Heights No. 1, this unit contains medium-grained sandstone at the top with interbedded sandy shale and siltstone with fine sandstone at the base.

Unit B, the evaporitic unit, is absent in both the Aquitaine wells. The sandstone unit in Contention Heights No. 1 is tentatively correlated with the evaporitic unit D in the Wilson Cliffs No. 1 well.

Thickness

The thicknesses of Carribuddy Formation encountered in the various wells include:

WAPET Sahara No. 1	:	393.5+ m
WAPET Kidson No. 1	:	1709.3 m
Aquitaine Wilson Cliffs No. 1	:	754.4 m
Aquitaine Contention Heights No. 1	:	431.6 m

The formation therefore appears to thicken towards the centre of the Kidson Sub-basin.

Stratigraphic relations

The contact of the Carribuddy Formation with the Goldwyer Formation is a disconformity. The contact with the overlying Tandalgoo Red Beds is sharply defined on electrical and gamma-ray logs. It is an abrupt, but apparently conformable, change from sandstone to dolomite.

Age

The dating of the Carribuddy Formation remains imprecise. In Aquitaine Contention Heights No. 1 well, rare spores with Devonian affinities and acritarchs are present, but the types and specimens are too unrelated to give any definite stratigraphic position (AAP, 1974). Fossils are absent in the other wells in the area. The formation disconformably overlies the Mid-Ordovician Goldwyer Formation and is overlain by the Early Devonian Tandalgoo Red Beds and is therefore inferred to be Late Ordovician to Early Devonian in age.

DEVONIAN

Tandalgoo Red Beds

The Tandalgoo Red Beds (Koop, 1966a) are a sequence of red and brown sandstone with minor siltstone and limestone overlying the Carribuddy Formation. The name of the formation is derived from Tandalgoo Rock Hole, 8 km north-northeast of WAPET Sahara No. 1 well (SAHARA) in which the type section is located between 1128 m and 1727 m. The formation has been intersected in all the wells drilled in the area.

Lithology

The Tandalgoo Red Beds are composed almost wholly of sandstone with interbeds of siltstone, shale and limestone. The red-brown sandstone ranges from very fine to coarse-grained and

has clean, well-rounded, moderately to well-sorted quartz grains. Some of the quartz grains are frosted. The sandstone is massive to well bedded and cross-bedded with foresets dip of up to 15o. The siltstone and shale interbeds are red-brown, argillaceous, and slightly calcareous. Rare limestone beds occur near the base of the sequence in WAPET Sahara No. 1 well.

Thickness

Sections penetrated in the wells:

WAPET Sahara No. 1	:	599 m
WAPET Kidson No. 1	:	733 m
Aquitaine Wilson Cliffs No. 1	:	684.4 m
Aquitaine Contention Heights No. 1	:	60 m

This indicates that the formation thickens rapidly westwards from Contention Heights No. 1 well to Wilson Cliffs No. 1 well and then gradually into the centre of the Kidson Sub-basin.

Stratigraphic relations

The boundary between the overlying Mellinjerie Limestone and the Tandalgoo Red Beds is sharply defined by a change in lithology from interbedded dolomite and siltstone to red-brown sandstone. In WAPET Sahara No. 1 well, the sandstone of the Tandalgoo Red Beds is separated from the carbonates of the Mellinjerie Limestone by a transitional unit of siltstone, limestone and shale. This contact is regarded as either transitional or slightly disconformable.

The contact between the Carribuddy Formation and the Tandalgoo Red Beds is an abrupt but apparently conformable one.

Age

The Tandalgoo Red Beds do not contain any fossils in either Aquitaine Contention Heights No. 1 or WAPET Kidson No. 1 wells. However, fish scales (Turinia australiensis) collected in a core about 425 m above the base of the formation in Aquitaine Wilson Cliffs No. 1 well date the Tandalgoo Red Beds as Early Devonian (Dittonian) (Gross, 1971).

Mellinjerie Limestone

The Mellinjerie Limestone is a sequence of limestone and dolomite with minor shale interbeds which overlies the Tandalgoo Red Beds. The name is derived from the Mellinjerie Rock Hole, 7 km northwest of WAPET Sahara No. 1 well. The type section of the formation is in WAPET Sahara No. 1 well from 931 m to 1128 m. The formation is also recognized in the other petroleum exploration wells drilled in the area.

Lithology

In WAPET Kidson No. 1 and Aquitaine Wilson Cliffs No. 1 wells, the formation is largely a carbonate sequence of anhydrite-bearing dolomite, in parts silty, grading to dolomitic siltstone with minor interbeds of shale. The sequence is red and ripple marked; small scour-and-fill structures occur.

In Aquitaine Contention Heights No. 1 well, the dominant lithology is soft, red to brown, ferruginous dolomitic shale with fine quartz grains interbedded with argillaceous dolomitic siltstone. Anhydrite is absent.

In WAPET Sahara No. 1 well, the formation contains very fine-grained limestone and dolomitic limestone and minor silty dolomite. Argillaceous siltstone beds occur near the top and bottom of the formation.

Thickness

WAPET Sahara No. 1	:	197 m
WAPET Kidson No. 1	:	266 m
Aquitaine Contention Heights No. 1	:	17.7 m
Aquitaine Wilson Cliffs No. 1	:	127.4 m

The formation thickens rapidly towards the centre of the Kidson Sub-basin.

Stratigraphic relations

The Mellinjerie Limestone rests on the underlying Tandalgoo Red Beds with probable disconformity which is well marked by an abrupt lithological change from clastics to carbonates. In all the wells, the Mellinjerie Limestone is overlain unconformably by the Permian Grant Formation. The contact between the two is a good seismic reflector.

Age

No macrofossils have been collected from the Mellinjerie Limestone, but the microflora indicate a Middle Devonian age for the formation (WAPET, 1966b). To the north of the area in Total Kempfield No. 1 well, a conodont fauna indicates a Frasnian (Late Devonian) to possibly Givetian (Middle Devonian) age for the Mellinjerie Limestone (Total, 1969).

PERMIAN

Paterson Formation

The Paterson Formation is identified as a conglomerate-bearing facies, partly laterally equivalent to the Grant Formation. It consists of unsorted conglomerate, sandstone and

graded siltstone and claystone, interpreted as glacial in origin. It occurs along the southern margin of the Canning Basin and is also widespread in the Officer Basin to the south.

Distribution and type locality

The type section of the Paterson Formation (Talbot, 1920; Traves et al., 1956) is outside the area, in the Paterson Range ($21^{o}45'00"S$, $122^{o}10'00"E$, PATERSON RANGE). In the area the formation occurs as scattered outliers resting on Precambrian rocks on RUDALL and RUNTON and is identified at the base of the Permian section near No. 26 Well on TABLETOP. It also occurs as scattered outcrops around the northwestern and northeastern margins of the Officer Basin on RUNTON and RYAN respectively, and has been tentatively identified in the Ryan Buttes (RYAN).

WAPET Sahara No. 1 and Kidson No. 1 wells intersected a basal conglomerate in the Grant Formation (WAPET, 1966b,c) and this is tentatively identified as Paterson Formation (termed Braeside Tillite by WAPET). In Aquitaine Wilson Cliffs No. 1 and Aquitaine Contention Heights No. 1 wells in the eastern part of the area, the Paterson Formation cannot be confidently identified, but to the northeast, in Aquitaine Point Moody No. 1 well (STANSMORE), the basal 1091 m of Permian is identified as Paterson Formation because of the occurrence of probably tillite in the section (AAP, 1966).

Lithology

On RUDALL the sequence normally consist of a basal, unsorted conglomerate containing some faceted and striated boulders set in a sandstone matrix unconformably overlying Precambrian rocks. This passes gradationally up into massive and laminated mudstone with a few dropstones, graded bedding (Plate 1) slump structures and lenses of cross-bedded sandstone and conglomerate. In southeastern RUDALL the sequence is disconformably overlain by unbedded, poorly sorted, silicified quartz

wacke which contains lenses of pebbles and boulders. The Paterson Formation on RUDALL commonly overlies a striated pavement which defines the shape of the Permian landsurface (Plate 2). The straight-sided northwest-trending valleys on RUDALL appear to be exhumed parts of this landsurface and in the Coolbro Creek area, a roche moutonnee structure was tentatively identified.

On RUNTON the Paterson Formation is subdivided into a glacial-lacustrine facies and a fluvio-glacial facies. The glacial-lacustrine facies consists of massive, very poorly sorted mudstone containing abundant dropstones ranging up to boulder size (Section A1, A2, A10, A12). The dropstones (Plate 3), some of which are faceted and striated (Plate 4), are composed of a wide variety of Precambrian rock types, granitoid rocks being most abundant. The fluvio-glacial facies is characterized by the presence of cross-bedded sandstone and mudstone which contains conglomerate clasts of a similar lithological range to the dropstones found in the glacial-lacustrine facies (Plate 5). Syn-sedimentary brecciation and slumping occur locally.

On RYAN the Paterson Formation overlies Precambrian rocks in the eastern part of the Sheet area and consists of both fluvio-glacial and glacial-lacustrine facies similar to the exposures on RUNTON. In the north-central part of the Officer Basin (MORRIS) the formation is not exposed, but a complete section does occur just south of the area in the Woolnough Hills Diapir on WARRI (see Jackson & van de Graaff, in prep.).

In the Ryan Buttes area (RYAN) the exposed rocks are tentatively assigned to the Paterson Formation following the practise of Jackson & van de Graaff (in prep.). There is no positive evidence of a glacial origin or a Permian age but the sequence does contain rock types similar to those found in the Paterson Formation elsewhere. The section (Section A3) consists mainly of fine to coarse-grained conglomeratic quartz arenite and quartz wacke. The lower part contains both small and large-scale

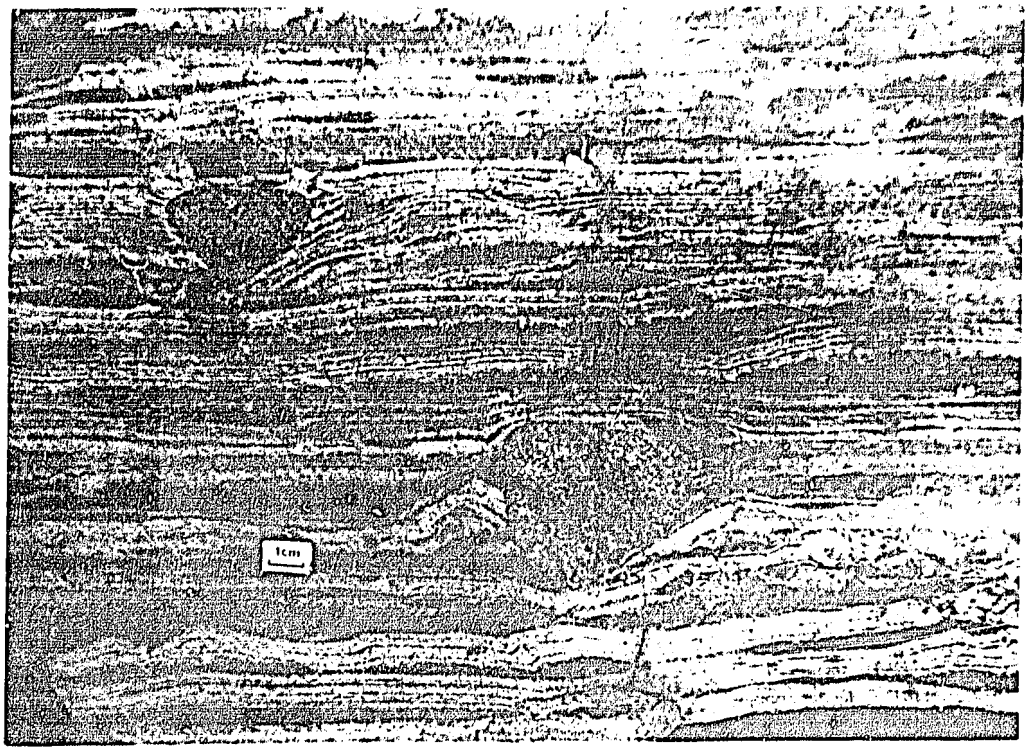


Plate 1: Graded sand and silt containing dropstones, interpreted as varves. Note depressed and penetrated laminae beneath the dropstones, Coolbro Creek, RUDALL. GSWA Negative

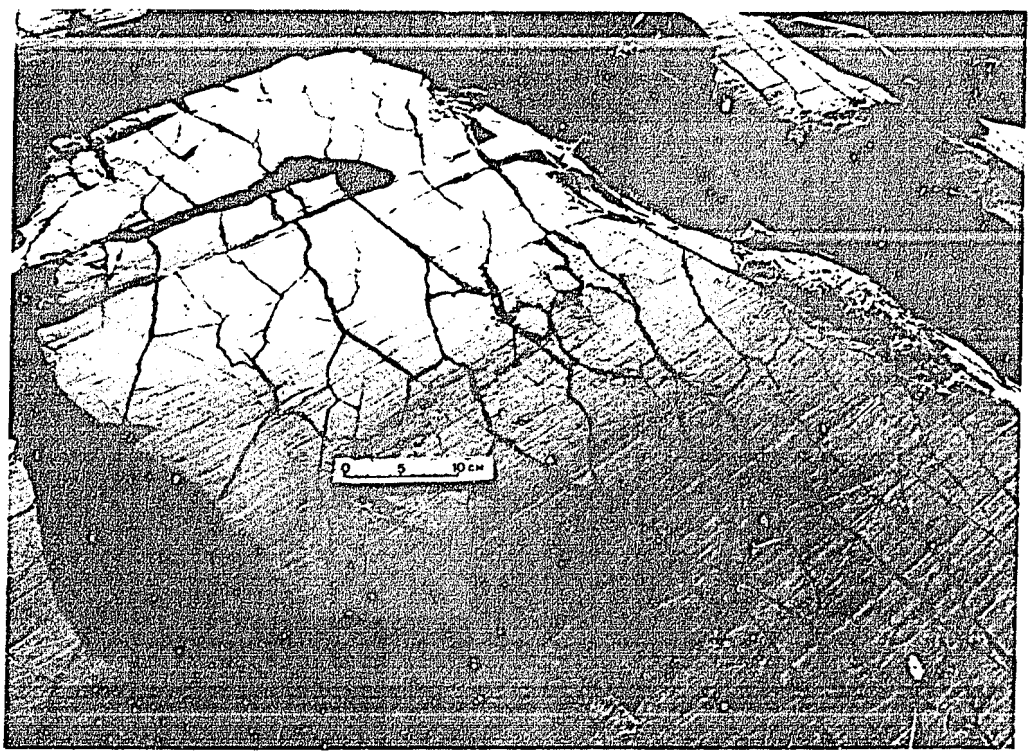


Plate 2: Striated pavement, RUDALL. GSWA Negative

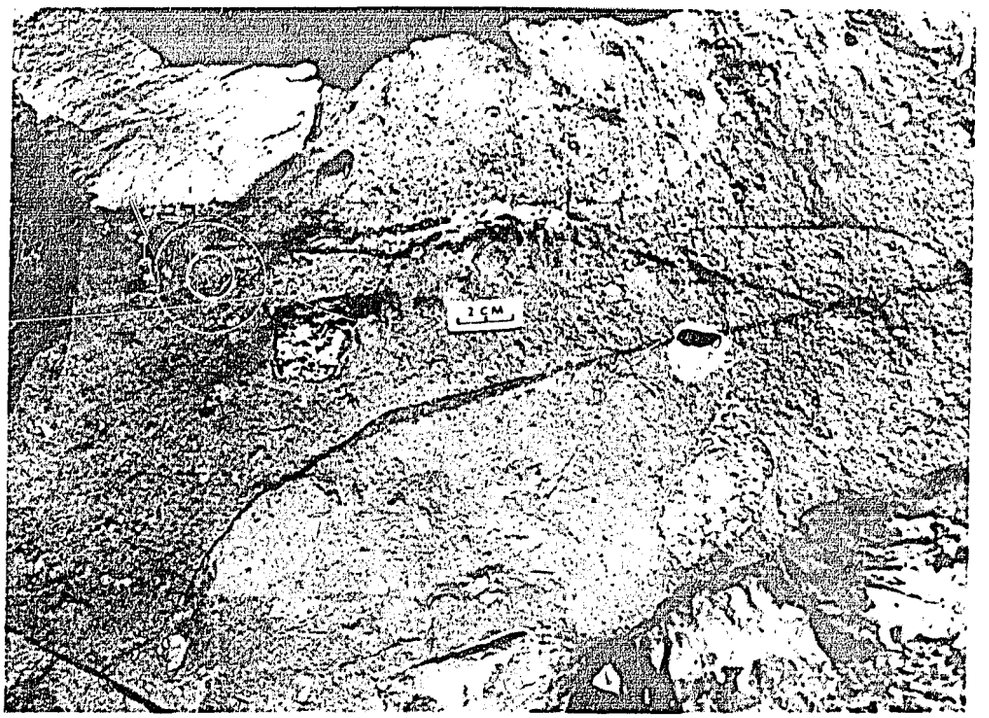


Plate 3: Weathered dropstones within poorly sorted massive mudstone, Paterson Formation, RUNTON. GSWA Negative.

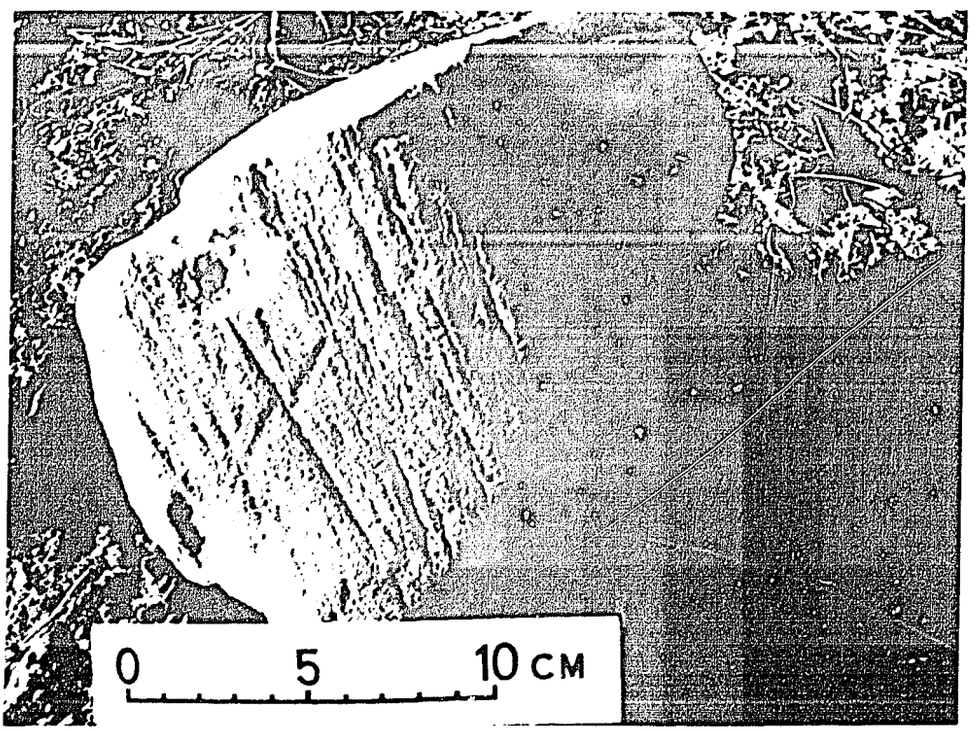


Plate 4: Striated boulder from the Paterson Formation in eastern RYAN. GSWA Negative.

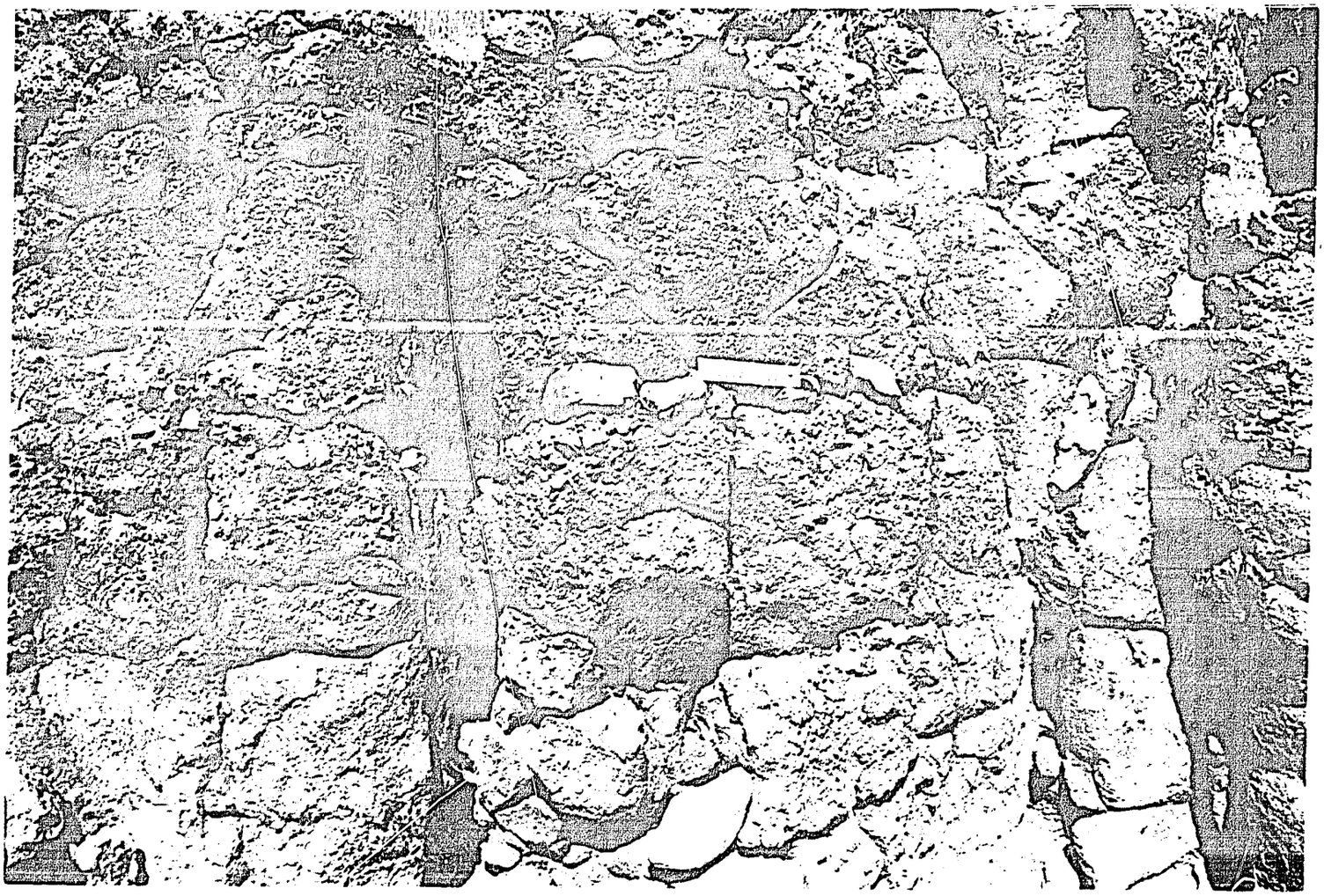


Plate 5: Very poorly bedded, fine to conglomerate sandstone from the upper part of Paterson Formation, RUDALL. GSWA Negative.

trough and planar cross-bedding with scour-and-fill structures and fining-up cycles about 5 m thick, the upper part comprises fine-grained quartz wacke with minor interbeds of granule conglomerate and abundant ripple cross-bedding and bioturbated beds. There is an overall upward decrease in grainsize and an increase in sorting.

In the Canning Basin, the tentatively identified Paterson Formation intersected in petroleum exploration wells consist of coarse to very coarse-grained sandstone and conglomerate with abundant granitic material. Smaller amounts of very fine-grained sandstone and mudstone also occur.

Thickness

The thickness of the Paterson Formation varies considerably as the unit occurs mainly as an infill of the valleys in the pre-existing landsurface. Sections on RUDALL are up to 75 m thick and in the Officer Basin the formation is 450 m thick just south of the area in Woolnough Hills Diapir. In the south Canning Basin the tentatively identified Paterson Formation in WAPET Kidson No. 1 well is 93 m thick between 1478 and 1571 m.

Stratigraphic relations

The Paterson Formation is a facies equivalent to parts of the Grant Formation (see Fig. 5). In the Canning Basin exposures it rests unconformably on Precambrian rocks and in the subsurface on Devonian and possibly other Early Palaeozoic sediments. The upper boundary with the Grant Formation is gradational and probably interfingering (see Fig. 5), and in the Officer Basin and on the southern margin of the Canning Basin the unit is unconformably overlain by Mesozoic rocks.

Fossils and age

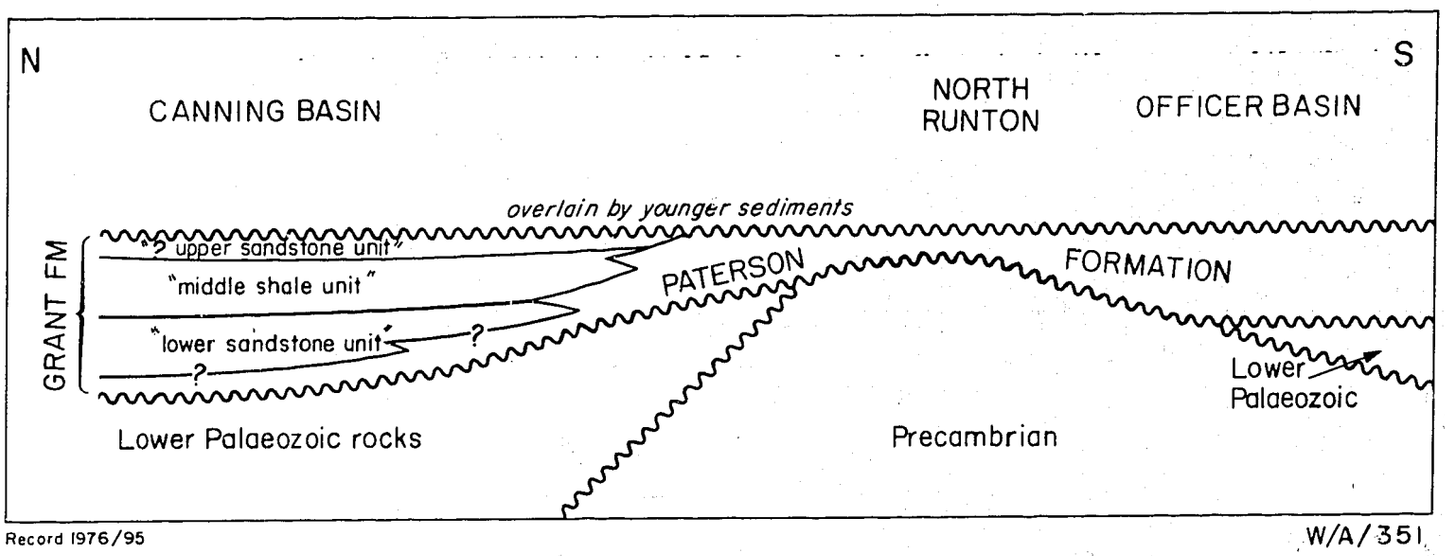
No age-diagnostic fossils are known from the Paterson Formation in the study area. To the south, in the Officer Basin, the unit is palynologically dated as Early Sakmarian (sensu stricto) by Kemp (1976). In the Canning Basin the formation has been intersected in coal-exploration bores in the Oakover River Valley (YARRIE & NULLAGINE) to the west of the area. In these bores it has been dated as Late Sakmarian (sensu lato) by J. Backhouse (writ. comm.), but the interval interpreted as Paterson Formation in WAPET Sahara No. 1 and WAPET Kidson No. 1 wells is probably of Early Sakmarian age (WAPET, 1966b, c) and this supports the diachronous relationship shown in Figure 5.

Environment of deposition

The Paterson Formation is interpreted as glacial in origin. It contains abundant dropstones, in some of which faceting and striation indicate their transport by ice. In places the sediment overlies a striated pavement which exhibits glacial geomorphic features.

In most exposures the dropstones are set in a massive mudstone matrix which indicates deposition from suspension in a standing body of water. Microfossil assemblages from the Officer Basin do not contain marine indicators so it is likely that the water-body was fresh. The interpretation of varves in the sequence (Jackson & van de Graaff, in prep.) supports this suggestion (see Kuenen, 1951), although time-equivalents of the formation in the Canning Basin are partly marine in origin.

In other outcrops, the formation is cross-bedded, and poorly sorted sandstone predominates over massive mudstone. In such exposures the depositional environment is interpreted as fluviatile.



Erosional contact —— Non-erosional contact

Fig 5 Relationships of Lower Permian Grant and Paterson Formations

In summary, the environment of deposition of the Paterson Formation is interpreted as continental, with deposition taking place in rivers and lakes under the influence of glacial climate.

Grant Formation

The Grant Formation consists of a sequence of sandstone with a middle mudstone part. It is not present in the Officer Basin, and in the Canning Basin only one area of exposure has been identified.

Distribution and type locality

Crowe & Towner (1976) have described how the Grant Formation can be divided into an 'upper sandstone unit', a 'middle shale unit' and a 'lower sandstone unit' in the northern part of the basin. These units are identified in all of the petroleum exploration wells drilled in the area (Appendix B).

A sequence that underlies the Poole Sandstone in the Well 26-27 area (TABLETOP) is identified as Grant Formation and is correlated with the 'upper sandstone unit' and the 'middle shale unit' in WAPET Sahara No. 1 and WAPET Kidson No. 1 wells (WAPET, 1966b, c).

The type section of the Grant Formation was defined by Guppy et al. (1952) in the Grant Range (lat. 18°02'S, long. 124°05'E, MOUNT ANDERSON).

Lithology

The 'middle shale unit' of the Grant Formation as exposed in the Lake George area consists of laminated siltstone and claystone with minor very fine-grained sandstone. Many of the laminae are well graded and they are interpreted as glacially formed varves (Plate 6). This interpretation is supported by the rare presence of dropstones (boulder size) in the

sequence. Near the top of this sequence sandstone becomes dominant and this upper part is tentatively correlated with the 'upper sandstone unit' of the northern part of the basin (Crowe & Towner, 1976).

The lithology and correlation of the sections between Well 26 and Well 27 is shown in Figure 6. This figure may be compared with Figure 46 of Veevers & Wells (1961) who did not differentiate the Cretaceous and Permian sediments in the Well 26-27 area.

The subsurface 'lower sandstone unit' consists mainly of fine to medium-grained sandstone with subsidiary interbeds of coarse-grained sandstone, mudstone and conglomerate. The conglomerate clasts include a wide variety of Precambrian rock types and may be glacially derived. The unit is calcareous and rarely pyritic, and in Aquitaine Wilson Cliffs No. 1 well it contains rare marine fossils (AAP, 1969c).

In the subsurface, the 'middle shale unit' consists mainly of sandy mudstone with minor argillaceous sandstone. It is commonly calcareous, micaceous and pyritic and the lower part is carbonaceous and contains coal. The unit contains rare pebbles and marine macrofossils in WAPET Sahara No. 1 well (WAPET, 1966b). In the subsurface, the 'upper sandstone unit' is dominantly fine to medium-grained sandstone with minor traces of mudstone and limestone. Pebbles are rare.

Thickness

The Grant Formation is 855 m thick in WAPET Kidson No. 1 well but thins towards the basin margin as it is 388 m thick in Aquitaine Wilson Cliffs No. 1 well and is probably less than 100 m thick between Wells 26 and 27.

Both 'lower sandstone unit' and the 'middle shale unit' are thickest in the Kidson Sub-basin, where they are 511 m and 264 m thick respectively in WAPET Kidson No. 1 well (WAPET,

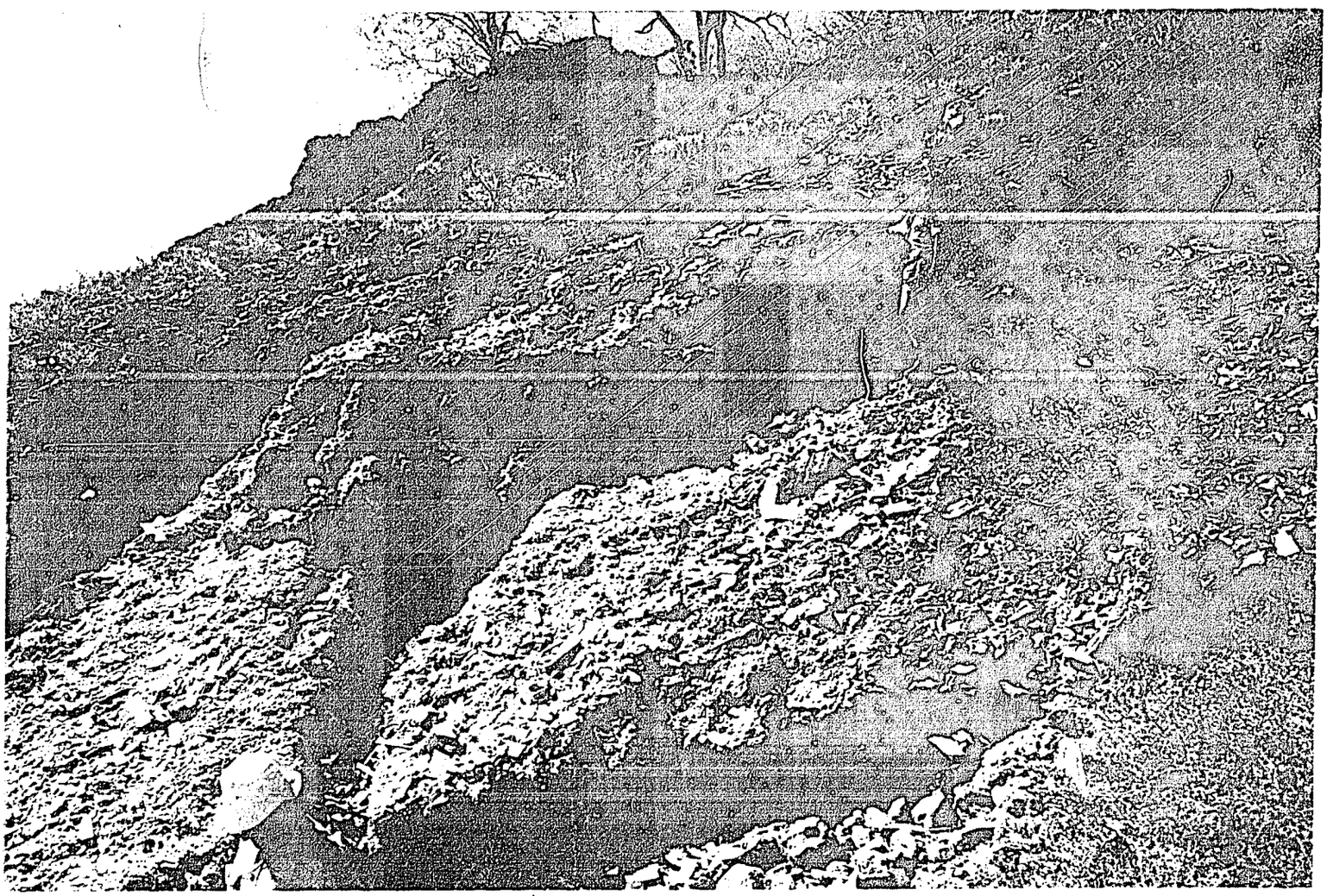


Plate 6: Exposures of fine-grained sandstone and siltstone (varves) of the Grant Formation near Well 26 on the Canning Stock Route, TABLETOP. GSWA Negative.

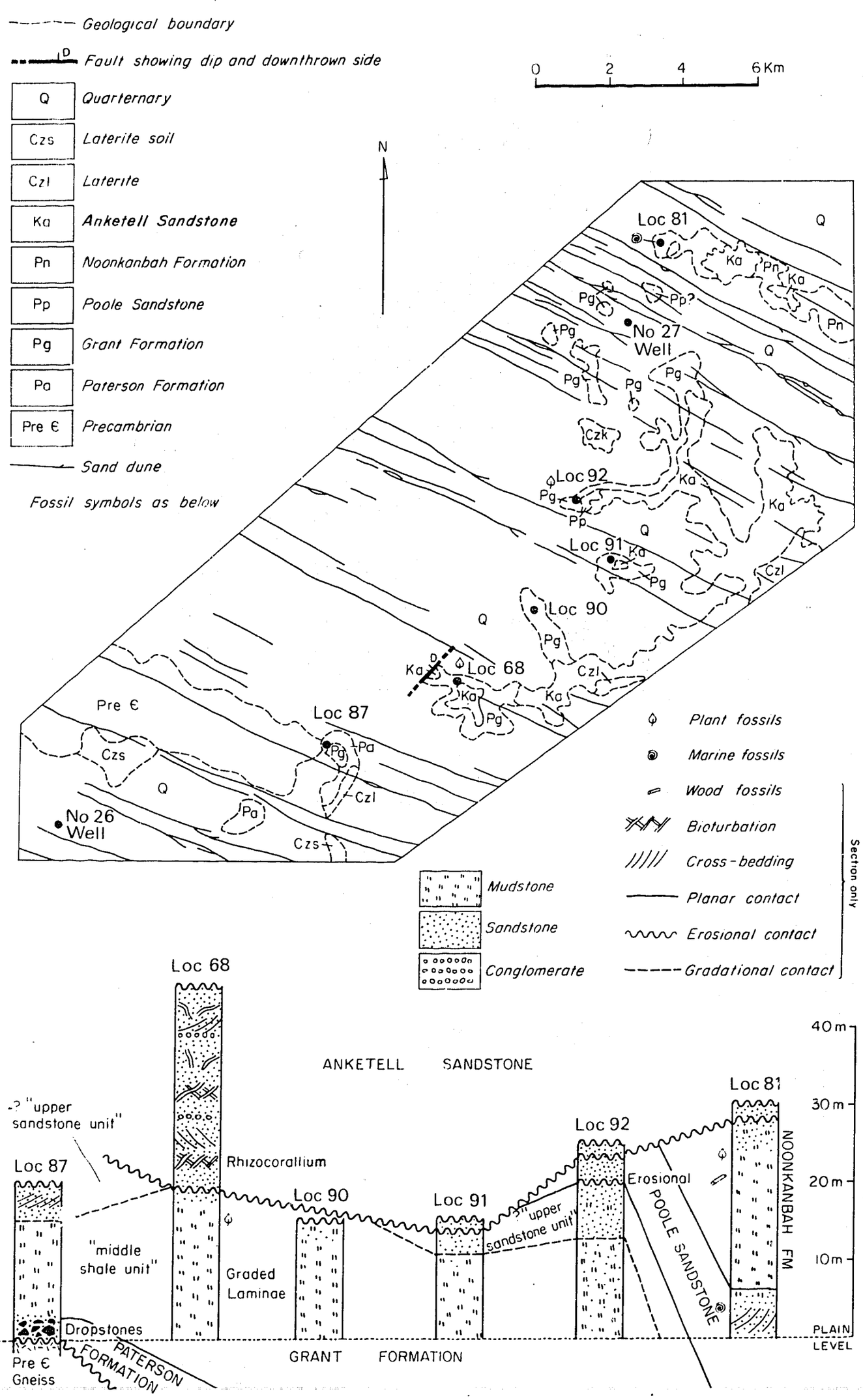


Fig 6 GEOLOGY OF WELL 26-27 AREA (TABLETOP)

1966c). The 'upper sandstone unit' is thickest in the western part of the area, where it is 82 m thick in WAPET Sahara No. 1 well (WAPET, 1966b).

Stratigraphic relations

The Grant Formation is interpreted as conformably overlying and interfingering with the Paterson Formation, which in turn unconformably overlies older rocks. Figure 5 shows these relations. In places where the Paterson Formation is missing the Grant Formation lies unconformably on the Devonian Mellinjerie Limestone (eg. Aquitaine Wilson Cliffs No. 1; AAP, 1969c) and probably on other Early Palaeozoic rocks and on Precambrian basement.

In outcrop, the upper boundary of the Grant Formation is an erosional contact, and as no angular relationship could be seen, it is probably a disconformity. The Early Cretaceous Anketell Sandstone also overlies the Grant Formation unconformably.

WAPET (1966b, c) termed the 'lower sandstone unit' and the 'middle shale unit' the Cuncudgerie Sandstone and the Dora Shale respectively; however, as defined by Traves et al. (1956), the terms refer to younger units, which in this report are identified as the Poole Sandstone and Noonkanbah Formation respectively.

Fossils and age

No age-diagnostic fossils have been found in the Grant Formation in the area, but palynological determinations elsewhere indicate a Sakmarian age (WAPET, 1966b, c). Farther north and west of the area, the Grant Formation extends into the Late Carboniferous, but available evidence suggests it is entirely Permian in the study area. A specimen of Glossopteris found in the Well 26-27 area is consistent with this age.

Environment of deposition

Glacial varves are interpreted in the exposed Grant Formation ('middle shale unit') and they imply deposition from suspension in a quiet standing body of fresh water which was covered in part by ice. However, subsurface information indicates that parts of the sequence are of marine origin so the water-body was at times connected to the sea. Coal in the unit elsewhere suggests the presence of vegetation, which was rapidly covered by sediments. The topmost part of the exposed sequence ('upper sandstone unit') contains large-scale cross-bedding and is coarser-grained, indicating some bed-load deposition by currents.

The subsurface 'lower sandstone unit' is commonly slightly calcareous and contains marine fossils in Aquitaine Wilson Cliffs No. 1 Well (AAP, 1969c) which indicate that at least part of it was laid down in a marine environment. The interbeds of immature coarse-grained sediments suggest shallow-water deposition. The variety of Precambrian rock types in conglomerate intersected in the wells suggest a glacial origin as a similar variety is present in the underlying Paterson Formation.

In summary, the Grant Formation was probably initially laid down in a shallow-water glacial environment with some marine influence. Later, deposition took place in deeper, quiet water which was partly covered in ice and periodically connected to the sea.

Nomenclature

As mapping of the Canning Basin progresses, particularly in the northern part, it is proposed to formally define the subdivisions of the Grant Formation (Crowe & Towner, 1976). These units, the 'lower sandstone unit', the 'middle shale unit' and the 'upper sandstone unit', will be given formation status and the Grant Formation will be upgraded to group status.

Poole Sandstone

The Pwole Sandstone is confined to the Canning Basin. It overlies the Grant Formation disconformably and is overlain conformably by the Noonkanbah Formation.

Distribution and type locality

The Poole Sandstone (Wade, 1936; Guppy et al., 1952) was identified on the surface in only two parts of the area. The best exposures are at, and to the south of, Helen Hill (TABLETOP; Figure 6 and Section A4) but poor exposures also occur to the south of Scott Bluff (TABLETOP). The unit has been identified in all the petroleum exploration wells in the area but it is not present in the Officer Basin.

The type section of the Poole Sandstone is defined by Guppy et al. (1958) in the Grant Range (MOUNT ANDERSON, lat. $17^{o}46'$S, long. $125^{o}51'$E).

Lithology

In outcrop, the Poole Sandstone consists of fine to medium-grained feldspathic quartz and lithic wacke with intraformational clay-pellet conglomerate. The lower part of the unit is massive, but the upper part is thinly bedded and contains large and small-scale planar cross-bedding and scour-and-fill structures. Marine fossils occur in ferruginized siltstone concretions and in the intraformational conglomerate.

In the subsurface, the Poole Sandstone consists mainly of fine and very fine-grained sandstone which is interbedded with siltstone. It is partly calcareous and pyritic and the lower half contains lignite and coal seams in Aquitaine Wilson Cliffs No. 1 and WAPET Kidson No. 1 wells (AAP, 1969c; WAPET, 1966c). The basal part of the unit is also coarse to very coarse-grained in these wells.

Thickness

The Poole Sandstone thickens eastwards from 51 m in WAPET Sahara No. 1 to 116 m in WAPET Kidson No. 1 to 206 m in Aquitaine Wilson Cliffs No. 1. Near Helen Hill, it is estimated to be about 75 m thick.

Stratigraphic relations

The exposures of the Poole Sandstone in the area correlate with the Cuncudgerie Sandstone, which was defined by Traves et al. (1956) on PATERSON RANGE. However, the outcrops can also be correlated with the Poole Sandstone intersected in the petroleum exploration wells in the area, and since the term Poole Sandstone has precedence, the name Cuncudgerie Sandstone is dropped.

The lower boundary of the Poole Sandstone with the Grant Formation is exposed to the south of Helen Hill (see Figure 6) and is an erosional disconformity. The upper boundary with the Noonkanbah Formation is planar and conformable.

Fossils and age

Pelecypods and brachiopods present in the Poole Sandstone in the area are listed in Appendix C.

The fossils are similar to those found in the Nura Nura Member of the Poole Sandstone which occurs in the northern part of the Canning Basin. An Artinskian age is indicated by these species and this agrees with the palynological date obtained from the unit in WAPET Kidson No. 1 well (WAPET, 1966c).

Environment of deposition

The fossils found in the Poole Sandstone indicate that it is marine. The massive, well-sorted nature of the sandstone

that occurs at the base of the unit is typical of sediments laid down in a near-shore environment where wave action causes a high degree of winnowing. The presence of coal in the lower part of the unit also suggests near-shore conditions.

In the upper part of the unit there are intraformational conglomerate lenses at the base of sets of cross-strata. These sequences are interpreted as current deposits possibly laid down in channels. Such deposits are commonly found in deeper water of the tidal and subtidal zones.

We, therefore, tentatively interpret the Poole Sandstone as a transgrassive sequence laid down in the area as the sea covered the post-Grant Formation landsurface.

Noonkanbah Formation

The Noonkanbah Formation consists of poorly bedded mudstone and laminated to thin-bedded quartz wacke. It is marine in origin and does not extend into the Officer Basin.

Distribution and type locality

The type section of the Noonkanbah Formation (Wade, 1936; Guppy et al., 1952) is defined by Guppy et al. (1958) near Bruten Hill (lat. 18°41'S, long. 125°38'E, NOONKANBAH) in the northern part of the basin.

In the study area the Noonkanbah Formation is identified in all the petroleum exploration wells, and it crops out at Helen Hill and Scott Bluff (TABLETOP) and low ridges and mounds east of Wilson Cliffs (WILSON). It is also exposed in small cliffs on the eastern margin of Lake Dora (PATERSON RANGE), just outside the area.

Lithology

The best exposure of the Noonkanbah Formation is at Helen Hill. This section is believed to be almost complete (Section A4) and consists of poorly bedded and laminated brown mudstone (white where leached) which contains poorly preserved fragmental plant remains. At Scott Bluff, the Noonkanbah Formation is carbonaceous near the lake level and passes gradationally up into Triwhite Sandstone. In east WILSON, the formation consists of deeply weathered laminated to thin-bedded micaceous lithic and quartz wacke.

In the subsurface, the Noonkanbah Formation is mainly siltstone with minor sandstone interbeds. In the east lignite is common (AAP, 1969c) and elsewhere it is carbonaceous and partly calcareous, pyritized and glauconitic. In WAPET Kidson No. 1 well minor dolomite is also recorded (WAPET, 1966c).

Thickness

The thickest recorded section of Noonkanbah Formation in the area is in WAPET Kidson No. 1, where it is 310 m thick. The unit thins to the east and is 192 m in Aquitaine Wilson Cliffs No. 1; it also thins southward towards the basin margin as the almost-complete section at Helen Hill is only 30 m thick. In WAPET Sahara No. 1, the formation is 228 m thick, but the section is not complete.

Stratigraphic relations

Exposures of the Noonkanbah Formation in the area were previously defined as Dora Shale (Traves et al., 1956). However, the outcrops can be correlated with the Noonkanbah Formation intersected in the petroleum exploration wells and so the name Dora Shale is dropped. The sections encountered in the wells are identified on the basis of their lithology, electric-log character, stratigraphic relations, and age.

The boundary of the Noonkanbah Formation with the underlying Poole Sandstone is a sharp, planar conformable contact. It is well exposed at the base of Helen Hill (Section A4). The upper contact with the overlying Triwhite Sandstone is gradational and is placed where sandstone predominates over mudstone. This latter boundary is exposed at Scott Bluff and about half way up the section exposed on the eastern side of Lake Dora (Section A5), just outside the area (PATERSON RANGE).

Fossils and age

Crespin (in Traves et al., 1956) assigned a Permian age to the species of foraminifera collected from the Noonkanbah Formation at the northern end of Lake Dora (PATERSON RANGE).

In WAPET Kidson No. 1 well, the Noonkanbah Formation has been dated by palynology as Artinskian (WAPET, 1966c). In Aquitaine Wilson Cliffs No. 1 well, marine macrofossils are common in the unit.

Koop (1966a) recorded marine macrofossils from the Dora Shale (Noonkanbah Formation) at Scott Bluff, but the species identified indicated a correlation with the Nura Nura Member of the Poole Sandstone. At that time (1966) the Poole Sandstone was not known to occur in the Scott Bluff area and it is likely that Koop's locality was to the south of Scott Bluff in the area where the Poole Sandstone is now mapped.

Environment of deposition

The presence of marine fossils in the Noonkanbah Formation indicates that it is marine in origin. The absence of sandstone over most of the area and well-defined bedding planes in the sequence suggest continuous deposition in a quiet standing body of water. This is supported by the association of pyrite and carbonaceous matter in the sequence which indicate

reducing, anaerobic conditions. Such conditions can only be maintained in 'the absence of turbulence or current activity, a low rate of deposition, and almost no reworking of sediment (Reineck & Singh, 1973). The abundance of sandstone in the formation in the far eastern part of the area may be due to near-shore conditions.

The environment of deposition is thus envisaged as an extensive shallow sea where deposition took place, below wave base, under mainly reducing conditions, and where there was little influx of terrigeneous material except in the east.

Triwhite Sandstone

The Triwhite Sandstone consists mainly of thin to medium-bedded quartz wacke interbedded with thin-bedded siltstone and shale. It is Early Permian in age and is marine in origin.

Distribution and type locality

Outcrops of the Triwhite Sandstone (Traves et al., 1956) are known only on TABLETOP, SAHARA and PERCIVAL, but it is probably present in the subsurface to the south and east of here. The type section is 1.6 km east of Dunn Soak (northwest TABLETOP). The unit appears to be restricted to the Kidson Sub-basin (see Fig. 9).

The best exposures are at Scott Bluff, Triwhite Hills and other unnamed mesas east of Lake Dora (TABLETOP). Good exposures are also present along parts of Percival Lakes (PERCIVAL) where an ancient drainage system has incised below the base of the overlying Mesozoic rocks.

Lithology

The Triwhite Sandstone is dominantly fine to medium-grained quartz wacke and quartz arenite interbedded with silt-

stone, shale and intraformational claystone conglomerate (Sections A6, A7, A8, A9). The sandstone is moderately to well sorted and laminated to medium-bedded. Planar cross-bedding commonly with horizontally stratified top-sets occurs, and thinner-bedded parts contain lenticular and wavy bedding. Ripple cross-lamination is present (Plate 7).

The siltstone and shale is laminated to thin-bedded with wavy laminations in places, but the shales are mainly planar laminated.

A minor, but characteristic, lithology of the Triwhite Sandstone is intraformational claystone conglomerate which occurs in beds up to 5 cm thick. These are commonly fossiliferous and contain ferruginous concretions; the claystone fragments, being platy and poorly rounded, define imbrication and indicate current deposition.

Thickness

No complete section of the Triwhite Sandstone is exposed (Sections A6, A7). In WAPET Kidson No. 1 well, it is 77.2 m thick (WAPET, 1966c) which is probably close to its maximum thickness. The unit probably thins towards the southern margin of the Canning Basin.

Stratigraphic relations

The Triwhite Sandstone is conformable on the Noonkanbah Formation and is unconformably overlain by the Lake George Beds, Callawa Formation and Anketell Sandstone. Its base is gradational in northwest TABLETOP; the actual contact is chosen where sandstone predominates over mudstone and siltstone of the Noonkanbah Formation (Section A5).

Lithologically, the Triwhite Sandstone is similar to the Lightjack Formation exposed in the Fitzroy Trough in the northern part of the basin, but since continuity between these two units has not been proved the name Triwhite Sandstone is retained.

Fossils and age

A fauna including pelecypods, brachiopods, gastropods, shark teeth and trace fossils (Plate 8, 9) was found at several localities in TABLETOP and at Shoesmith Cliffs, PERCIVAL (Appendix C). Rare wood fragments are also present. The fossils indicate an Early Permian age and suggest that the Triwhite Sandstone is a time-equivalent of the Lightjack or Noonkanbah Formations exposed in the Fitzroy Trough to the north.

Environment of deposition

The gradual upward increase in grainsize from mudstone of the Noonkanbah Formation to sandstone of the Triwhite Sandstone suggests regressive conditions. In the Triwhite Sandstone, shallow-water conditions are indicated by channel deposits (cross-bedding, intraformational conglomerate) interbedded with suspension deposits (shale and mudstone units). Wavy and lenticular bedding is also characteristic of shallow-water marine conditions.

LATE TRIASSIC? TO EARLY CRETACEOUS

Most of the study area is underlain by Late Triassic to Early Cretaceous rocks, and there has been confusion about the nomenclature of this sequence (cf. Traves et al., 1956; Veevers & Wells, 1961; Playford et al., 1975). We believe the reason for this confusion is that the described units define diachronous facies. Figure 7 shows our interpretation of the stratigraphic relations of the units involved.

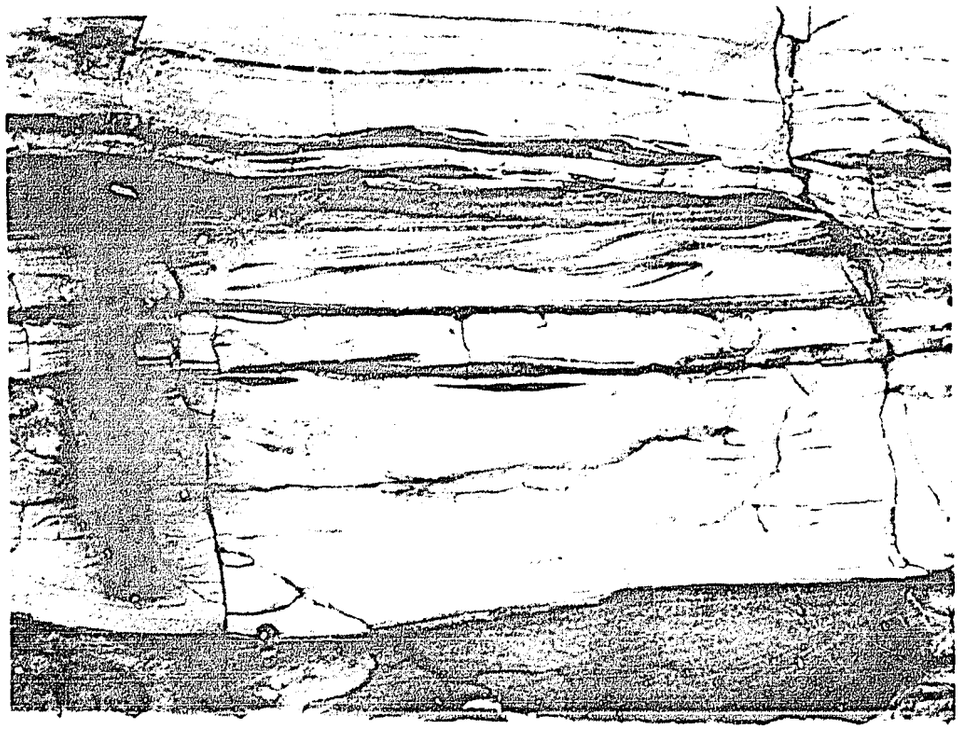


Plate 7: Ripple cross-laminated fine-grained quartz sandstone and micaceous siltstone of the Triwhite Sandstone near Scott Bluff, TABLETOP. BMR Negative GB/1080

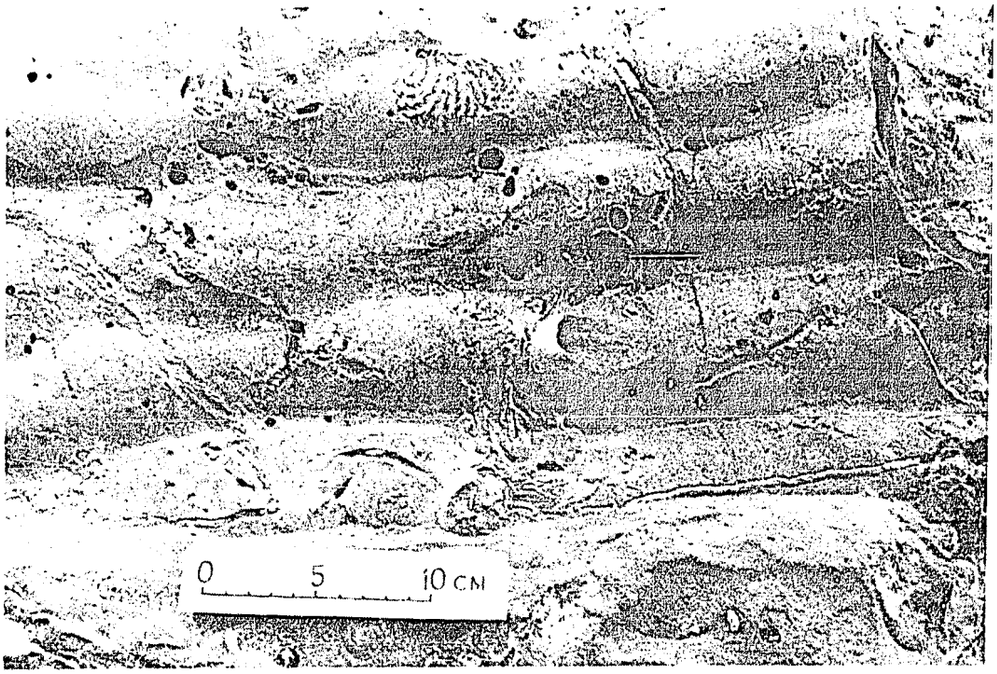


Plate 8: Trace fossils on ripple marked surfaces of the Triwhite Sandstone, Shoesmith Cliffs on edge of Percival Lakes, PERCIVAL. GSWA Negative

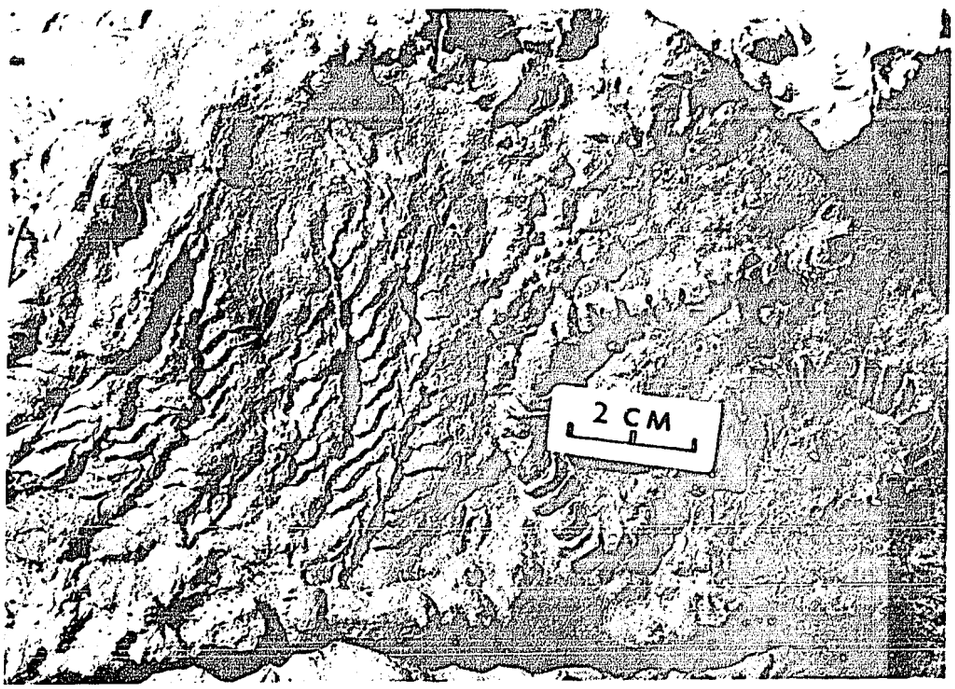
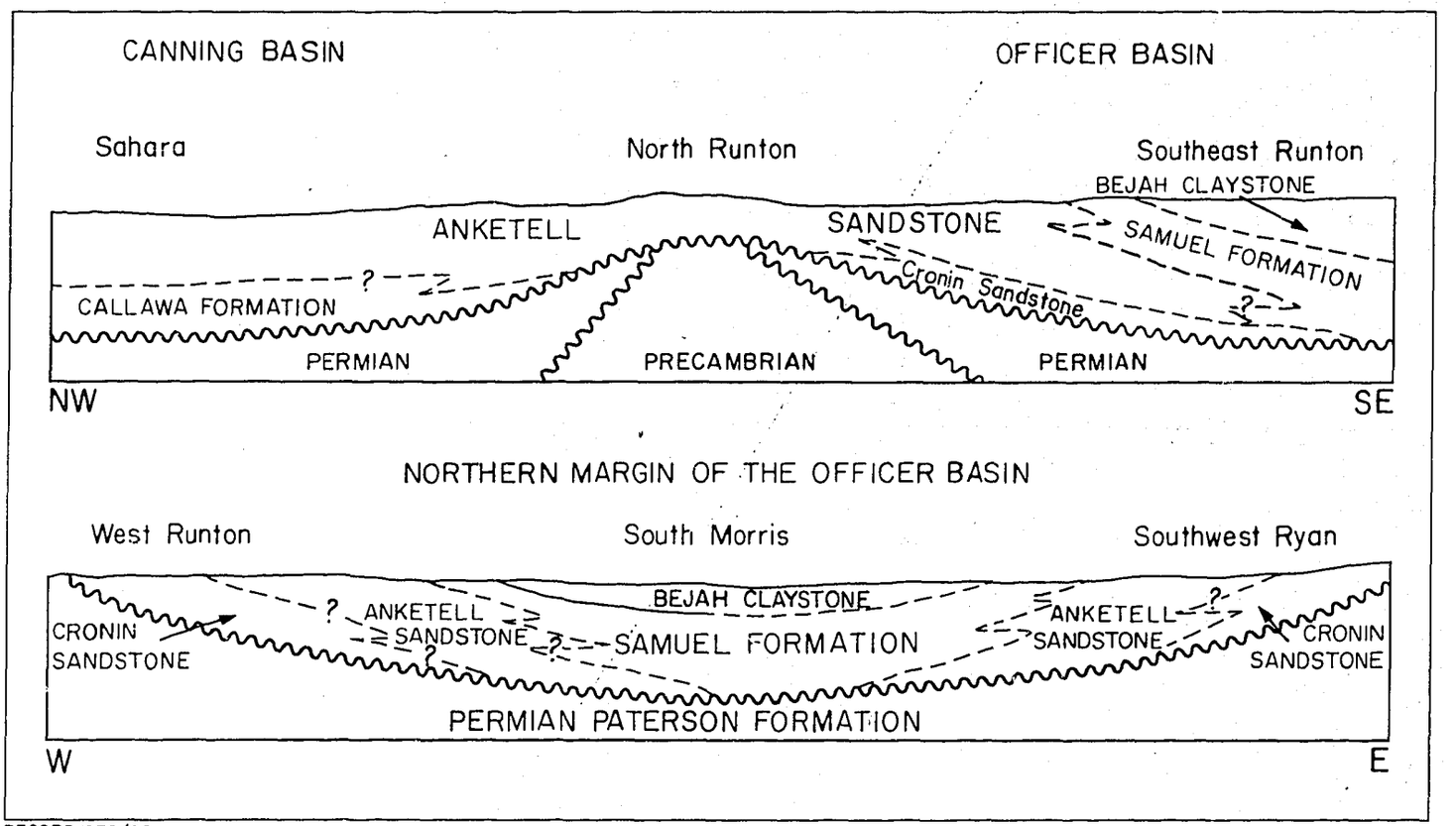


Plate 9: Trace fossils (?Zoophyeus) from the Triwhite Sandstone, TABLETOP. GSWA Negative.



RECORD 1976/95

W/A/353

~~ unconformity — sharp conformable contact -- gradational contact

Fig 7 Schematic sections showing relationships of Mesozoic units in south Canning Basin and north Officer Basin

Following the suggestion of Playford et al. (1975), the term Anketell Sandstone is retained as originally defined by Traves et al. (1956). The term Kidson Beds (Veevers & Wells, 1961) is not used, and all the areas shown as Kidson Beds on Veevers & Well's map are assigned to the Anketell Sandstone. On TABLETOP and PERCIVAL the exposures shown as Mesozoic undifferentiated by Veevers & Wells are now assigned to the Callawa Formation (Traves et al., 1956), and the Cronin Sandstone (Veevers & Wells, 1961) is extended throughout RUNTON in the northern Officer Basin. The marine Samuel Formation and Bejah Claystone (Lowry et al., 1972) are both recognized in the southern part of the study area.

Callawa Formation

The Callawa Formation is the lowermost Mesozoic unit in the Canning Basin part of the area. In consists of cross-bedded conglomerate, sandstone and mudstone, and is interpreted as fluviatile in origin.

Distribution and type locality

The Callawa Formation was defined by Traves et al. (1956) and the type section is in the Callawa Hills (lat. 20°23'S, long. 120°36'E), outside the area mapped. The formation is identified in the Canning Basin part of the area on TABLETOP, SAHARA, PERCIVAL, and WILSON. The unit has not been differentiated from the overlying Anketell Sandstone in the petroleum exploration wells in the area.

Lithology

The Callawa Formation is lithologically heterogeneous and consists mainly of conglomeratic, coarse to very coarse-grained quartz wacke interbedded with fine-grained feldspathic and quartz wacke and mudstone. It is extensively cross-bedded with individual large-scale trough-shaped sets mostly less than 50 cm thick. Cosets are 3 to 5 m thick and have conglom-

eratic erosional bases and pass gradationally up into small-scale cross-bedded (Kappa type of Allen, 1963) sandstone which in turn passes gradationally into laminated mudstone. These sequences are repeated vertically.

Exposures of the formation are ferruginized and this gives them a dark tone on the airphotos. The formation is best exposed along the flanks of the north-trending depression which contains Lake Auld, particularly at its northern end. It is also well exposed at King Hill and Thring Rock.

Thickness

No complete section of the Callawa Formation is exposed and it has not been recognized in the subsurface. We estimate an approximate thickness of 100 m for the unit, based on topographic evidence. In the northern part of the area (SAHARA) it may be thicker.

Stratigraphic relations

The lower boundary of the Callawa Formation with Permian rocks is an unconformity and is exposed at lat. 22°23'S, long. 123°44'E (TABLETOP). The upper boundary of the coarser-grained Callawa Formation with the overlying finer-grained Anketell Sandstone is gradational and is exposed beside the road 19 km west of the type section of the Anketell Sandstone (TABLETOP). This upper gradational boundary between the formations is probably diachronous and the units may inter-finger in places (e.g. southern PERCIVAL).

The Callawa Formation is probably, at least in part, equivalent to the Cronin Sandstone that occurs in the northern Officer Basin. However, available evidence indicates that the two units may be of slightly different ages and it cannot be shown that they were ever continuous. Consequently it is preferred, at this stage, to retain the two separate units.

Fossils and age

No age-diagnostic fossils were collected from the Callawa Formation in the study area. However, outside the area, the unit has yielded plant fossils which Brunnschweiler (in Traves et al., 1956) regarded as Early Jurassic or Late Triassic in age. White (in Veevers & Wells, 1961) re-examined the collections and believes the forms are Late Jurassic or Early Cretaceous.

Environment of deposition

The fining-up cyclic nature of the Callawa Formation and the associated cross-bedding types indicate meandering-channel deposition. The poorly sorted, heterogenous nature of the unit suggests continental deposition and the presence of well-preserved plant fossils in the unit supports this suggestion. The formation is therefore thought to be fluviatile in origin.

Cronin Sandstone

The Cronin Sandstone is similar to, and may be laterally equivalent to, parts of the Anketell Sandstone. It is the oldest Mesozoic unit in the Officer Basin part of the area and may correlate with the Callawa Formation in the Canning Basin.

Distribution and type locality

The Cronin Sandstone (Veevers & Wells, 1961) was previously only identified around the Cronin Hills (RUNTON) but is now traced over most of RUNTON. The type section is at the eastern end of the Cronin Hills (lat. 23°18'S, long. 123°21'E).

Lithology

At its type section (Section A10), the Cronin Sandstone consists of a lower part of bioturbated fine and very

fine-grained quartz wacke with minor mudstone and pebble conglomerate, and an upper part of medium to coarse-grained quartz wacke which is cross-bedded and moderately sorted. The lower part contains mainly small-scale ripple cross-bedding with some large-scale planar cross-bedding, whereas the upper part contains large-scale trough cross-bedding. This sequence is similar to exposures of Anketell Sandstone on northern RUNTON, and the position of the boundary between the two units is therefore tentative (Fig. 3).

Two small hills to the west of Bejah Hill (southeast RUNTON) are also identified as Cronin Sandstone on lithological grounds. In these exposures the bedding is partly destroyed by bioturbation but is probably also cross-bedded (Section A11).

Thickness

Only 24 m of Cronin Sandstone is preserved above the Paterson Formation at Cronin Hills (Section A10). The unit may thicken southeast of there but probably does not exceed 100 m. In southeast RUNTON the formation gradually thins to the south and it is not present at Woolnough Diapir on adjoining WARRI (van de Graaff, 1975).

Stratigraphic relations

The Cronin Sandstone lies unconformably on the Paterson Formation at Cronin Hills and at other exposures to the south and southeast. The unconformity surface appears fairly flat, but absence of bedding in the Paterson Formation makes it difficult to detect any angular relationship. The upper boundary of the Cronin Sandstone is more problematical. The lithological similarity of the unit to the Anketell Sandstone suggests a gradational boundary which may or may not be diachronous. Available age data on the two formations suggests they are chronologically distinct, and it is on this basis that the Anketell Sandstone is thought to overlie the Cronin Sandstone.

In southeast RUNTON the Cronin Sandstone is overlain by the Samuel Formation (Fig. 7) but the contact, near Bejah Hill, is not exposed.

The Cronin Sandstone is probably partly equivalent to the Callawa Formation of the Canning Basin, but as explained above we prefer to retain the two as separate formations.

Fossils and age

The Cronin Sandstone contains well-preserved fossil leaves including Taeniopteris, Elatocladus, and Ptilophyllum which White (in Veevers & Wells, 1961) regards as Late Triassic or Jurassic in age. Thus, according to White, the Cronin Sandstone could be older than Callawa Formation (Late Jurassic or Early Cretaceous). Therefore, a re-examination of the collection from Cronin Hills is desirable in order to clarify the above problem.

Environment of deposition

The cross-bedded, poorly sorted nature of the sediment and the presence of well-preserved plant fossils in the Cronin Sandstone suggest that it was laid down in a continental environment, possibly fluvial.

CRETACEOUS

Anketell Sandstone

The Anketell Sandstone (Traves et al., 1956) is a sequence of alternating fine and coarse-grained quartz wacke interbedded with mudsto onglomerate. It now includes the Kidson Beds of Veev ells (1961), so this latter name is dropped, in accordance with the Australian Code of Stratigraphic Nomenclature.

Distribution and type locality

The Anketell Sandstone (Traves et al., 1956) is present throughout the area. The best exposures of it are in mesas along the edge of an eroded plateau in northwest URAL, southeast SAHARA, southwest and southeast PERCIVAL and eastern TABLETOP. The best section is at Kidson Bluff, URAL (Section A13), and we propose that this be a reference section for the Anketell Sandstone. The type section is at a hill 25.7 km east of Lake Auld at lat. 22°08', long. 124°20'E (northeast TABLETOP). The Anketell Sandstone has not been differentiated from other Mesozoic units in the subsurface.

Lithology

The Anketell Sandstone consists of siltstone and fine-grained quartz wacke interbedded with coarse-grained quartz wacke and granule and pebble conglomerate. The Anketell Sandstone is thinner-bedded, finer-grained and less cross-bedded than the Callawa Formation (Sections A13, A14, A15).

The formation is laminated to thin-bedded with interbedded lenticular units of poorly sorted, coarse-grained quartz wacke and granule and pebble conglomerate. Intraformational claystone clasts also occur. Within these beds, high-angle planar cross-bedding is present, grading upwards into ripple cross-bedding. The contacts between the coarse and fine-grained parts of the sequence are sharp.

The fine-grained units, in contrast, are mainly parallel laminated. Some have wavy lamination. Scour-and-fill contacts are present where these beds are overlain by coarse units with intraformational claystone conglomerate present at the base of the coarse units.

The Anketell Sandstone is bioturbated in places, and contains some small-scale slump structures.

Thickness

No complete sections are known. The thickest measured section is 30 m at Kidson Bluff (Section A13, URAL). The unit is probably no thicker than 100 m.

Stratigraphic relations

The Anketell Sandstone lies conformably on the Callawa Formation, and in many places the contact is gradational. The Anketell Sandstone is interpreted as being laterally equivalent to the Samuel Formation in the southern part of the area where both units are horizontally bedded and occur at the same topographic level, and where one appears to grade into the other.

The Anketell Sandstone in places overlaps the Callawa Formation and lies unconformably on Permian and Precambrian rocks. The unit is also unconformably overlain by the Lake George Beds, and is capped by Cainozoic laterite.

Fossils and age

The only known fossils in the unit are foraminifera (Traves et al., 1956), rare wood fragments, and trace fossils which include the burrow Rhizocorallium. Bioturbation is also abundant. The Anketell Sandstone was thought to be Early Cretaceous on the basis of Rhizocorallium (Traves et al., 1956; Veevers, 1962), but this fossil is no longer considered a Early Cretaceous index fossil (Hantzschel, 1962). However, foraminifera collected from the units in ANKETELL indicate an Early Cretaceous age (Crespin in Traves et al., 1956) which is consistent with the interpretation that the Anketell Sandstone is laterally equivalent to the Samuel Formation, also of Early Cretaceous (Aptian) age (Appendix D).

Environment of deposition

The Anketell Sandstone appears to be transitional between the Callawa Formation to the north and the Samuel Formation to the south. The Callawa Formation is interpreted as a fluviatile deposit and the Samuel Formation is marine. Foraminifera found in the Anketell Sandstone indicate marine or brackish-water conditions (Crespin, in Traves et al., 1956). Rhizocorallium is also commonly associated with brackish environments.

The occurrence of trough and planar cross-bedded, fining-upwards cycles in the formation indicates deposition in channels, particularly near the base of the unit (Sections A2, A13, A15). Abundant flaser-bedded sandstone units (Section A2, A13) are commonly formed in a tidal environment where alternating periods of strong current activity and slack water allow preservation of flasers. The extensive bioturbation in the formation (Sections A2, A13) probably reflects a slow rate of deposition.

In summary, the sedimentological and palaeontological evidence suggests that the Anketell Sandstone was deposited under brackish-water conditions, probably in a nearshore environment.

Samuel Formation

The fossiliferous, marine Samuel Formation consists of fine-grained sandstone and mudstone, with minor glauconite. It is of Aptian age.

Distribution and type locality

The Samuel Formation (Lowry et al., 1972) occurs in southeastern RUNTON, western RYAN and most of MORRIS. The

type section is at Mount Charles (lat. 25°45'S, long. 126°11'E, BENTLEY) to the south of the area where the unit is widespread (Jackson & van de Graaff, in prep.). The best exposures of the formation in the area are in the breakaways on eastern MORRIS and on southeastern RUNTON and at Traeger Hills and other more isolated hills on MORRIS.

Lithology

Typically the Samuel Formation consists of thin-bedded, fine and very fine-grained quartz and feldspathic wacke interbedded with mudstone. Ripple cross-bedding and bioturbation are common, and the unit characteristically weathers yellow or brown. A few lenses of coarse-grained quartz wacke occur, and the unit contains glauconite.

Thickness

The thickest measured section of the Samuel Formation is 14.5 m (Section A16) but is incomplete. The formation is thought to be 30 m thick at Bejah Hill but it may be thicker to the east.

Stratigraphic relations

At lat. 23°54'15"S, long. 125°52'35"E about 10 m of fine-grained quartz wacke and mudstone, identified as Samuel Formation, overlies very coarse-grained, moderately to poorly sorted quartz wacke with angular grains which is assigned to the Anketell Sandstone (see also Veevers & Wells, 1961). The contact between these two units is gradational. The Samuel Formation is also interpreted as being laterally facies equivalent to the Anketell Sandstone in northern MORRIS and these relationships are shown in Figure 7.

The upper boundary of the Samuel Formation with the Bejah Claystone is essentially conformable, but it is locally erosional (Section A16) and is probably diachronous. The Lampe Beds unconformably overlie the Samuel Formation, and the formation has a well developed laterite profile in most areas.

Fossils and age

Fossils in the Samuel Formation include pelecypods and gastropods (Appendix D). They indicate an Early Cretaceous (Aptian) age which agrees with palynological evidence to the south of the area (Kemp, 1976).

The Samuel Formation is probably a time-equivalent of the Anketell Sandstone and may be partly equivalent to the Callawa Formation and the Cronin Sandstone.

Environment of deposition

Marine fossils and glauconite indicate deposition in a marine environment. The interbedding of sandstone and mudstone and the presence of ripple marks suggest that deposition took place in a shallow sea, but the absence of large-scale cross-bedding probably indicates that deposition was subtidal. The Anketell Sandstone is interpreted as a nearshore facies of the sea that deposited the Samuel Formation (and the Bejah Claystone). The Early Cretaceous sea in which these sediments were laid down, was connected to the oceans along the south coast of the Australian continent (Jackson & van de Graaff, in prep.), and there is no evidence to suggest that it was connected to the Indian Ocean via the Canning Basin. However, the sea did extend into the southern Canning Basin, indicating that the Warri Gravity Ridge area (the boundary between the two basins) was not a raised topographic high during the Early Cretaceous.

Bejah Claystone

The marine Bejah Claystone consists almost entirely of claystone, with only minor siltstone and sandstone. It is of Aptian-Albian age.

Distribution and type locality

The Bejah Claystone (Veevers & Wells, 1961; Lowry et al., 1972) occurs in southeast RUNTON and MORRIS and at the Traeger Hills. It is widespread in the Officer Basin, south of the area (Jackson et al., 1975). The type section is at Bejah Hill (lat. 23°46'S, long. 124°08'E, RUNTON) but we believe that the lower part of the Bejah Hill section is Samuel Formation and only the upper 3-4 m can be confidently assigned to the Bejah Claystone.

Lithology

The Bejah Claystone is almost entirely composed of claystone, with only minor amounts of siltstone and rare thin laminae of very fine-grained sandstone. At Bejah Hill, there is an apparently coarse-grained bed, but examination with a hand lens shows that the 'grains' are in fact mostly weathered-out radiolaria with a siliceous cement.

The formation is normally massive to poorly bedded and no sedimentary structures were discernible; however, in places mottled weathering patterns may indicate bioturbation.

At Section A16 the base of the Bejah Claystone is marked by a porcellanized clay pellet conglomerate, but elsewhere it appears gradational (Jackson et al., 1975).

Thickness

The Bejah Claystone is not more than 4 m thick at its type section but it may be as much as 10 m thick at the Traeger Hills, MORRIS.

Stratigraphic relations

The Bejah Claystone lies essentially conformably on the Samuel Formation although the boundary is locally erosional. The formation is unconformably overlain by the Lampe Beds and it is lateritized.

Fossils and age

The radiolaria Lithocyclia exilis and Cenosphaera sp. have been found in the Bejah Claystone in the area and they indicate an Albian age (Crespin in Veevers & Wells, 1961). Outside the area the unit contains pelecypods which Skwarko (1967) believes indicate an Aptian age.

The lower boundary of the Bejah Claystone with the Samuel Formation is probably diachronous, so the two units are probably partly time-equivalents.

Environment of deposition

The Bejah Claystone contains a marine fauna which indicates that it is a marine deposit. The fine grain size of the sediment and the absence of sedimentary structures indicate extremely quiet deposition with little influx of terrigenous material by currents. Such deposits appear to have been laid down over large parts of Australia during the Early Cretaceous (Brunnschweiler, 1958) and they indicate that the particular conditions responsible were not restricted to the Officer and southern Canning Basins.

UNDIVIDED MESOZOIC

About 10 m of fine to medium-grained, moderately to poorly sorted sandstone with clay pellets together with granule conglomerate and laminae of mudstone, is exposed (Section A17) at Dowling Hills, a group of small, low hills in southwest RYAN

(lat. 23°45'S, long. 126°12'E). The sequence is undated but may be equivalent to the Callawa Formation. Since the Dowling Hills area is transitional between the Canning and Officer Basins, the sandstone exposed there could also be correlated with the Cronin Sandstone. As there is no evidence to indicate which of these correlations is correct, the sequence is mapped as Mesozoic undivided. Palynological data would probably be needed to solve the problem.

CRETACEOUS TO TERTIARY

Lake George Beds (new name not yet approved)

The Lake George Beds consist of massive sandstone and granule conglomerate which are interpreted as overbank deposits and partly pedogenic. The Beds unconformably overlie the Callawa Formation and the Anketell Sandstone.

Distribution and type locality

The Lake George Beds occur in SAHARA, PERCIVAL, TABLETOP, RUNTON and URAL. The best exposure is at the type section, 8 km southeast of Helen Hill, on TABLETOP. Good exposures also occur in southern PERCIVAL, southeast SAHARA and at Winnecke Rock, RUNTON. Photo-interpretation suggests the unit is widespread in northwest SAHARA.

Lithology

The Lake George Beds are composed of poorly sorted, fine to very coarse-grained quartz wacke and granule conglomerate. The massive appearance of the Lake George Beds distinguishes them from the underlying rocks. Interstices contain limonite, chalcedonic silica and clay.

Silicified pipe-like structures, possibly caused by solution, are present within the Beds. Moulds interpreted as root casts also occur.

Thickness

At the type section the Lake George Beds are 5 m thick, but they may be thicker elsewhere.

Stratigraphic relations

The Lake George Beds unconformably overlie the Callawa Formation and the Anketell Sandstone. Locally the contacts are gradational. The Beds are capped by laterite.

Fossils and age

No age-diagnostic fossils are known from the unit. A Cretaceous to Tertiary age is assigned to the Lake George Beds because they occupy a similar stratigraphic and topographic position to the Lampe Beds.

Environment of deposition

The Lake George Beds are interpreted as overbank deposits which have been deeply weathered. The absence of bedding and sorting, the gradational lower contact of the beds with the underlying units, and the presence of moulds interpreted as root casts suggests that the unit may be pedogenic in part. It is envisaged that the Lake George Beds formed contemporaneously with the Lampe Beds, which are interpreted as fluviatile deposits.

Lampe Beds

The Lampe Beds (Lowry et al., 1972) consist of silcretized sandstone and conglomerate which overlie Cretaceous and Permian rocks in the Gibson and Great Victoria Deserts. They are interpreted as fluviatile in origin and are assigned a Cretaceous-Tertiary age.

Distribution and type locality

The Lampe Beds were recognized in the south Canning Basin for the first time during field mapping in 1975, where they occur as cappings on mesas and small rises on RYAN, MORRIS and RUNTON. The type section is located at Mount Johnson (lat. 25°24'S, long. 124°25'E) on HERBERT in the Officer Basin.

Lithology

Silicified quartz pebble and granule conglomerate together with coarse to very coarse-grained poorly-sorted quartz wacke are the dominant lithologies of the Lampe Beds. The constituent grains are subrounded to subangular. Many of the exposures lack distinct bedding, but where present the bedding is thick and is locally cross-bedded. The Beds are commonly altered to silcrete.

Stratigraphic relations

The Lampe Beds unconformably overlie Proterozoic sediments, the Paterson and Samuel Formations, and the Bejah Claystone. The upper contact of the Lampe Beds is commonly an erosional surface, but at Cromer Cone (RUNTON) laterite overlies the Lampe Beds. However, at the Traeger Hills (MORRIS) laterite is also overlain by the Lampe Beds.

Fossils and age

The age of the Lampe Beds is uncertain as no fossils have been found in them. The beds are younger than the Early Cretaceous Bejah Claystone and are considered to be older than the main laterite horizons, which may be early Tertiary in age (see under Palaeodrainages).

Thickness

No sections were measured but the maximum thickness observed in the field is approximately 2 m.

Environment of deposition

The coarse nature and poor sorting of the Lampe Beds indicate that they are fluviatile (Jackson & van de Graaff, in prep.; van de Graaff, et al., in prep.).

CAINOZOIC

Calcrete, chalcedony (Czk)

Calcrete and chalcedony occur mainly in palaeo-drainage depressions and were probably mostly deposited as the drainages were drying up in the early Tertiary. However, some calcrete bodies may be younger than early Tertiary so the unit is mapped as a Cainozoic deposit.

The calcrete consists of impure argillaceous and arenaceous limestone with secondary chalcedony locally abundant. In many places most of the carbonate is weathered out, and all that is present on the surface are slightly calcareous deposits. In the Well 30 area, the calcrete is cavernous; the collapse of some caves has caused a 'hummocky' (karst) topography (TABLETOP).

Calcrete bodies are important aquifers in the region and most wells on the Canning Stock Route are sited in them.

Laterite (Czl)

Laterite is ubiquitous in the area and where it is not mapped on the surface it is probably present under the blanket of aeolian sand. On finer-grained rocks (Samuel Formation and Bejah Claystone) in the southern part of the

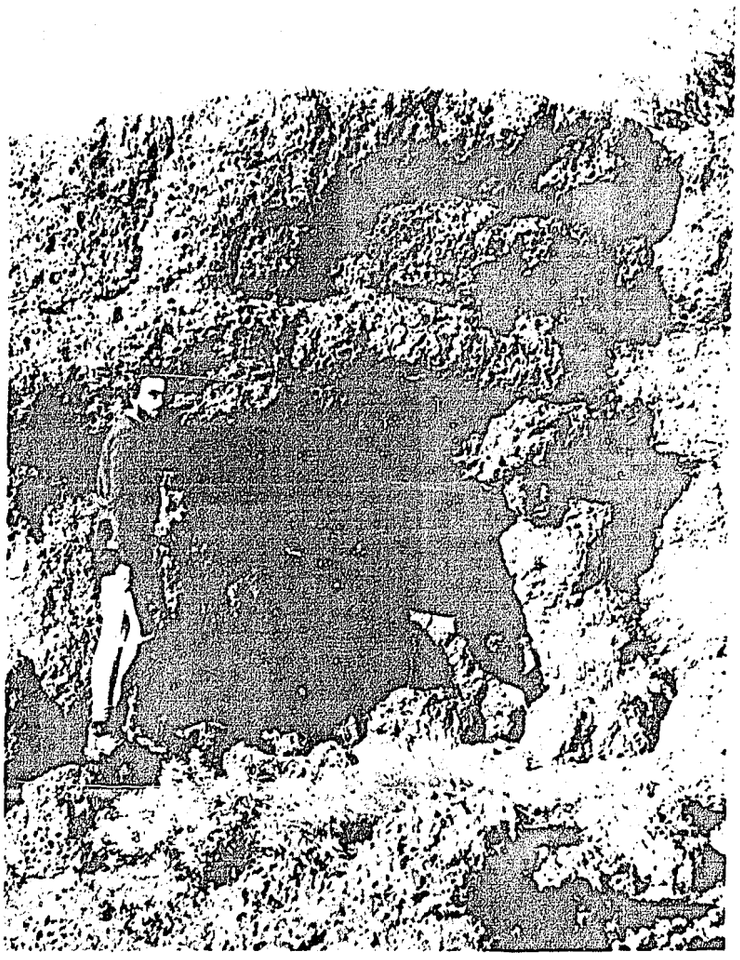


Plate 10: Outcrop of massive, pisolitic laterite forming thick capping in western WILSON. BMR Negative GB/1078

area the massive or pisolitic laterite capping (Plate 10) may be up to 10 m thick. On the coarser-grained sediments of the northern part of the area it is not as thick and is associated with other weathering products such as ferricrete and silcrete.

In the Gibson Desert, the laterite preserves the palaeodrainages, and the present lateritic surfaces represent a more subdued replica of the landscape under which it was formed. The laterite was probably formed as the palaeodrainages began to dry up in the Early Tertiary (van de Graaff et al., in prep.) but as younger laterites are known in Western Australia we prefer to map the unit as Cainozoic in age.

All the pre-Early Cretaceous Phanerozoic rock units are lateritized to a greater or lesser extent, and the Cretaceous to Tertiary Lampe Beds are both overlain and underlain by the laterite. The Lake George Beds - the probably equivalent of the Lampe Beds - are also lateritized.

Lake deposits (Ql)

Lake deposits occur in the palaeodrainage depressions in which they were deposited. Most of the playas are still active sites of sedimentation as clay, silt and minor sand are washed into them during heavy rain. Consequently the surface deposits are marked as Quaternary in age; however, many of the larger lakes contain thick sequences (probably up to 100 m), of sediments and such deposits probably date back to the Tertiary.

The playas containing these deposits probably formed as the palaeodrainages became dammed with sediments due to insufficient run-off. This is thought to have occurred in the Early Tertiary (van de Graaff et al., in prep.).

Authigenic gypsum is common in the lake deposits and also near Scott Bluff (TABLETOP), where layers of authigenic gypsum crystals (up to 10 cm thick) occur in deeply weathered exposures of Paterson Formation around the shores of Lake Blanche.

Alluvium (Qa)

Surface deposits of alluvium are rare in the area as there are few modern drainages. Some deposits occur beside the Rudall River (RUDALL) and other creeks that drain the Precambrian highland areas. A few smaller deposits also occur as washout fans, where small creeks drain breakaways. Most alluvium in the area is mixed with aeolian sand and is mapped as 'mixed aeolian and alluvial deposits'. This unit occurs mainly in the palaeodrainage depressions where surface run-off (mainly sheet wash) has deposited finer-grained sediment (silt, clay and minor sand) in the depressions and this has later become mixed with aeolian sands during dry periods.

Aeolian Sand (Qz)

Aeolian sand is abundant and occurs in the northern, eastern and western parts of the area. It mainly occurs as longitudinal (seif) dunes but some small sand plains without dunes also occur (eg. east RUNTON). The sand dunes are mainly fixed by vegetation, and significant sand movement occurs only after the vegetation has been burned off. In such places the dunes appear to have been eroded rather than maintained or rebuilt (Plate 11).

Crowe (1975) has described the formation, evolution and distribution of the sand dunes in this part of the desert and he has shown that denser dune patterns correspond with depressions. All of Crowe's (1975) three types of sand dunes occur: simple longitudinal, chain longitudinal (Plate 12), and net-like dunes. The sand dunes in the area were formed by easterly winds, which still prevail.

The sand that comprises the sand dunes was probably derived from:

(a) erosion of Precambrian rocks to the east of the area
(b) erosion and retreat of breakaways in the area
(c) redistribution of soil that must have existed over the laterite when it formed.

The third source is probably the most important as evidenced by the abundance of sand dunes over the more weathered sandy bedrock and their absence over the more resistant clayey bedrock.

4. PALAEODRAINAGES

Palaeodrainages are conspicuous and important features of the landscape over much of the area. Many of the ancient valleys show up clearly on the airphotos and many are reflected in the mapped distribution of Cainozoic units (e.g. MORRIS). Bunting et al. (1974) have shown that, to the south of the study area, contour maps can be used to elucidate the ancient drainage patterns, even in areas that are obscured by the thin cover (less than 5 m) of aeolian sand. The map (Figure 8) and the following summary is based mainly on a paper by van de Graaff et al. (in prep.).

Palaeodrainage patterns and age

Fine-textured palaeodrainage patterns, such as occur on MORRIS, are characteristic of fine-grained impermeable clayey bedrock, whereas coarser-textured patterns, such as occur on URAL, are typical of areas with sandy bedrock (Bunting et al., 1974) (Plate 13). Another example of bedrock control on the ancient drainage pattern is seen where the chain of playas that includes Lakes Dora and Blanche has a northwesterly trend parallel to the regional strike of the bedrock.

Most palaeodrainages in the area drained towards Lake Dora (see Fig. 8) and from there into the Indian Ocean via the present-day location of the De Grey River; however, in the eastern part of the area there is an enclosed depression centred about playas on RYAN. Van de Graaff et al. (in prep.) believe that the drainages in this depression originally flowed south to the Great Australian Bight via Lake Newell (COBB) but that epeirogeny along the site of the Warri Gravity High (probably during the Early Tertiary) resulted in diversion of the drainages and the formation of an area of internal drainage. They also believe that the 'S' bend in which Lake Auld is situated was caused by diversion of the Percival Lakes drainage system southwards into the system that contains Lakes Blanche and Dora (Plate 14).

The maximum possible age of the palaeodrainages in most of the area is early Late Cretaceous, as the ancient valleys are incised into the marine Bejah Claystone of Aptian-Albian age. Van de Graaff et al. (in prep.) believe that the Lampe Beds represent early deposits of the ancient drainages. However, at present, the Lampe Beds have not been dated accurately. On the edges of the Precambrian shield (on RUDALL) some palaeodrainages follow exhumed Early Permian valleys; however, none of these palaeodrainages are demonstratably as old as that, and they are more likely to be superimposed features. Evidence for the minimum age of the palaeodrainage is not present in the area, but Bunting et al. (1974) have shown that, about 600 km to the south of the area, on the edge of the Nullarbor Plain, significant water-flow had ceased in the ancient valleys before the Middle Miocene, as marine sediments of that age, in the Eucla Basin, abut the old valleys.

Implications of the palaeodrainages

The presence of such a well-developed Late Cretaceous to Early Tertiary drainage system in the area indicates that the climate of that period was more humid than at present. This is supported by the presence of laterite, which requires a higher

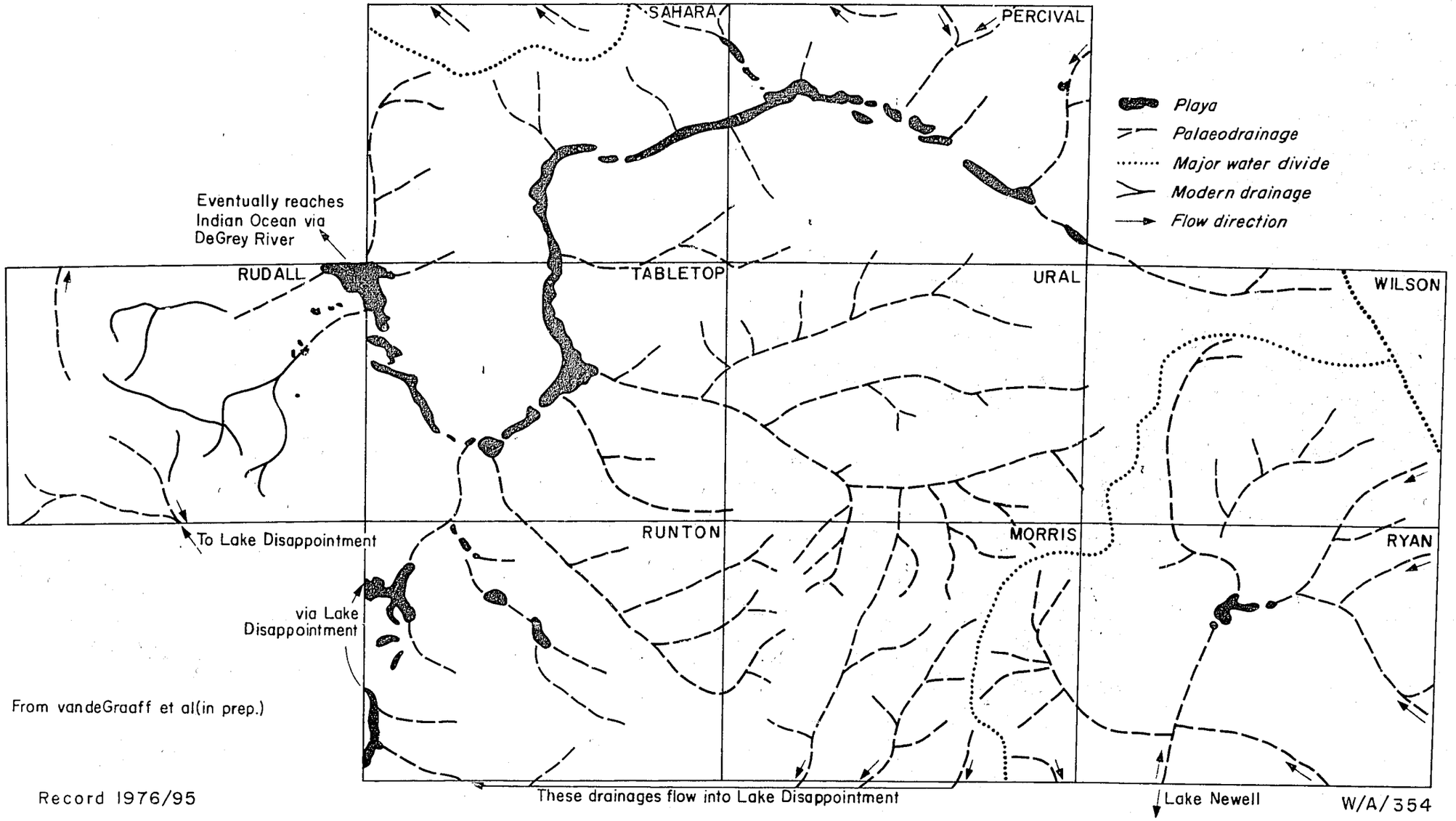


Fig 8 PALAEODRAINAGES OF THE SOUTH CANNING BASIN

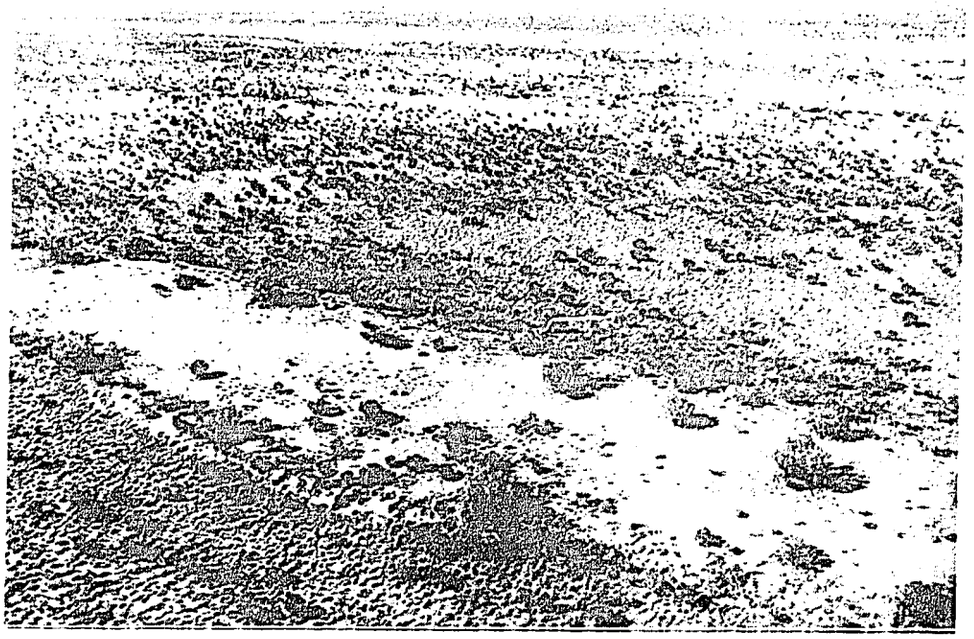


Plate 11: Eroded sand dunes with the crest almost completely flattened indicating active erosion of sand dunes in the area, WILSON. GSWA Negative.



Plate 12: Simple, longitudinal dune merging into chain longitudinal dunes in the background, Western WILSON. GSWA Negative.



Plate 13: Lines of dense vegetation mark the trunk valleys of the fossil drainage channels, with laterite flanking these valleys in the middle background, URAL. GSWA Negative.

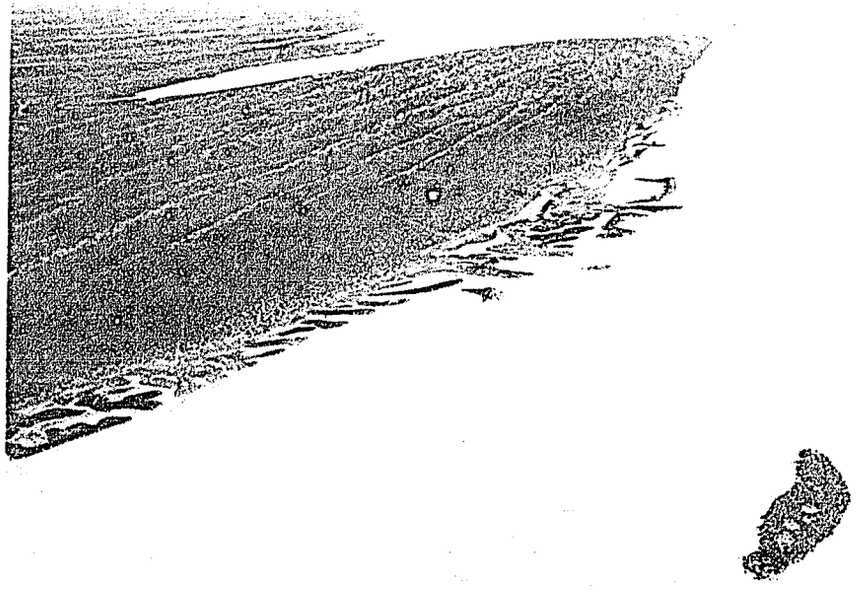


Plate 14: View looking southwest of western end of the Percival Lakes, PERCIVAL. These lakes mark one of the prominent palaeodrainages in the area. Note the dense dunes adjacent to the lakes. GSWA Negative.

rainfall than occurs in the area today. The laterite has preserved the ancient drainage system from erosion, but the main reason that the valleys are still so well preserved is that the area has experienced remarkable tectonic stability and an arid climate, resulting in little erosion and only minor burial.

5. STRUCTURAL GEOLOGY

Parts of the four tectonic units that occur within the area are described below. They are the Phanerozoic Canning Basin, the Proterozoic-Phanerozoic Officer and Amadeus Basins, and the Precambrian Arunta Block. These are depicted in Figure 9.

Rocks of the Arunta Block crop out in a small area in southeast WILSON, where they consist of folded sedimentary rocks intruded by adamellite. Immediately to the east, on WEBB, the Arunta Block is composed of tightly folded Archaean metamorphic rocks which trend parallel to the foliation trends of the Mount Webb Adamellite and to the closely-spaced jointing within the acid lavas of the Pollock Hills Formation (Blake & Towner, 1974).

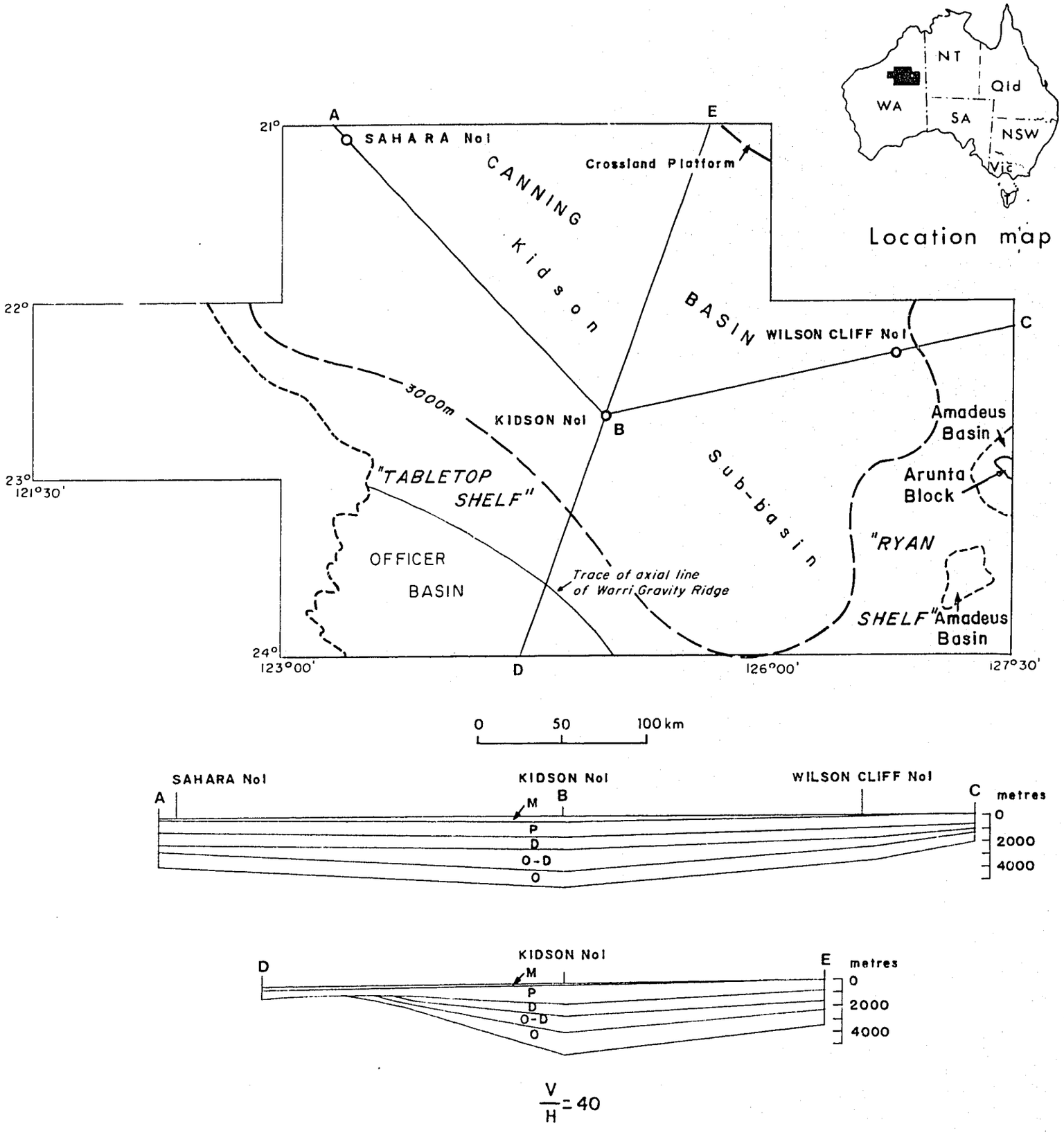
The western fringe of the Amadeus Basin occurs in the east of WILSON and RYAN. The Amadeus Basin is a complex intracratonic depression elongated east-west in central Australia and containing Late Adelaidean and Early Palaeozoic sediments which have been folded and faulted several times. Evidence for two of these events is present on RYAN. The Areyonga Movement produced the unconformity between the Bitter Springs Formation and the Ellis Sandstone, and the Petermann Range Orogeny (Late Proterozoic or Early Cambrian) was responsible for tight folding of the Ellis Sandstone and Maurice Formation (Wells et al., 1964; 1970).

A small part of the Officer Basin occurs within the area in southern RUNTON and southwest MORRIS. The Officer Basin contains a Proterozoic and Phanerozoic sequence which may be up to 12 000 m thick in places (Jackson, 1966; Lowry et al., 1972; M.J. Jackson, pers. comm.). The boundary between the Officer and Canning Basins remains uncertain. However, a gravity high, the Warri Gravity Ridge, part of the Anketell Regional Gravity Ridge, is interpreted as representing an area of very shallow basement, and other geophysical evidence indicates that the thickness of sedimentary rocks on either side becomes greater away from the feature (Darby & Fraser, 1969). Thus, the boundary between the two basins is tentatively placed along the axial region of Bouguer anomaly contours (Fig. 4). Surface information does not allow any more precise definition of this boundary although there are stratigraphic differences between the two basins.

Further seismic information across the Warri Gravity Ridge is needed to delineate the nature of the boundary more accurately.

Most of the area described in this report belongs to the Canning Basin, of which the Kidson Sub-basin (WAPET, 1966a) forms a major subdivision. A small portion of the Crossland Platform is present along with the 'Tabletop Shelf' (Koop, 1966a) and the 'Ryan Shelf' (Fig. 9; Basin Studies Group, pers. comm.).

The Crossland Platform is present in the northeast on PERCIVAL and WILSON. Though it is a platform with respect to the tectonic elements in the northern part of the Canning Basin, it slopes gradually southward into the Kidson Sub-basin, and the boundary as shown in Figure 9 is arbitrarily taken at the 3000 m depth-to-basement isopach (Basin Studies Group, pers. comm.). The BMR Basin Studies Group is currently reviewing the structural nomenclature of the Canning Basin, and the results will be published shortly.



Record 1976/95

W/A/331

Fig 9 Provisional tectonic map and cross-section of the southern part of Canning Basin

The Kidson Sub-basin succession has a gentle regional dip towards its axial region, which trends northwest across the area. The regional dip is up to 2° below the base of Grant Formation and up to 1° above it. A few low-amplitude flexures are suggested by gravity results in northwest SAHARA (WAPET, 1963b). A seismic survey conducted over these areas confirmed the presence of broad anticlines with gentle relief.

There are apparently no major faults cutting the Kidson Sub-basin sequence. Along the southwest margin in TABLETOP, seismic surveys have revealed subsurface faults with up to 200 m of near-vertical displacements cutting the pre-Middle Devonian section. A few similar subsurface faults are present near the edge of the Kidson Sub-basin in RYAN and WILSON. A northwest-trending zone of en echelon north-trending faults is present centred on Scott Bluff, TABLETOP. However, it is unlikely that these faults have vertical displacements of more than 20 m.

At latitude $22^{o}58'18''$, longitude $123^{o}35'48''$ is a small reverse fault zone which is younger than the Anketell Sandstone in age. The movement along the fault has caused the coarse-grained, bioturbated quartz wacke of the Anketell Sandstone to crop out beside the graded siltstone and fine quartz wacke of the Grant Formation. Aerial reconnaissance in northern WILSON in 1973 and 1975 by the authors over a zone of major earthquake epicentres (Denham et al., 1974) did not reveal any surface evidence of fractures.

The Veevers Crater found during the survey is thought to be of meteoritic origin (Yeates et al., 1976) but it is structurally insignificant within the Kidson Sub-basin sequence.

6. GEOLOGICAL HISTORY

In at least the eastern part of the area, Archaean sand, silt and mud were metamorphosed during Proterozoic times to form the Arunta Complex. In the mid-Carpentarian, following a period of uplift and erosion, acid volcanics and sedimentary

rocks (Pollock Hills Formation) accumulated during a marine transgression, and simultaneously or shortly afterwards, acid magma (Mount Webb Adamellite) intruded the sequence. A long period of erosion ensued until in the Adelaidean, when sand, silt and gravel (Heavitree Quartzite) were deposited in a widespread shallow sea which flooded the bevelled crystalline basement. Sand, mud and lime, and possibly evaporites, then accumulated in barred lagoons (Bitter Springs Formation). The final phase of Amadeus Basin sedimentation was the deposition of sand and silt (Ellis Sandstone and Maurice Formation) probably in alternating fluvial and near-shore marine environments.

Near the end of the Adelaidean or early in the Cambrian, possibly during the Petermann Ranges Orogeny (Wells et al., 1970), the Adelaidean sediments were strongly folded and faulted, and the area was uplifted to form a landmass, part of which may subsequently have been the provenance for early Palaeozoic sedimentation in the Canning Basin.

In the very late Adelaidean, or in the earliest Cambrian, mud accumulated along the extreme western edge of the Amadeus Basin and in the Canning Basin.

Following a period of erosion during which the landscape became relatively flat, silt, sand and lime were deposited when the sea flooded a large area in northwestern Australia. These sediments represent earliest deposition in an area that was to become the Canning Basin during Early to Middle Ordovician time (Goldwyer Formation). No sedimentation occurred in the southern part of RUNTON and MORRIS. In the Late Ordovician, the sea became shallower, and it partly retreated from the area, allowing evaporitic conditions to prevail. Salt deposition was more extensive in the centre of the Kidson Sub-basin, as peripheral areas became slightly emergent during Late Ordovician to Early Devonian times. Silt and clay of probable continental origin were laid down during salt deposition (Carribuddy Formation).

In the Early Devonian, red sand and silt was deposited by winds and rivers in a dominantly continental environment (Tandalgoo Red Beds).

Postdating the deposition of the Tandalgoo Red Beds, mobilization of the salt units within the Carribuddy Formation may have occurred producing structural features referred to as 'salt wells' recognized in the northern Canning Basin (Willmott, 1962).

The sea returned during the Middle Devonian and covered a large part of the area. Lime and sand accumulated (Mellinjerie Limestone), the thickest deposit occurring in the centre of the Kidson Sub-basin.

Throughout Ordovician to Middle Devonian time, the area was slowly sinking by tilting and subsidence, the subsidence occurring at a slightly faster rate in what is now the axial region of the Kidson Sub-basin. The area south of latitude 23°S and west of longitude 126°E (that is, RUNTON and southwest MORRIS) was probably emergent and formed a landmass.

From late Middle Devonian to early Late Carboniferous time, sand, mud and lime may have accumulated periodically within the area as it did in the Fitzroy Trough and Gregory Sub-basin to the north. However, post-Middle Devonian to pre-Permian uplift and subsequent erosion has stripped most of the inferred Devonian-Carboniferous sediments from the area.

In the earliest Permian, adjacent areas were undergoing glaciation as indicated by striated pavements. Within the exhumed valleys in the Precambrian landmass and probably on various parts of the pre-Permian floor of the Canning and Officer Basins, deposition of silt and sand with striated pebbles was taking place in rivers and lakes under the influence of a glacial climate (Paterson Formation). Following this the whole of the area was blanketed by silt, sand and minor gravel laid down in shallow water with some marine influence (Grant Formation).

As the climate became warmer, by late Sakmarian to early Artinskian times, sand, silt and minor gravel (Poole Sandstone) were laid down in a sea to the north of the site of the Warri Gravity Ridge. Rivers in the east probably contributed some detrital material.

In late Artinskian times, this shallow sea deposited mud, lime and some sand (Noonkanbah Formation), mainly under reducing conditions. Terrigenous material was deposited mainly in the eastern part of the area. Then the sea probably regressed from the area, the water shallowed, and the influx of terrigenous material increased as sand and silt (Triwhite Sandstone) were laid down.

A period of non-deposition and some erosion followed until the Late Jurassic to Early Cretaceous, when meandering rivers deposited sand and gravel in the Kidson Sub-basin (Callawa Formation) and in the Officer Basin (Cronin Sandstone). In the Early Cretaceous (Aptian), shallow seas extended from the Officer Basin area northwards as far as southern RUNTON, western RYAN and most of MORRIS, depositing sand and mud in a possible subtidal environment in which invertebrates flourished (Samuel Formation). Simultaneously, near-shore conditions prevailed to the north of this sea and the Anketell Sandstone was deposited in brackish water.

In Albian times, clays were deposited under extremely quiet conditions in a marine environment with little influx of material from outside the area (Bejah Claystone).

Following the final retreat of the sea in the Late Cretaceous, deep chemical weathering affected the basin area which was mainly of low relief with the exception of Baron Range (RYAN). Soils formed on the alluvial plains of the Anketell and Callawa Formations (Lake George Beds), and a large drainage system formed over most of the area; sand and gravel of the Lampe Beds represent early deposits of these rivers. As the

climate became hotter and humid, extensive laterite profiles developed. Lateritic processes may also have continued at intervals throughout the Cainozoic until the climate eventually became arid.

With the onset of arid conditions, dessication of the laterite surface and the formation of mesas and buttes occurred. Drainages became dammed with alluvium and lakes developed. Calcrete and minor evaporites formed in these lakes and in the drainage channels, and may still be forming at present. Sub-aerial erosion of the laterite surfaces produced sand dunes.

7. ECONOMIC GEOLOGY

Petroleum

Estimates of source-rock and reservoir-rock potential for the Kidson Sub-basin sequence is summarized in Table 2.

The Ordovician sequence, known from Aquitaine Wilson Cliffs No. 1 (AAP, 1969c) and Contention Heights No. 1 (AAP, 1974) has source-rock potential, and as it contains sandy facies it may also have reservoir potential. However, in both these deep drill holes, the sandstone was found to have low porosity.

The Carribuddy Formation and the overlying Tandalgoo Red Beds, being deposited mainly under oxidizing conditions, have low source potential. However, evaporites within the Carribuddy Formation may be potential cap rocks because of the impermeability associated with evaporites. Diapiric folding, a feature of evaporitic sequences, occurs within the formation in the north of the Canning Basin. If present in the south Canning Basin, it could provide suitable structural traps for petroleum.

The Mellinjerie Limestone may also be prospective. It has some potential as a source rock and it contains sandy facies which have a moderate porosity.

Drew & Evans (1975) have interpreted possible reef structures in the Ordovician-Devonian sequence on the Crossland Platform to the north of the area on HELENA. Since the Phanerozoic sequence dips generally towards the axial region of the Kidson Sub-basin, any petroleum generated within the sediments would most likely migrate up-dip towards the margins of the sub-basin and towards the Crossland Platform.

The Permian sequence, apart from the Noonkanbah Formation, appears to lack generative source rocks and, in all parts of the area, it is too close to the surface to have undergone sufficient thermal diagenesis to generate petroleum. The sequence does, however, contain potential reservoirs such as the Grant Formation and Poole Sandstone. The Noonkanbah Formation is a prospective cap rock.

The Mesozoic rocks have no petroleum potential.

Groundwater

The area is prospective for groundwater. Th. present distribution of wells in the area has not completely tested the resources. All water wells drilled and utilized by petroleum exploration companies in the area were found to be dry or collapsed when examined during 1975. The condition of water wells on the Canning Stock Route in the area is summarized in Table 3. Their positions are accurately located on the respective 1:250 000 preliminary geological maps.

The water-table is generally within 10 m of the surface in the larger ancient drainages, and deeper elsewhere.

The few petroleum exploration and stratigraphic wells have indicated mainly saline water for most pre-Permian units encountered. However, the Early Devonian Tandalgoo Red Beds contained fresh water in Aquitaine Wilson Cliffs No. 1 (AAP,

Table 2. Summary of petroleum potential for pre-Permian units

Age	Stratigraphic Unit	Porosity	Permeability	Remarks
Middle Devonian	Mellinjerie Limestone	generally low	low	Porosity in sandstone units
Early Devonian	Tandalgoo Red Beds	variable; low to good	variable low to high	Potential reservoirs; flushed with fresh water deposited mainly in oxidizing conditions
Late Ordovician to Early Devonian	Carribuddy Formation	low to moderate	low	Evaporitic; low source potential; some reservoir potential; if diapiric folding exists it could provide suitable structure.
Ordovician	Undivided - includes Goldwyer Formation and informally named units in Aquitaine Wilson Cliffs No. 1 and Contention Heights No. 1	low	low	Reasonable source potential; known sandstones lack good porosity and are water saturated; traces of methane recorded (AAP, 1969c; 1974).

1969c) and in WAPET Kidson No. 1 (WAPET, 1966c). Good porosity and fair permeability have been indicated in some intervals of the unit (WAPET, 1966c). The Tandalgoo Red Beds are therefore a prospective aquifer, but they occur at a much greater depth than more prospective units above them.

Parts of the Grant Formation and overlying Poole Sandstone are excellent aquifers in other parts of the Canning Basin (Veevers & Wells, 1961; Yeates et al., 1975) and they may yield good water in this area. Much of this sequence is composed of porous, clean quartzose sandstone units with porosities of up to 20% in WAPET Kidson No. 1 (WAPET, 1966c). The overlying shales and siltstones of the Noonkanbah Formation provide confining beds for these aquifers. The Triwhite Sandstone would most probably yield small supplies of saline water.

The Callawa Formation and sandy facies within the Anketell Sandstone have yielded water in bores sunk and utilized during petroleum exploration surveys. The quartzose sandstone and conglomerate, being porous and widespread, make the units prospective for groundwater where they can be intersected beneath the water-table. However, much of their known distribution (especially around the edges of the basin) would be above the water-table.

Deposits of the ancient drainage system are excellent aquifiers. Many of the wells along the Canning Stock Route are located in such settings, principally within calcrete. The ancient drainage system, in many places, has dissected the base of the Mesozoic rocks, so that the Cainozoic deposits lie on the relatively impervious rocks of the Triwhite Sandstone and the Noonkanbah Formation. The water salinity within these aquifers is variable; it becomes more saline towards the large salt lakes of the area, where the salt water is less than 1 m below the lake surface.

Table 3. Condition of water wells along Canning Stock Route, July 1975

Well	Condition
26	Unknown; not visited
27	Unknown; not visited
28	Unknown; not visited
29	Timber of well in reasonable condition, but loose at surface; water is weed-filled, uncovered
30	Dry; caved-in and silted-up to within 2 m of surface
31	Dry; caved-in and silted-up; very insecure timbering; uncovered
32	Timber secure; uncovered; water polluted with dead birds
33	Timber secure; partly covered; water polluted with dead birds and dingo
34	Timber secure; uncovered; water green with algae
35	Dry; caved-in
36	Timber insecure; uncovered; water polluted with dead animals
37	Timber insecure; uncovered; water filled with algae and weeds
38	Dry rockhole; numerous small rockholes nearby contained a total of about 70 litres of water collectively, July 1975
39	Timber secure; uncovered; water putrid with dead animals and algae
40	Timber secure; uncovered; water contained dead birds and green algae
41	Timber insecure; uncovered; water contained dead birds
42	Secure open cut well; water full of green algae
43	Timber secure; half-covered; water putrid from dead dingo.

Coal

Thin coal seams have been intersected in the Grant Formation, Poole Sandstone and Noonkanbah Formation. However, as the coal occurs in predominantly marine units, the prospects of finding large deposits are slight.

Evaporites

Thick sequences of evaporites (chiefly halite and gypsum) are present at depth in the Carribuddy Formation (Glover, 1973). Evaporites (chiefly gypsum) up to 1 cm thick cover the surface of the large salt lakes, and further thin layers are present within the lake sediments.

Uranium

No uranium has been found in the area, but there is a possibility of secondary concentrations occurring within deposits of the ancient drainage systems.

Constructional materials

Goethite pisolites within laterite and reworked laterite are present within the area in large quantities and are suitable for constructing roads.

8. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance of Glen Roberts while he was under contract to the BMR to deliver fuel from Port Hedland to Lake Auld (TABLETOP). He provided very useful information on the condition of tracks and water bores in the area.

The Basin Study Group of BMR gave assistance with the compilation of subsurface data.

9. REFERENCES

ALLEN, J.R.L., 1963 - The classification of cross-stratified units with notes on their origin. Sedimentology, 2, pp. 93-114.

AUSTRALIA, BUREAU OF CENSUS AND STATISTICS, 1970 - Official year book of the Commonwealth of Australia, No. 56 Canberra, Aust. Govt. Publ. Serv.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1965 - Pollock Hills aeromagnetic survey (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 65/4619.

ASSOCIATED AUSTRALIAN OILFIELDS N.L., 1972 - Billiluna-Helena aeromagnetic survey (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 71/422.

ASSOCIATED AUSTRALIAN RESOURCES N.L., 1974 - Thornton seismic survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 72/3362.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1966 - Point Moody No. 1, Well Completion Report. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 65/4174.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1968 - Dakota seismic and gravity survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 67/11161.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969a - Ryan seismic and gravity survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 68/3026.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969b - Terry Range magneto-telluric survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 68/3016.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969c - Wilson Cliffs No. 1, Well Completion Report. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 68/2011.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969d - Contention Heights seismic refraction survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 69/3036.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1969e - Baron Range seismic and gravity survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 69/3052.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1972 - White Hills area high sensitivity aeromagnetic survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 71/508.

AUSTRALIAN AQUITAINE PETROLEUM PTY LTD, 1974 - Contention Heights No. 1, Well Completion Report. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 73/230.

AUSTRALIAN CODE OF STRATIGRAPHIC NOMENCLATURE, 1973 - J. geol. Soc. Aust., 20(1), 105-112.

BEARD, J.S., 1969 - The natural regions of the deserts of Western Australia. J. Ecol., 57, 677-711.

BEARD, J.S., & WEBB, M.J., 1974 - Vegetation survey of Western Australia - Sheet 2, Great Sandy Desert. Univ. West. Aust.

BLAKE, D.H., HODGSON, I.M., and MUHLING, P.L., 1973 - Geology of the Granites and Precambrian parts of the Billiluna, Lucas and Stansmore 1:250 000 Sheet areas, Northern Territory and Western Australia. Bur. Miner. Resour. Aust. Rec. 1973/71 (unpubl.).

BLAKE, D.H., & TOWNER, R.R., 1974 - Geology of the Webb 1:250 000 Sheet area, Western Australia. Bur. Miner. Resour. Aust. Rec. 1974/53 (unpubl.).

BLATCHFORD, T., 1924 - Braeside lead deposits. Ann. Rep. Dep. Min. West. Aust. for 1924. Append. 22, 79.

BREMNER, C. St J., 1940 - Aerial geological reconnaissance of the Fitzroy Desert Basin, Western Australia. (Unpubl. Company Report). Caltex (Aust.) Oil Development Pty Ltd.

BREMNER, C. St J., 1942 - Aerial reconnaissance of the south margin of the Fitzroy Basin, Western Australia. (Unpubl. Company Report). Caltex (Aust.) Oil Development Pty Ltd.

BROWN, G.A., 1959 - Desert dune sands from the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1959/82 (unpubl.).

BRUNNSCHWEILER, R.O., 1958 - New Aconeceratinae (Ammonoidea) from the Albian and Aptian of Australia. Bur. Miner. Resour. Aust. Bull. 54.

BUNTING, J.A., VAN DE GRAAFF, W.J.E., & JACKSON, M.J., 1974 - Palaeodrainages and Cainozoic palaeogeography of the Eastern Goldfields, Gibson Desert and Great Victoria Desert. Geol. Surv. W. Aust. Ann. Rep. for 1973.

CARNEGIE, D.W., 1898 - SPINIFEX AND SAND. London, Pearson.

CASEY, J.N., & WELLS, A.T., 1964 - The geology of the north-east Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 49.

CREEVEY, K.J., 1971 - Recent information and prospects in the Kidson Sub-basin. APEA J., 53-58.

CROWE, R.W.A., 1975 - The classification, genesis and evolution of sand dunes in the Great Sandy Desert. Geol. Surv. West. Aust. Ann. Rep. for 1974.

CROWE, R.W.A., & TOWNER, R.R., 1976 - Permian stratigraphy of the Noonkanbah 1:250 000 Sheet area. Bur. Miner. Resour. Aust. Rec. 1976/24 (unpubl.).

DARBY, F., & FRASER, A.R., 1969 - Reconnaissance helicopter gravity survey, Canning Basin, W.A., 1968. Bur. Miner. Resour. Aust. Rec. 1969/37 (unpubl.).

DENHAM, D., EVERINGHAM, I.B., & GREGSON, P.J., 1974 - East Canning Basin Earthquake, March 1970. J. geol. Soc. Aust., 21(3), 353-358.

DEPARTMENT OF MINERALS AND ENERGY, 1973 - Atlas of Australian Resources. Second series. Division of National Mapping.

DREW, M.F., & EVANS, G.R., 1975 - Recent geological nd geophysical results in the northeastern Canning Basin. APEA J., 1-11.

ELLIOTT, R.M.L., 1961 - New and amended Formation names. Appendix 7 in WAPET 1961, Thangoo No. 1 and No. 1A Wells, Western Australia. Bur. Miner. Resour. Aust. Petrol. Search. Subs. Act Publ. 14.

EVANS, G.R., & BROWN, L.N., 1974 - Reports of the 1973 field mapping programme, Exploration Permits 58, 59 and 70 (W.A.). (Unpubl. Company Report). Mines Administration Ltd.

FEEKEN, E.H.J., FEEKEN, C.E.E., & SPATE, D.H.K., 1970 - THE DISCOVERY AND EXPLORATION OF AUSTRALIA. Sydney, Nelson.

FLAVELLE, A.J., 1974 - Canning Basin gravity surveys, 1953-1962. Bur. Miner. Resour. Aust. Rec. 1974/181 (unpubl.).

FLAVELLE, A.J., & GOODSPEED, M.J., 1962 - Fitzroy and Canning Basins reconnaissance gravity survey, Western Australia 1952-60. Bur. Miner. Resour. Aust. Rec. 1962/105 (unpubl.).

FRENCH PETROLEUM CO. (AUST.) PTY LTD, 1967 - Reflection/refraction seismograph and gravity survey of McLarty Prospect, West. Australia. (Unpubl. Company Report). Bur.Miner.Resour.Aust. file 67/11145

FORMAN, D.J., WYBORN, L., KURYLOWICZ, L.E., PASSMORE, V.L., & MAYNE, S.J., 1973 - Summary of sedimentary basins in Australia and Papua New Guinea, 1973. Bur. Miner. Resour. Aust. Rec. 1973/98 (unpubl.).

GARDENER, C.A., 1942 - The vegetation of Western Australia. J. Roy. Soc. W. Aust., 28.

GENTILLI, J., & FAIRBRIDGE, R.W., 1951 - PHYSIOGRAPHIC DIVISIONS OF AUSTRALIA. New York, The Geographical Press. Columbia University.

GLOVER, J.E., 1973 - Petrology of the halite-bearing Carribuddy Formation, Canning Basin, Western Australia. J. geol. Soc. Aust., 20(3), 361-372.

GOUDIE, A.S., 1972 - On the definition of calcrete deposits. Z. Geomorph., 16(4), pp. 464-468.

GOUDIE, A., 1973 - DURICRUSTS IN TROPICAL AND SUBTROPICAL LANDSCAPES. Clarendon Press, Oxford. 174 pp.

GROSS, W., 1971 - Unterdevonishe Thelodontier-und Acanthedin Schippen aus Westaustralien. Palaont. Z., 45 (3/4), 97-106.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1952 - The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. XIXieme Cong. geol. int. (Gondwana Symposium) Alger, 1952.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1958 - The geology of the Fitzroy Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 36.

HANTZSCHEL, W., 1962 - Miscellanea, in MOORE, R.C., Ed., Treatise on Invertebrate Paleontology, Part W Geol. Soc. Amer. and Univ. Kansas Press.

INGRAM, R.L., 1954 - Terminology for the thickness of stratification and parting units in sedimentary rocks. Geol. Soc. Amer. Bull., 65, 937-938.

JACKSON, M.J., & VAN DE GRAAFF, W.J.E., in prep. - Geology of the Western Australia part of the Officer Basin. Bur. Miner. Resour. Aust. Bull.

JACKSON, M.J., VAN DE GRAAFF, W.J.E., & BOEGLI, J.C., 1975 - Shallow stratigraphic drilling in the Officer Basin, Western Australia, 1972. Bur. Miner. Resour. Aust. Rec. 1975/49 (unpubl.).

JACKSON, P.R., 1966 - Geology and review of exploration, Officer Basin, Western Australia. Hunt Oil Co. Rep. (unpubl.).

JOKLIK, C.F., 1955 - The geology and mica-fields of the Harts Range, central Australia. Bur. Miner. Resour. Aust. Bull. 26.

JONES, L.J., 1922 - A geological reconnaissance of Locke Oil Co. Lease 21H, Canning Basin, W.A. Geol. Surv. W. Aust. File No. 121/22 (unpubl.).

KEMP, E., 1976 - Palynological observation in the Officer Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 160.

KIDSON, E., 1921 - General magnetic survey of Australia and on an expedition over the Canning Stock Route, W.A., 1914. Carneg. Inst. Wash., Dep. terrest. Mag., 4, 164.

KING, D., 1960 - The sand ridge desert of South Australia. Trans. Roy. Soc. S. Aust., 83, 99-108.

KOOP, W.J., 1966a - Sahara No. 1 Well, stratigraphic nomenclature. Appendix 1 in WAPET 1966, Sahara No. 1 Well. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 80.

KOOP, W.J., 1966b - Recent contributions to Palaeozoic geology in the south Canning Basin, Western Australia. APEA, J., 105-9.

KUENEN, P.H., 1951 - Mechanics of varve formation and the action of turbidity currents. Geol. Foren. Stockholm Fortz., 73, 69-84.

LESLIE, R.B., 1961 - Geology of the Gibson Desert, W.A. Frome-Broken Hill Pty Ltd Report. (unpubl.).

LONSDALE, G.F., & FLAVELLE, A.J., 1968 - Amadeus and south Canning Basins gravity survey, Northern Territory and Western Australia, 1962. Bur. Miner. Resour. Aust. Rep. 133.

LOWRY, D.C., JACKSON, M.J., VAN DE GRAAFF, W.J.E., & KENNEWELL, P.J., 1972 - Preliminary results of geological mapping in the Officer Basin, Western Australia, 1971. Geol. Surv. W. Aust. Ann. Rep. for 1971.

MACK, J.E., & HERRMANN, F.A., 1965 - Reconnaissance Geological survey of the Alliance Gibson Desert Block PE 205H, 206H, Western Australia. Union Oil Development Corporation (Unpubl. Company Report).

McKAY, D.F., 1934 - The Mackay aerial survey expedition, Central Australia, May-June. Geogr. J., 84(6), 511-24.

McWHAE, J.R.G., PLAYFORD, P.E., LINDER, A.W., GLENISTER, B.F., & BALME, B.E., 1958 - The stratigraphy of Western Australia. J. geol. Soc. Aust., 4(2).

MARJORIBANKS, R.W., & BLACK, L.P., 1974 - Geology and geochronology of the Arunta Complex, north of Ormiston Gorge, central Australia. J. geol. Soc. Aust., 21, 291-9.

PAGE, R.W., BLAKE, D.H., & MAHON, M.W., 1976 - Geochronology and related aspects of acid volcanics, associated granites and other Proterozoic rocks in The Granites-Tanami region, northwestern Australia. BMR Journal of Australian Geology and Geophysics, 1, 1-13.

PETTIJOHN, F.J., 1957 - SEDIMENTARY ROCKS (2nd edn). N.Y., Harper & Row.

PETTIJOHN, F.J., POTTER, P.E., & SIEVER, R., 1972 - SAND AND SANDSTONES. Berlin, Springer-Verlag.

PLAYFORD, P.E., COPE, R.N., LOW, C.H., COCKBAIN, A.E., & LOWRY, D.C., 1975 - Geology of Western Australia. Geol. Surv. W. Aust. Mem. 2.

QUILTY, J.H., 1960 - Canning Basin aeromagnetic reconnaissance survey, W.A. 1954. Bur. Miner. Resour. Aust. Rec. 1960/11 (unpubl.).

REEVES, F., 1949 - Geology and oil prospects of the Desert Basin, W.A. Rep. for Vacuum Oil Co. Pty Ltd (unpubl.).

REINECK, H.E., & SINGH, I.B., 1973 - Depositional sedimentary environments; with reference to terrigeneous clastics. Berlin, Springer-Verlag.

SKWARKO, S.K., 1967 - Moeozoic Mollusca from Australia and New Guinea. Bur. Miner. Resour. Aust. Bull. 75.

TALBOT, H.W.B., 1910 - Geological observations in the country between Wiluna, Halls Creek, and Tanami. Geol. Surv. W. Aust. Bull., 39, 1-88.

TALBOT, H.W.B., 1920 - Geology of North-west, North-east and Central Divisions. Bull. geol. Surv. W. Aust., 75.

TRAVES, D.M., CASEY, J.N., & WELLS, A.T., 1956 - The geology of the southwestern Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 29.

VAN DE GRAAFF, W.J.E., 1975 - Warri, W.A. - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SG/51-4.

VAN DE GRAAFF, W.J.E., CROWE, R.W.A., BUNTING, J.A., & JACKSON, M.J. (in prep.) - Relict Early Cainozoic drainages in arid Western Australia. Paper read at 1976 International Geological Congress, Sydney.

VEEVERS, J.J., 1957 - Operations of the 1957 Canning Basin party. Bur. Miner. Resour. Aust. Rec. 1957/90 (unpubl.).

VEEVERS, J.J., 1962 - Rhizocorallium in the Lower Cretaceous rocks of Australia. In, Bur. Miner. Resour. Aust. Bull. 62.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 60.

WADE, A., 1936 - The Geology of the West Kimberley District of Western Australia. Final Report on Concession held by Freney Kimberley Oil Co. (unpubl.).

WADE, A., 1937 - The geological succession in the West Kimberley Desert of Western Australia. Rep. Aust. Ass. Adv. Sci., 23, 93.

WARBURTON, P.E., 1875 - JOURNEY ACROSS THE WESTERN INTERIOR OF AUSTRALIA. London, Sampson Low, Marston, Low and Searle.

WELLS, A.T., 1963 - Reconnaissance geology of helicopter in the Gibson Desert, W.A. Bur. Miner. Resour. Aust. Rec. 1963/59. (unpubl.)

WELLS, A.T., 1968 - Macdonald, Western Australia - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SF/52-14.

WELLS, A.T., FORMAN, D.J., & RANFORD, L.C., 1964 - Geological reconnaissance of the Rawlinson and Macdonald 1:250 000 Sheet areas, Western Australia. Bur. Miner. Resour. Aust. Rep. 65.

WELLS, A.T., FORMAN, D.J., RANFORD, L.C., & COOK, P.J., 1970 - Geology of the Amadeus Basin, central Australia. Bur. Miner. Resour. Aust. Bull. 100.

WELLS, A.T., RANFORD, L.C., STEWART, A.J., COOK, P.J., & SHAW, R.D., 1967 - The geology of the northeastern part of the Amadeus Basin, Northern Territory. Bur. Miner. Resour. Aust. Rep. 113.

WELLS, L.A., 1902 - Journey of the Calvert Scientific Exploring Expedition 1896-97. W. Aust. Parl. Pap. 46.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1963a - Sahara regional gravity survey Canning Basin. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 63/1910.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1963b - Sahara seismic reconnaissance survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 63/1539

WEST AUSTRALIAN PETROLEUM PTY LTD, 1963c - Joanna Springs gravity survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 63/1908

WEST AUSTRALIAN PETROLEUM PTY LTD, 1964 - Tandalgoo Nos. 1, 2, 3. Stratigraphic Wells. (Unpubl. Company Report).

WEST AUSTRALIAN PETROLEUM PTY LTD, 1965a - Southeast Kidson gravity survey. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 65/4814.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1965b - Southeast Kidson seismic survey. (Unpubl. Company Report). Bur. Miner. Resour Aust. file 65/11014.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966a - South Canning Basin aeromagnetic survey, Western Australia, 1962-1963. Bur. Miner. Resour. Aust. Petrol. Search Subs. Act Publ. 72.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966b - Sahara No. 1 Well, Completion Report. Bur. Miner. Resour. Aust. Petrol. Search Subs Act Publ. 80.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1966c - Kidson No. 1, Well Completion Report. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 65/4177.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1970a - Tabletop reconnaissance (266) seismic project. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 70/392

WEST AUSTRALIAN PETROLEUM PTY LTD, 1970b - Helena (267) reconnaissance seismic project. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 70/504.

WEST AUSTRALIAN PETROLEUM PTY LTD, 1971a - Lake Auld (285) seismic project. (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 70/933

WEST AUSTRALIAN PETROLEUM PTY LTD, 1971b - Crossland (268) reconnaissance seismic survey. (Unpubl Company Report). Bur. Miner. Resour. Aust. file 70/687

WILLIAMS, H., TURNER, F.J., & GILBERT, C.M., 1958 - PETROGRAPHY - an introduction to the study of rocks in thin sections. San Francisco, Feeeman & Co.

WILLIAMS, I.R., BRAKEL, A.T., CHIN, R.J., & WILLIAMS, E.J., 1976 - The stratigraphy of the eastern Bangemall Basin and the Paterson Province. Ann. Rep. Geol. Surv. West. Aust. for 1975.

WILLMOTT, S.P., 1962 - Geological Report on Frome Rocks No. 2 well. Bur. Miner. Resour. Aust. Petrol. Search Subsidy Acts Publ. 8.

YEATES, A.N., (in press) - Helena, Western Australia - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes SF/52-5.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, LESLEY A.I., & PASSMORE, VIRGINA, L., 1975 - Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rec. 1975/77 (unpubl.).

YEATES, A.N., CROWE, R.W.A., & TOWNER, R.R., 1976 - The Veevers Crater: a possible meteoritic feature. BMR Journal of Australian Geology and Geophysics, 1(1), 77-78.

TOTAL, 1969 - Kemp Field No. 1 well completion report (Unpubl. Company Report). Bur. Miner. Resour. Aust. file 68/2048

APPENDIX A

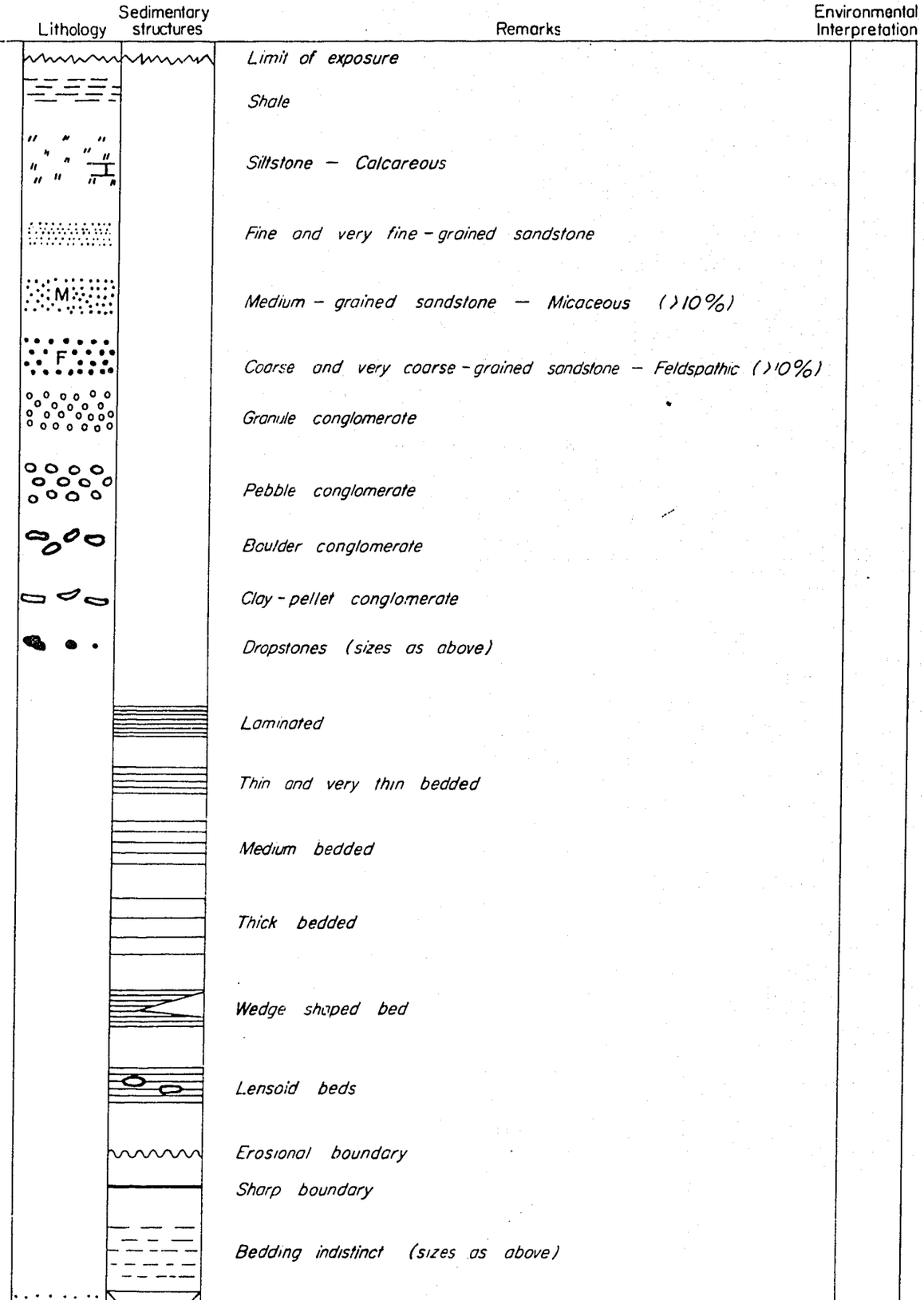
MEASURED SECTIONS

SECTION No.

REFERENCE

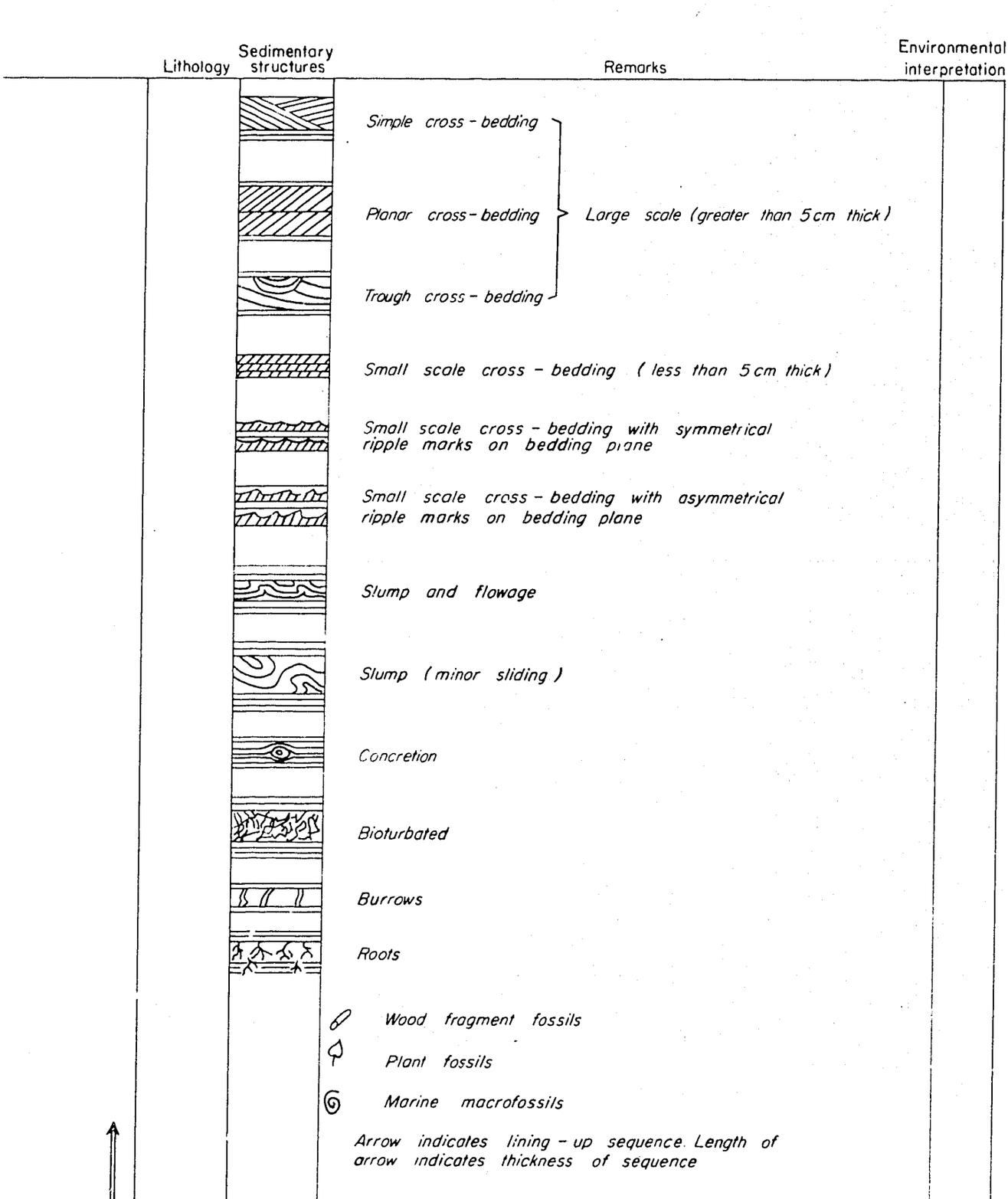
Latitude and Longitude

Status



CONTINUED

Record 1976/95



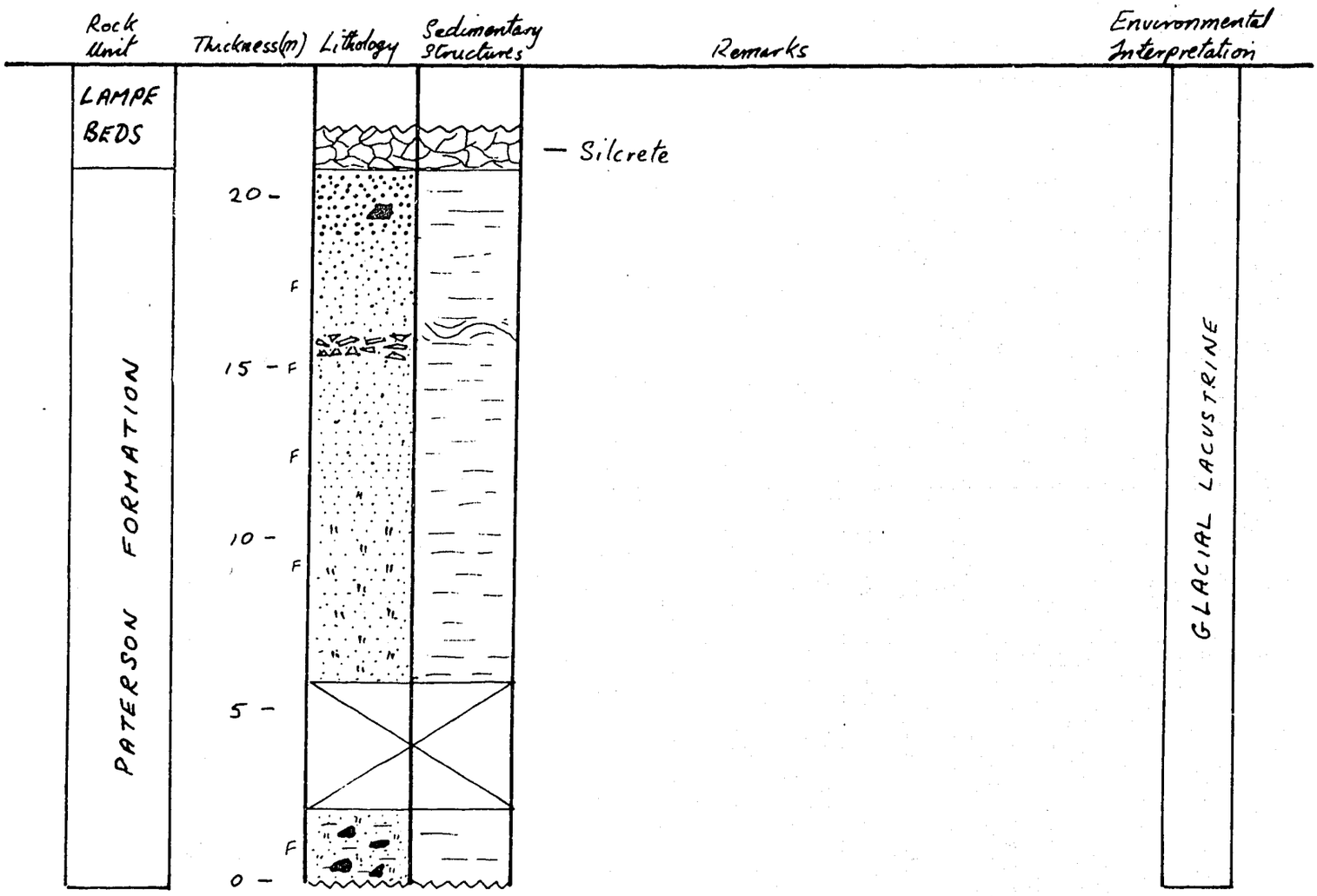
Record 1976/95

E 51/A12/2

SOUTH WEST RUNTON

SECTION NO. A1

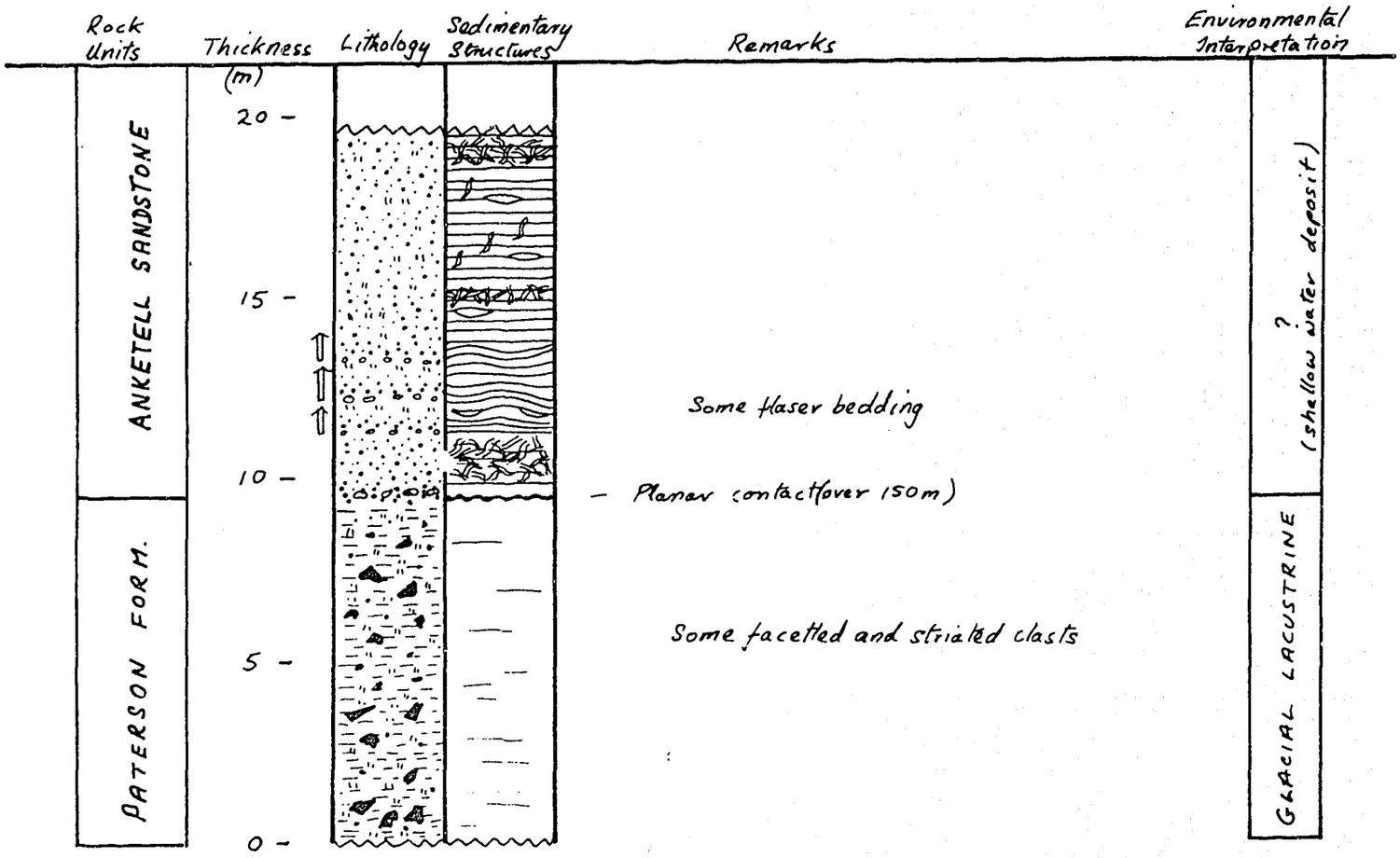
23° 55' 00" S. 24° 25' 40" E



NORTH RUNTON

SECTION NO. A2

23° 07' 00"S. / 123° 35' 45"E.



Record 1976/95

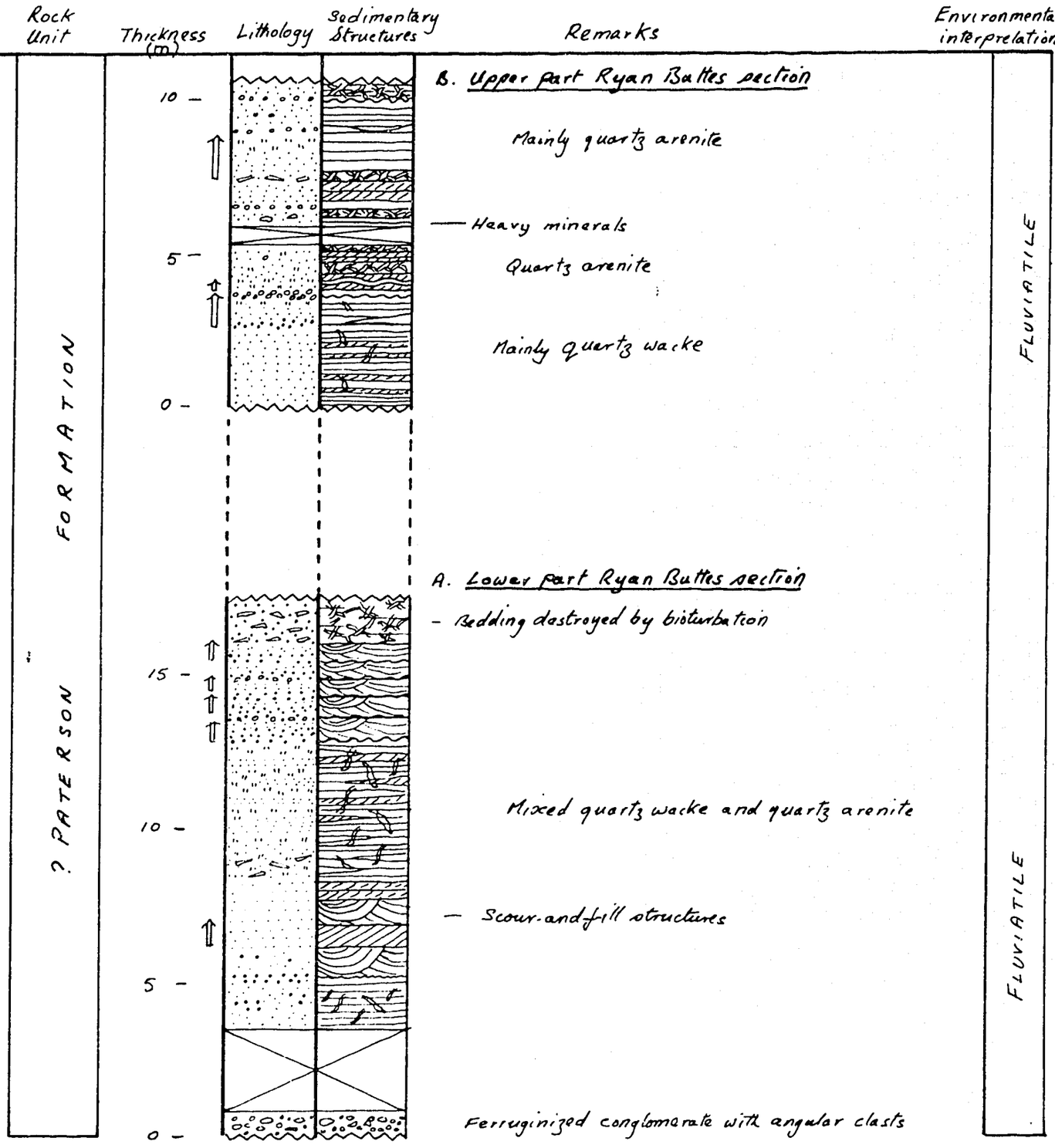
W/A/334

RYAN BUTTES

SECTION No. A3

A. 23° 59' 18", 126° 30' 24"

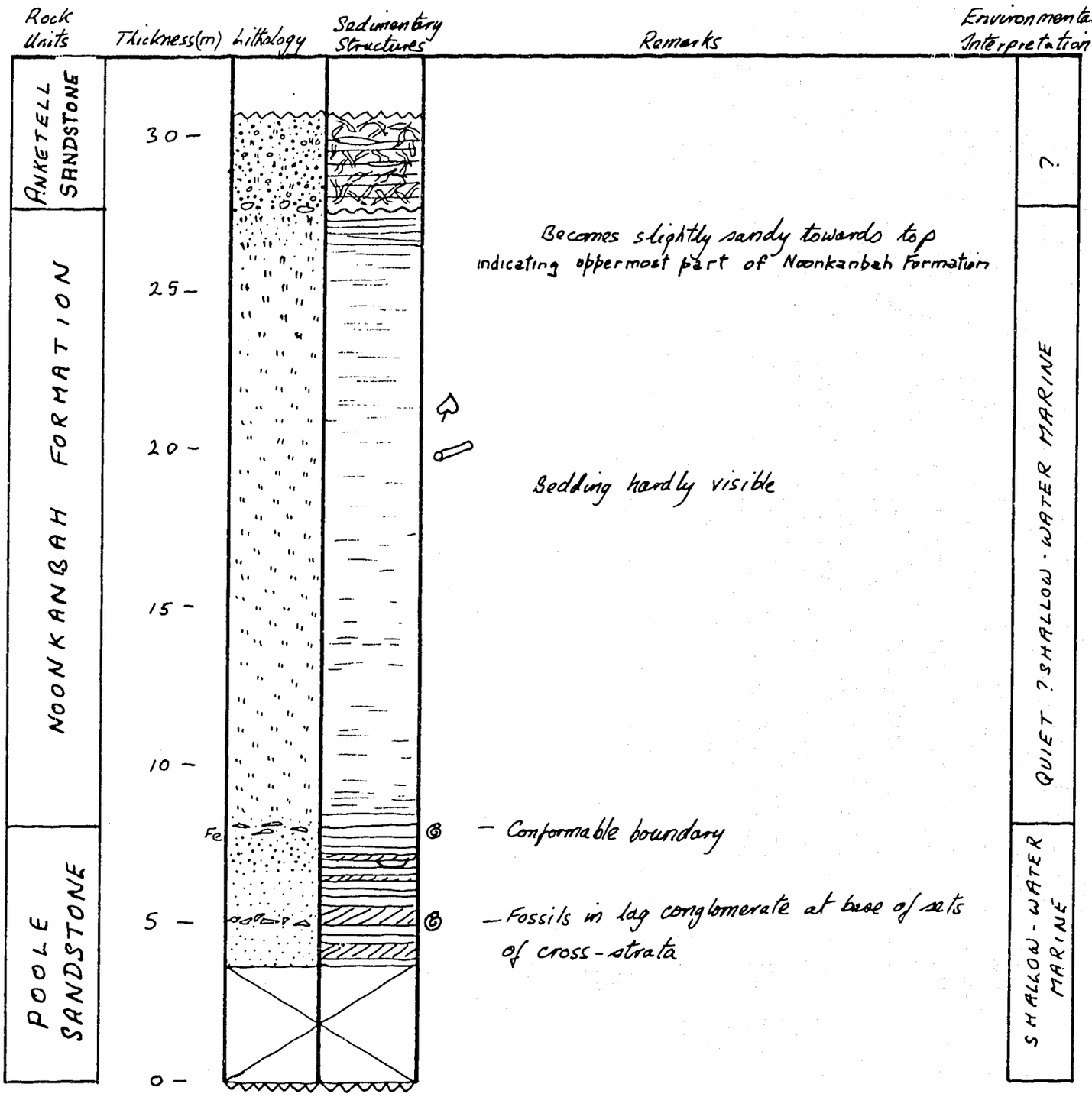
B. 23° 53' 48", 126° 40' 51"



HELEN HILL

SECTION No. A4

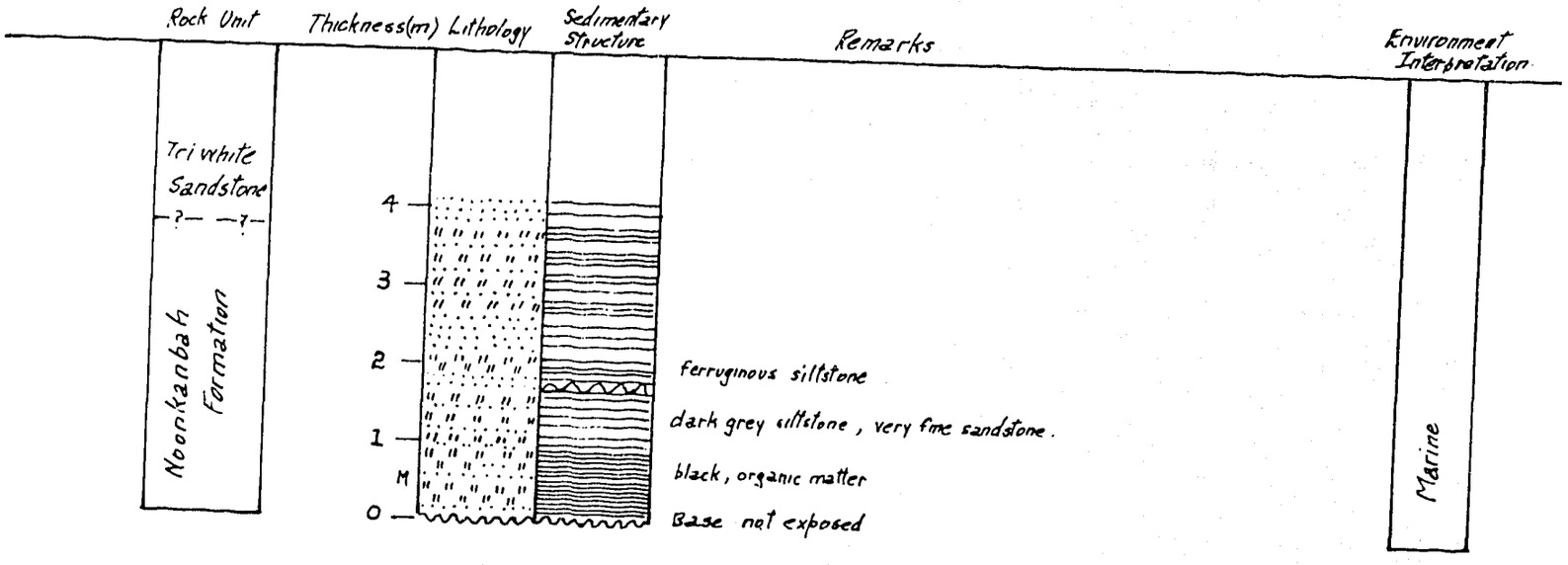
22°47'15"S. 123°39'10"E



SOUTH EAST PATERSON RANGE (on edge Lake Dora)

SECTION A5

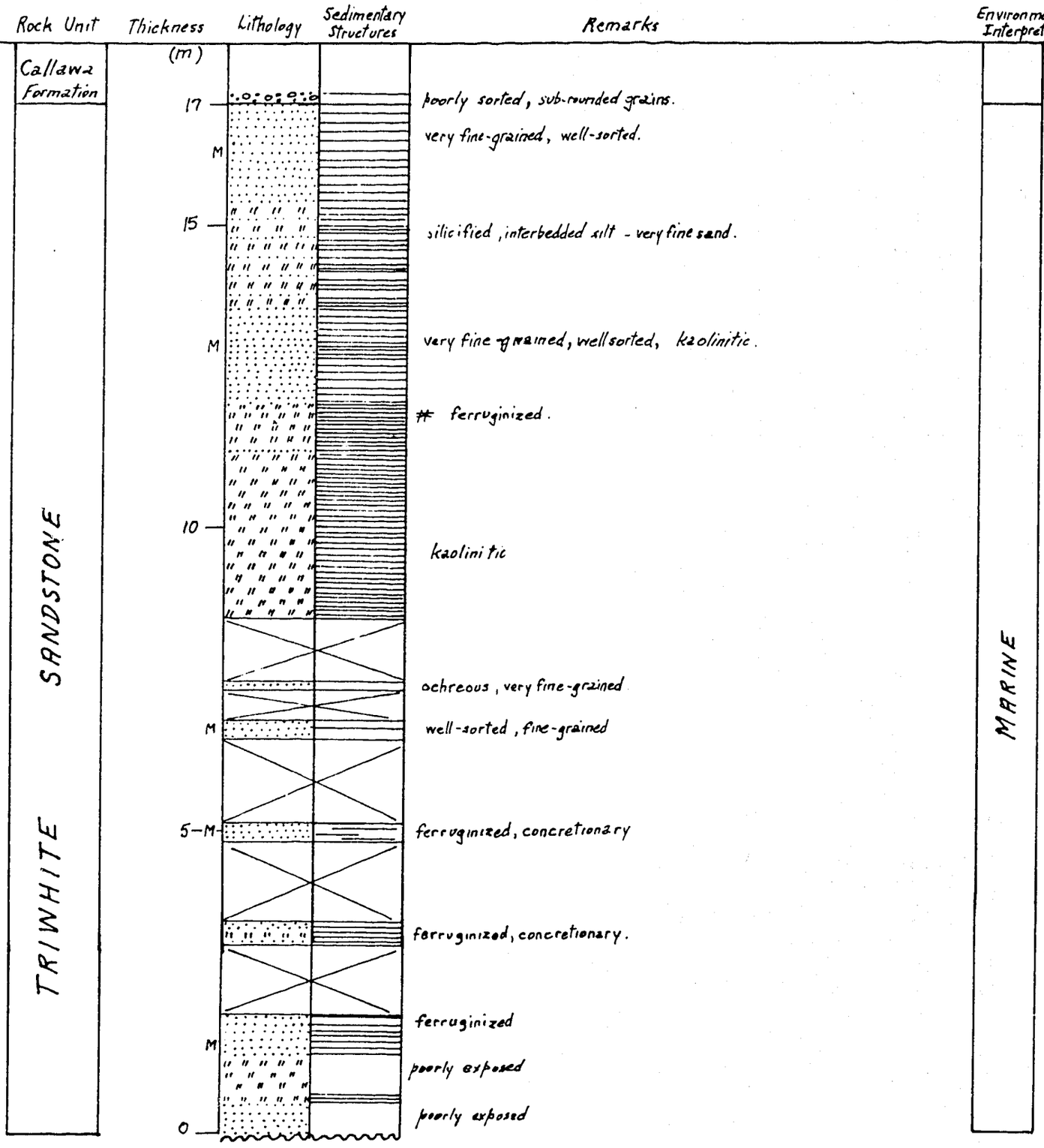
21° 59' 00" S, 121° 59' 00" E



TRIWHITE HILLS.

SECTION A6

22° 05' 30" S, 123° 13' 40" E



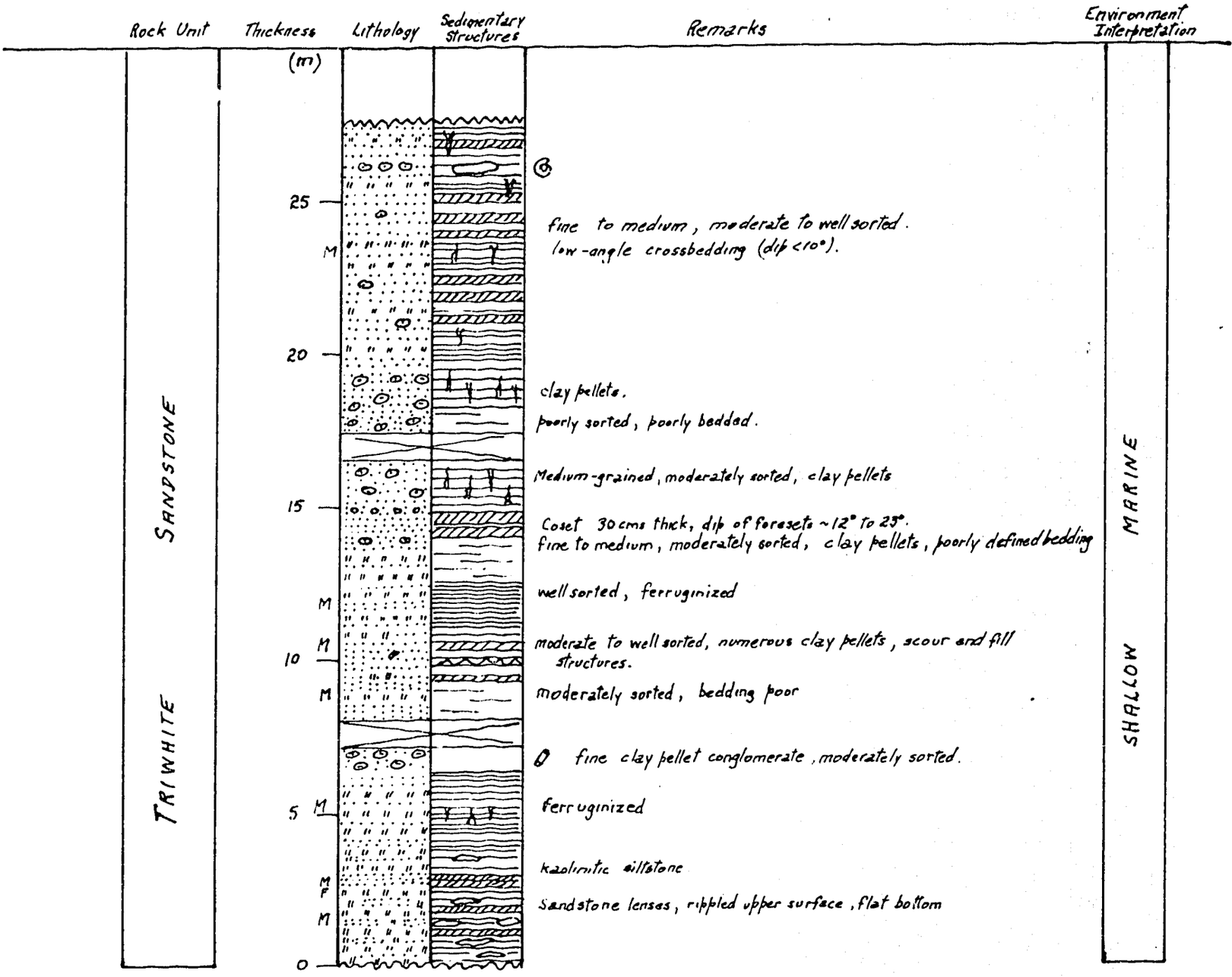
Record 1976/95

W/A/338

WEST-CENTRAL TABLETOP

SECTION A7

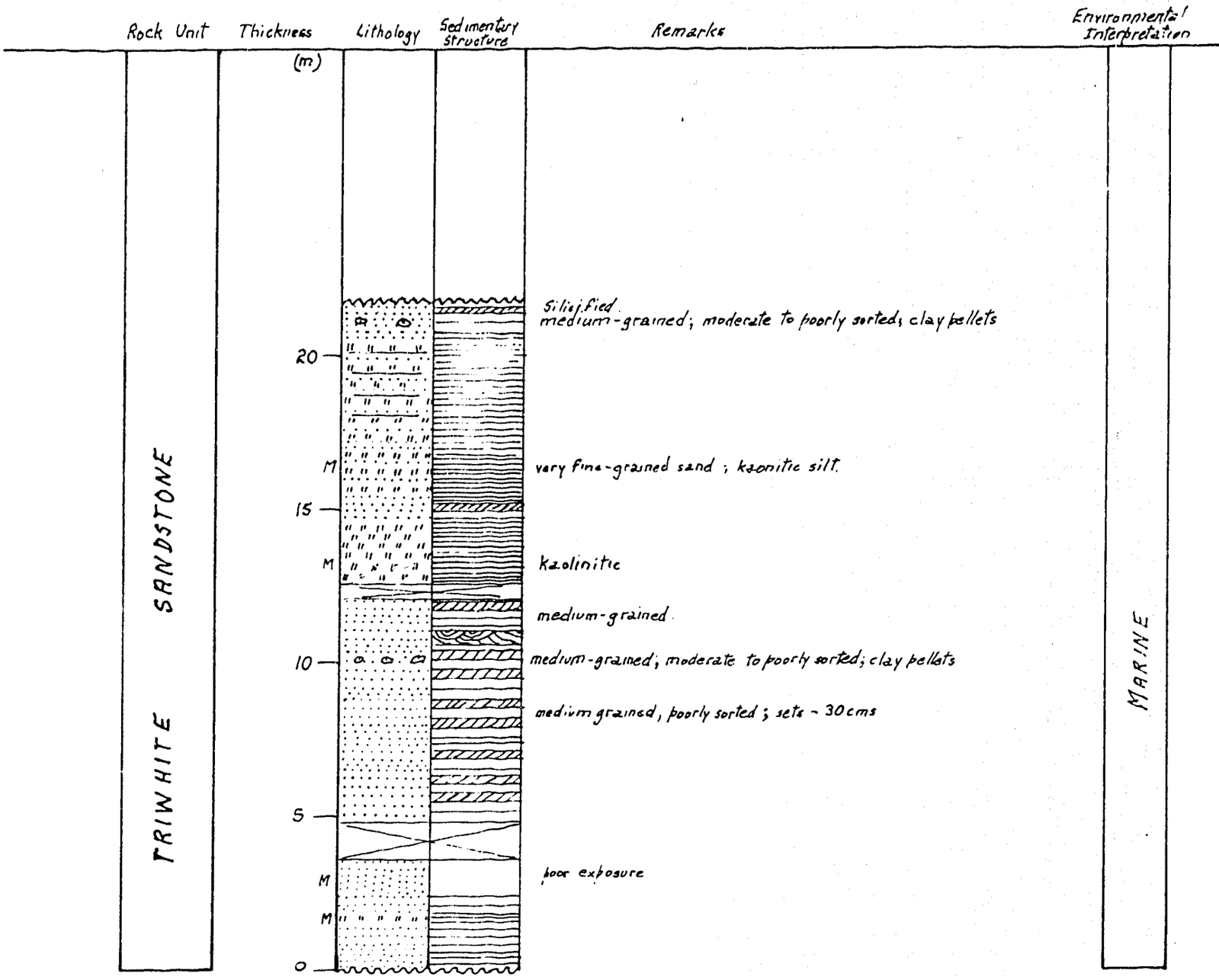
22° 29' 06'S, 123° 16' 21"E



WEST CENTRAL TABLETOP

SECTION A8

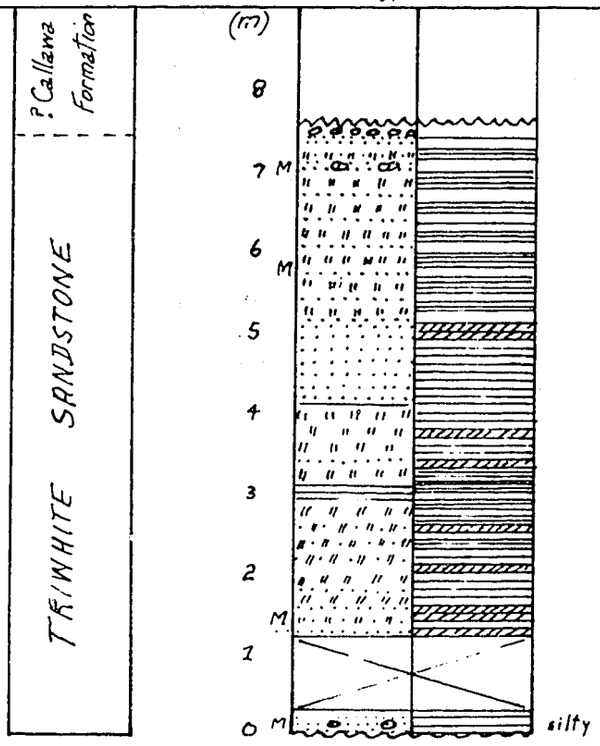
22° 32' 00" S, 123° 17' 15" E



EAST - CENTRAL TABLETOP

SECTION A9

22° 34' 03"S 124° 14' 12" E

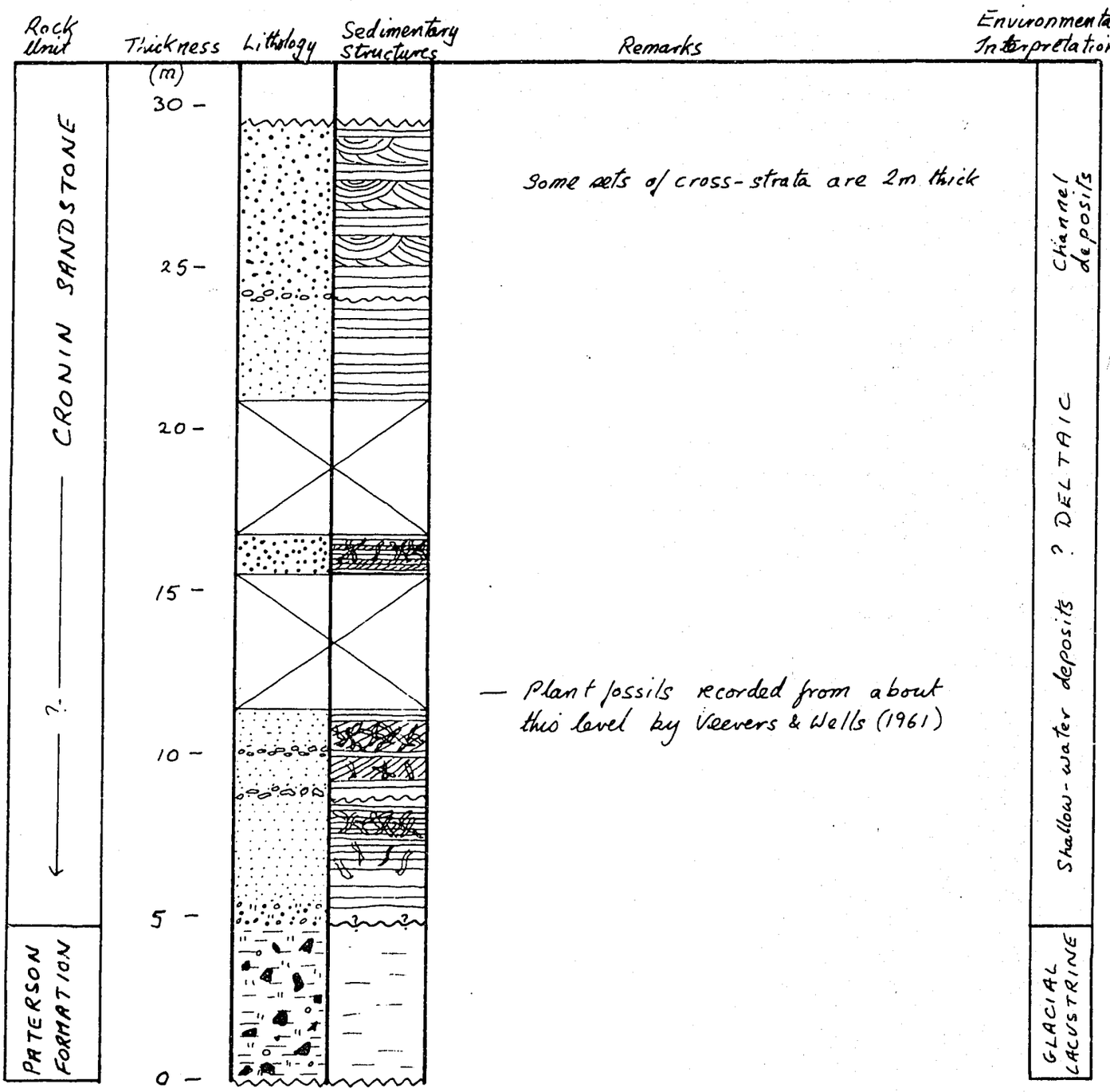


CRONIN HILLS

SECTION NO. A10

23° 14' 40"S. 123°22'20"E

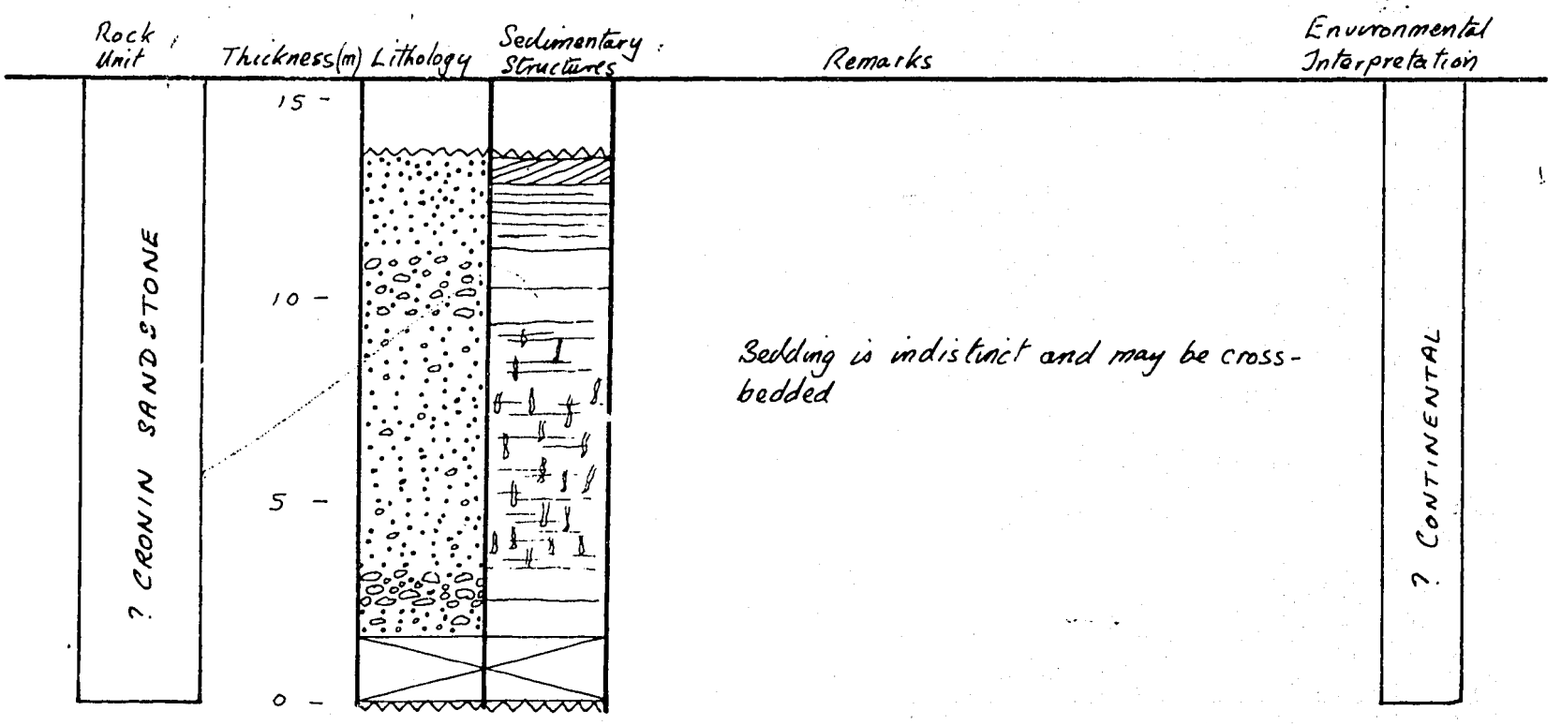
Type section of Cronin Sandstone



SOUTH EAST RUNTON

SECTION NO. A11

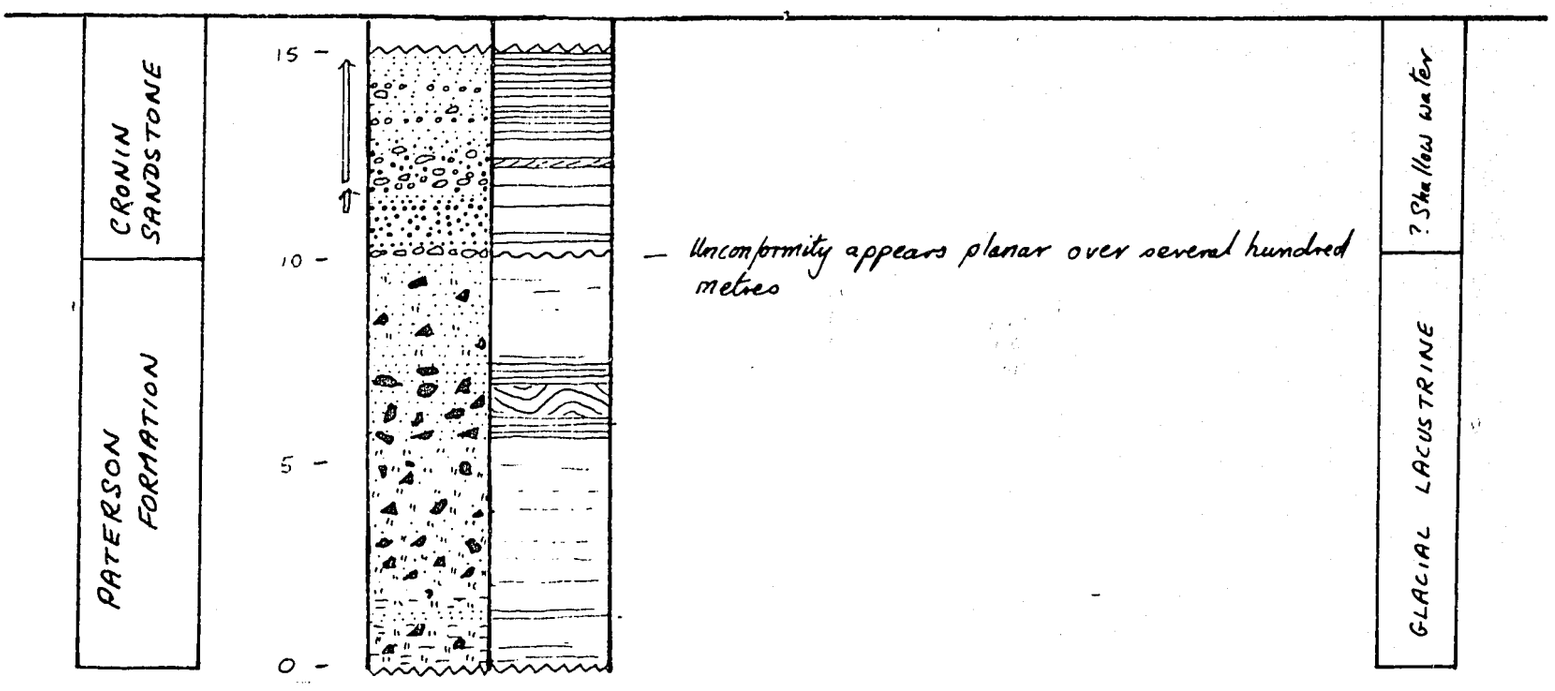
23° 45'55"S. 124°05'50"E.



WEST CENTRAL RUNTON

SECTION NO. A12

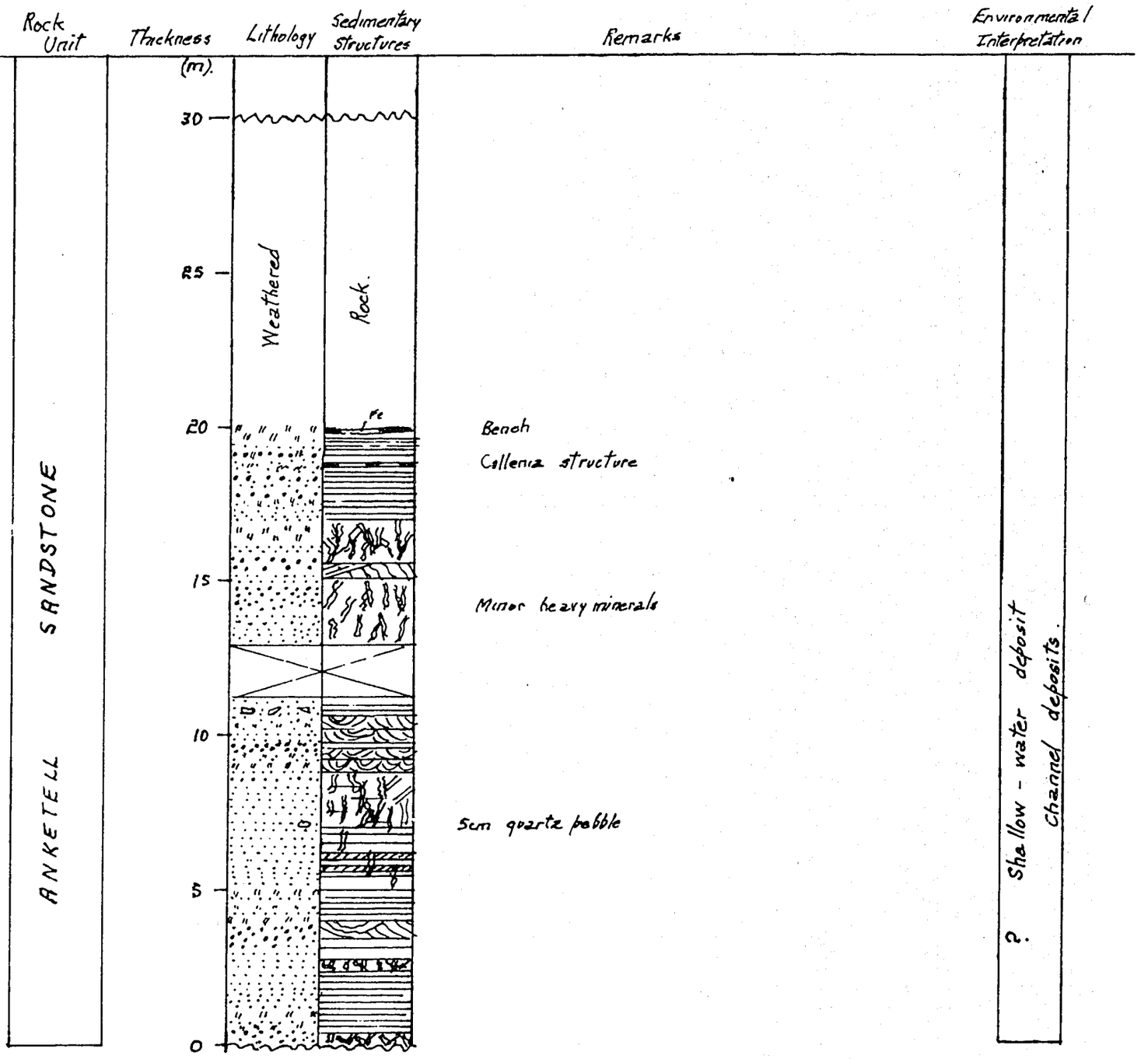
23°23'30"S. 123°28'25"E.



KIDSON BLUFF

22° 15' 36" S , 125° 03' 56" E

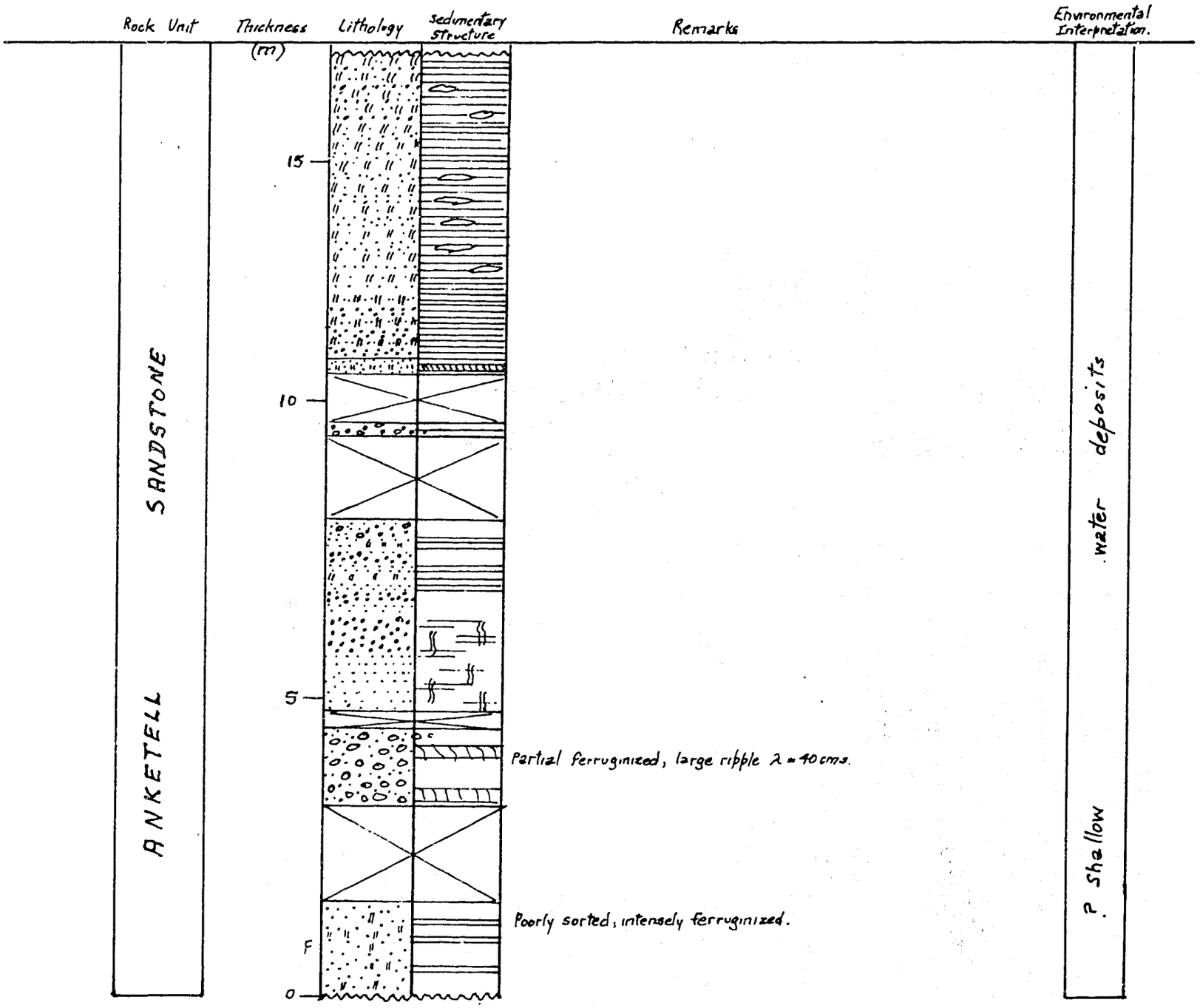
SECTION No. A13



SOUTH-WEST URAL

SECTION No. A14

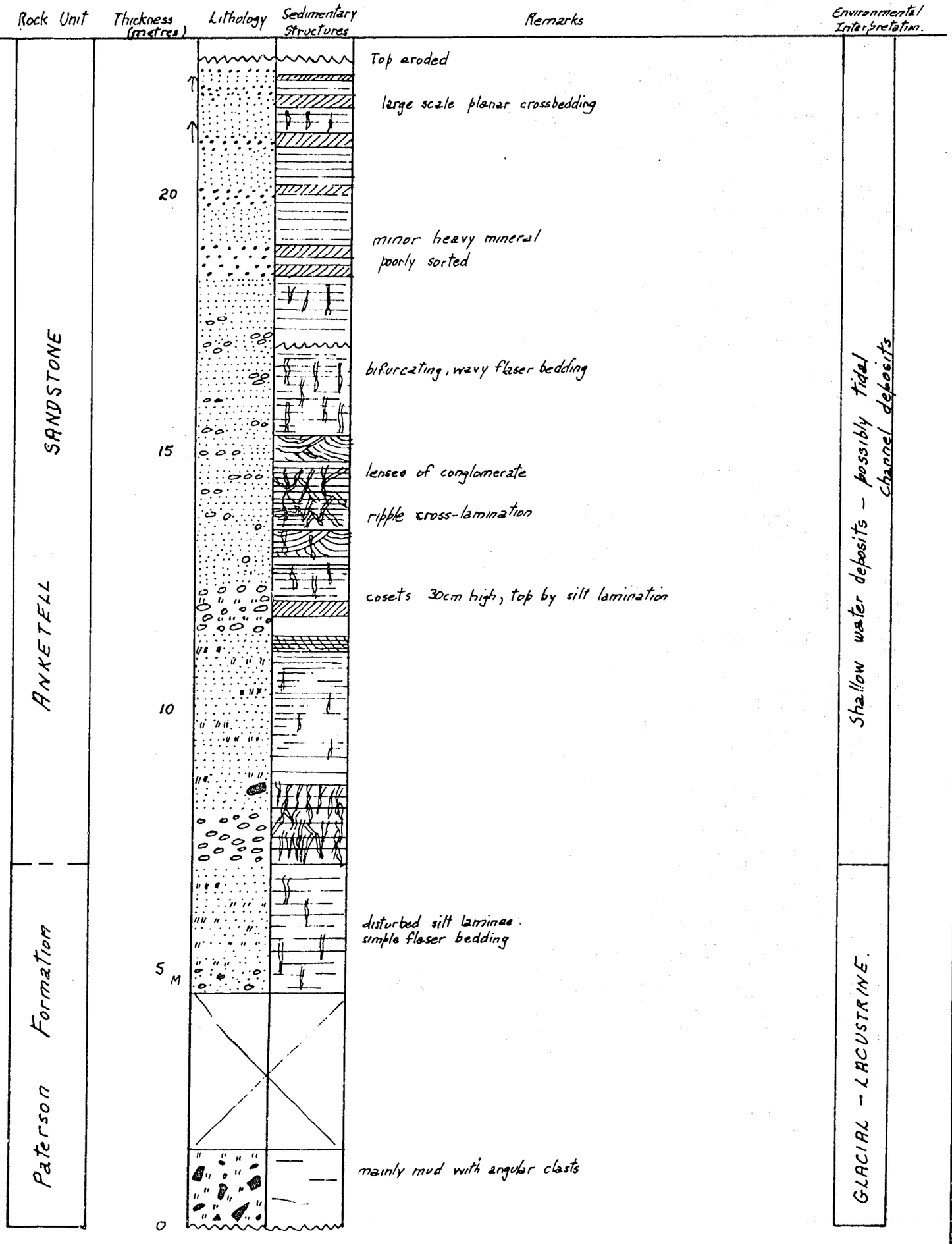
22° 41' 03" S, 124° 45' 36" E



NORTH RUNTON

SECTION No A15

23° 11' 09"S , 123° 31' 03"E.



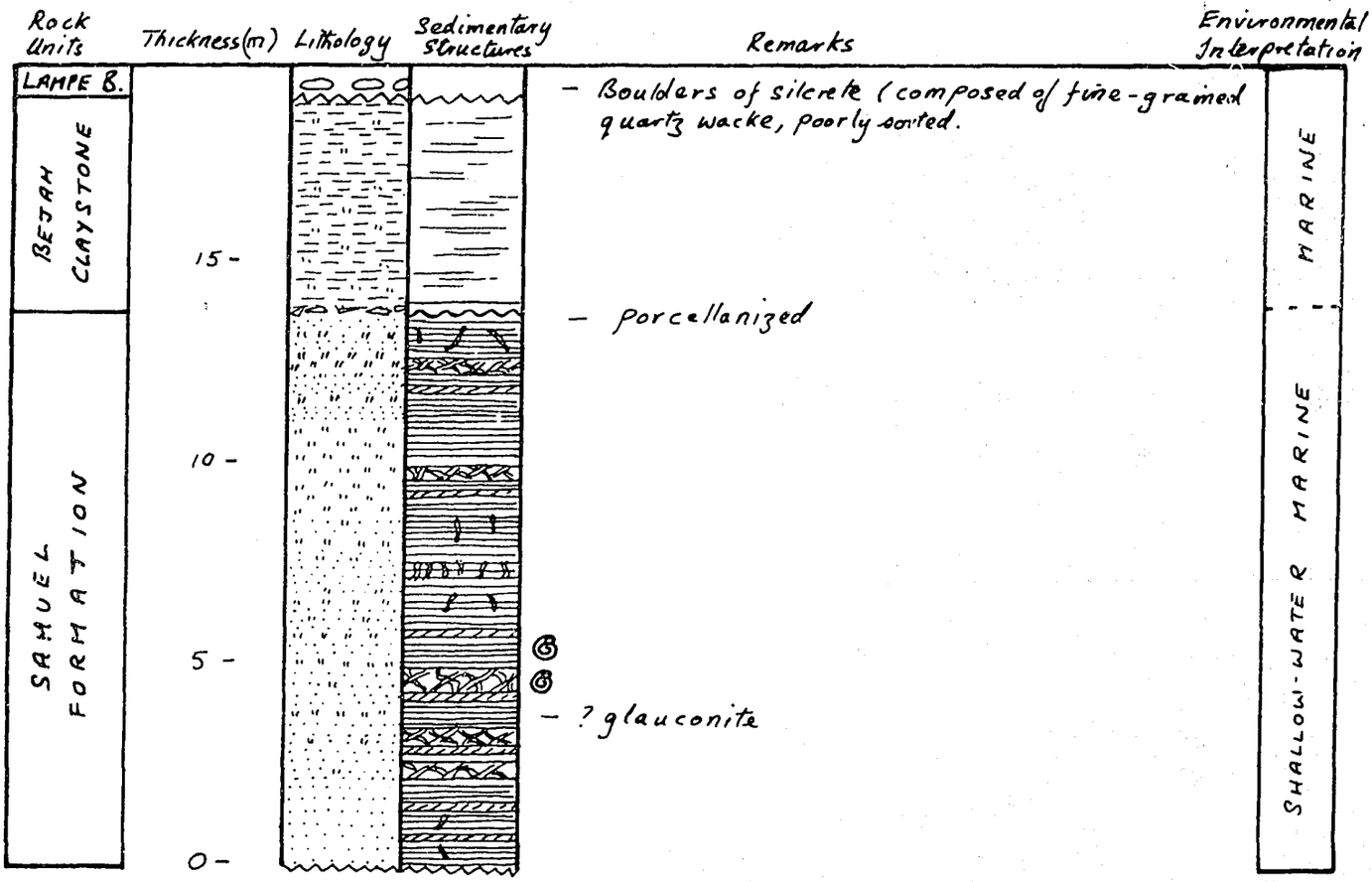
Record 1976/95

W/A/346

SOUTH EAST MORRIS

SECTION No. A16

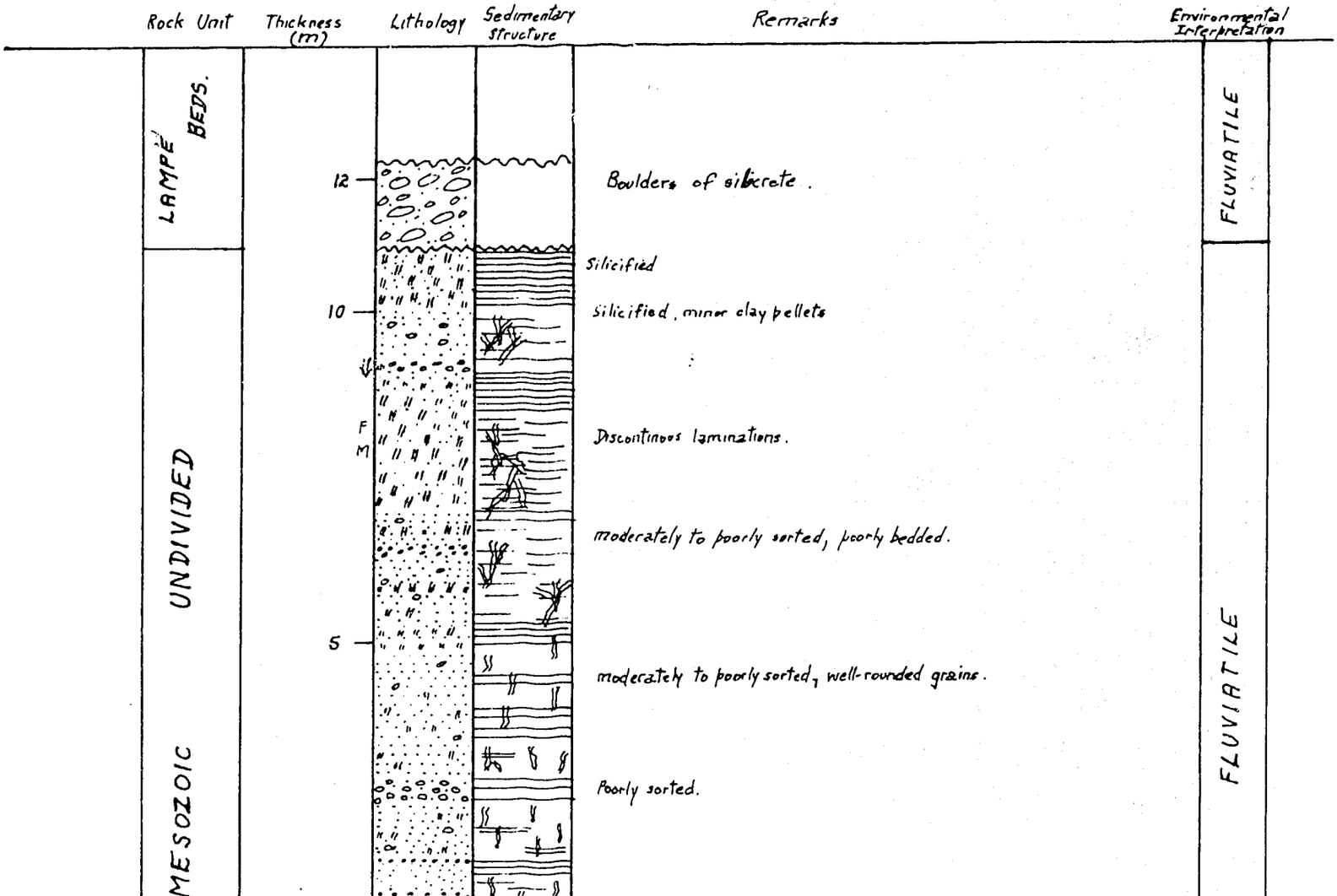
23°55'40"S. 125°43'25"E

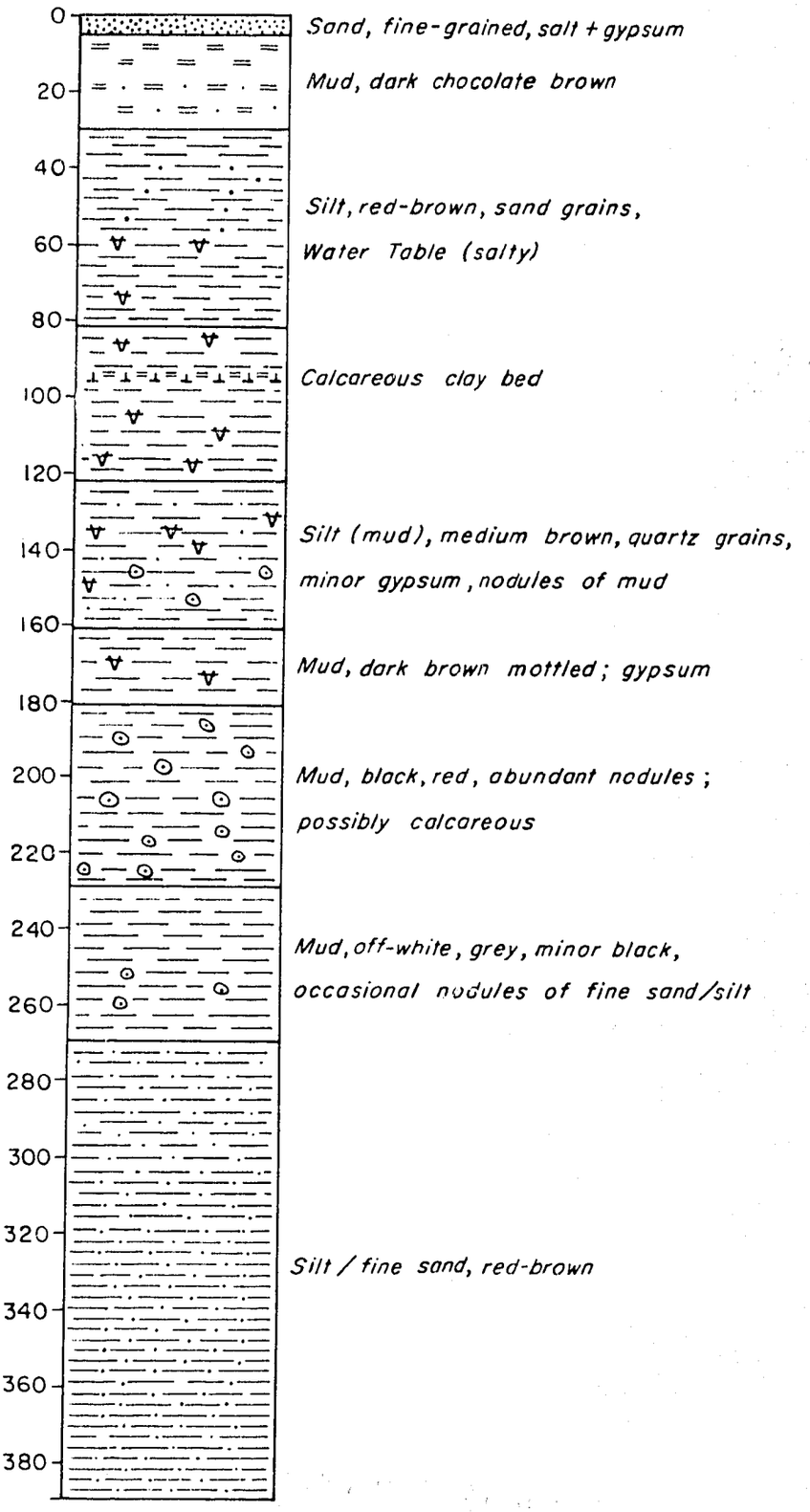


DOWLING HILLS

SECTION A17

23° 53' 48"S, 126° 17' 42" E.





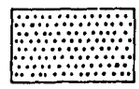
Record 1976/95 W/A/326

Section A18 Auger hole section in Lake Auld, Tabletop 1:250 000 Sheet area.

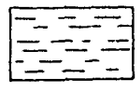
APPENDIX B

PETROLEUM EXPLORATION WELLS

Key to Lithology of Wells



Sandstone



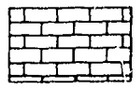
Claystone



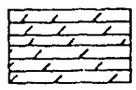
Shale



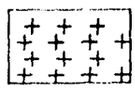
Siltstone



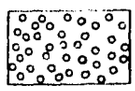
Limestone



Dolomite



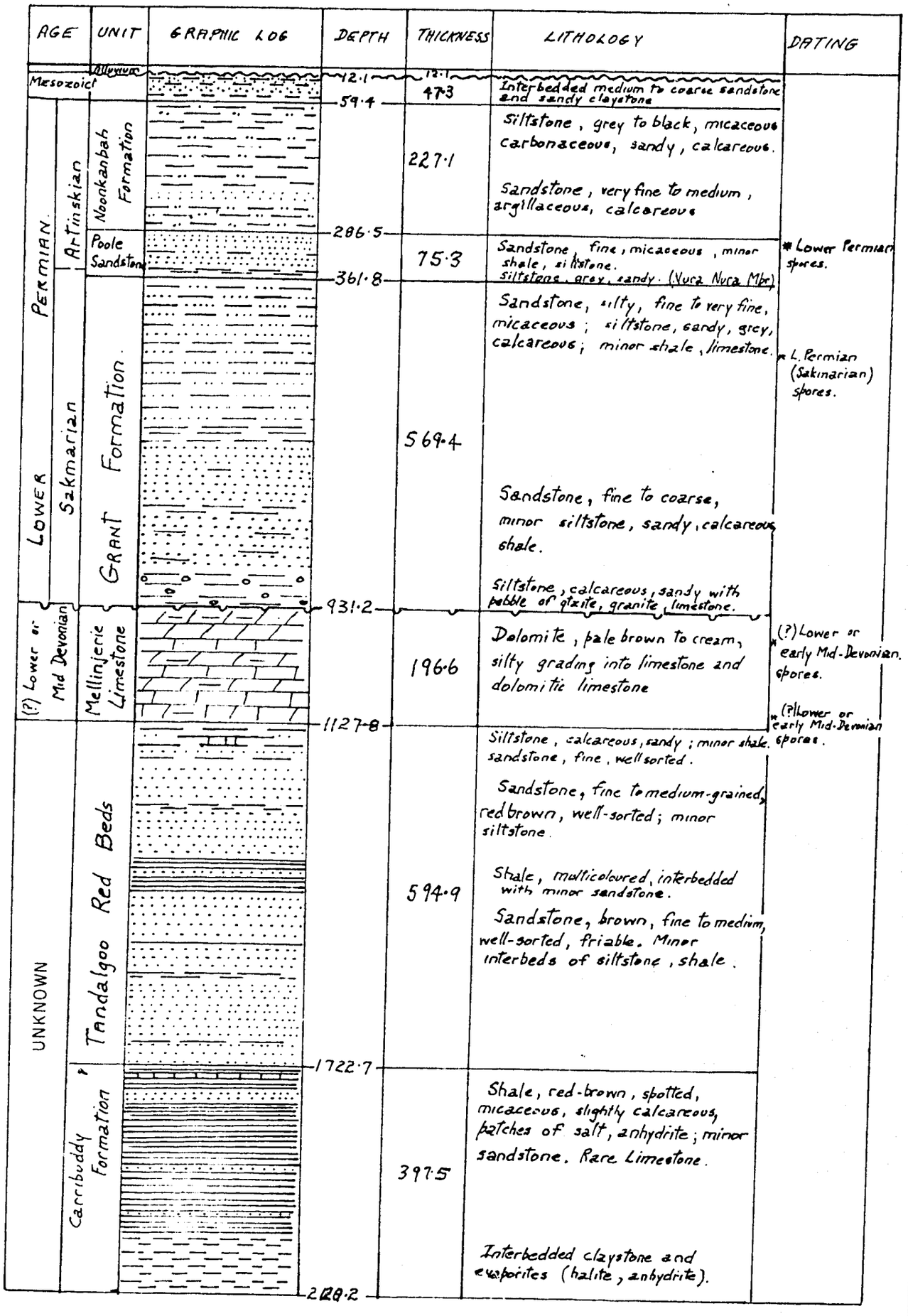
Halite (salt)



Conglomerate

BI: WAPET SAHARA No 1

Scale:- 1cm = 100m

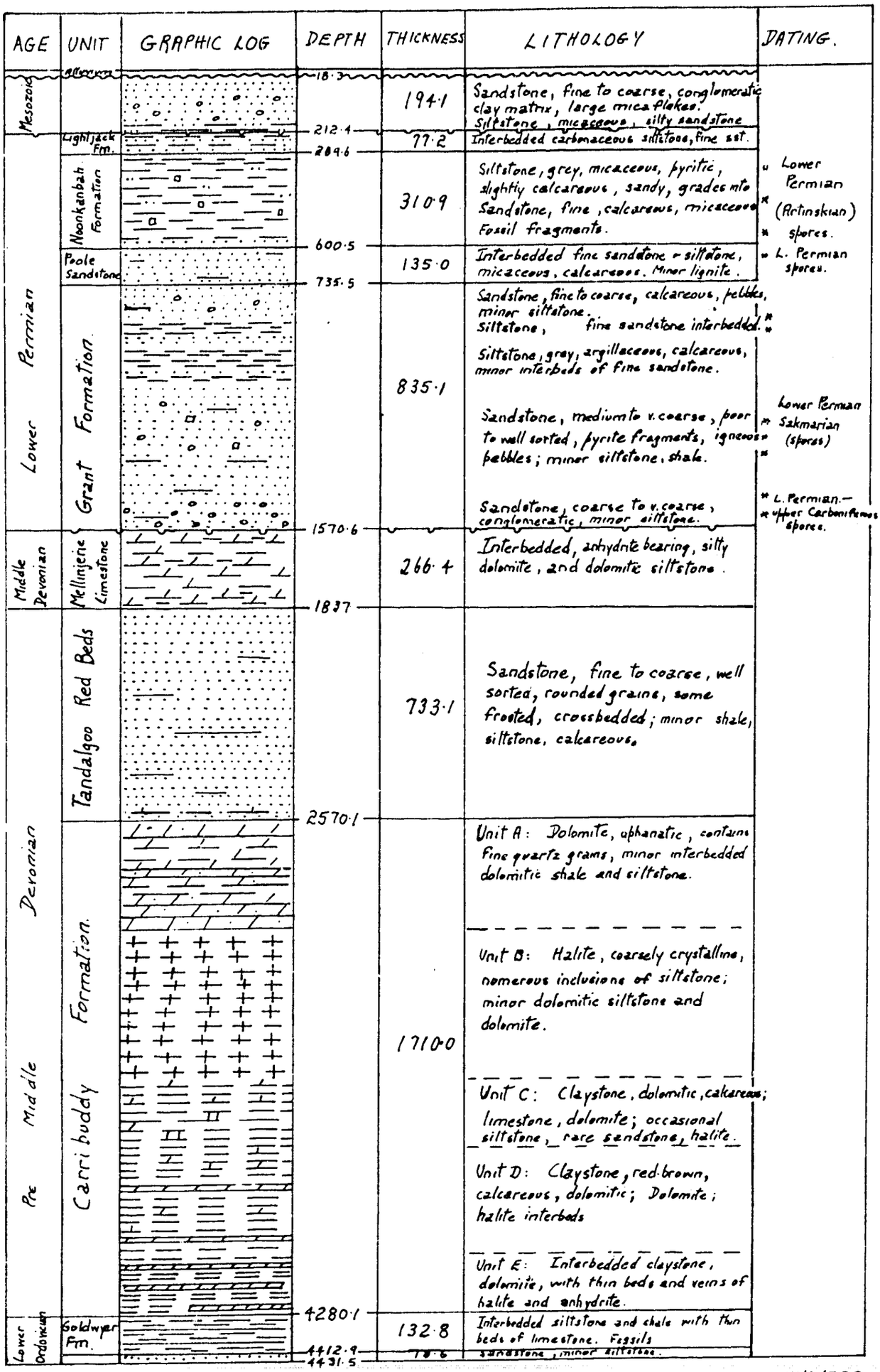


Record 1976/95

W/A/327

B2: WAPET KIDSON No 1

Scale: 1cm = 200m.

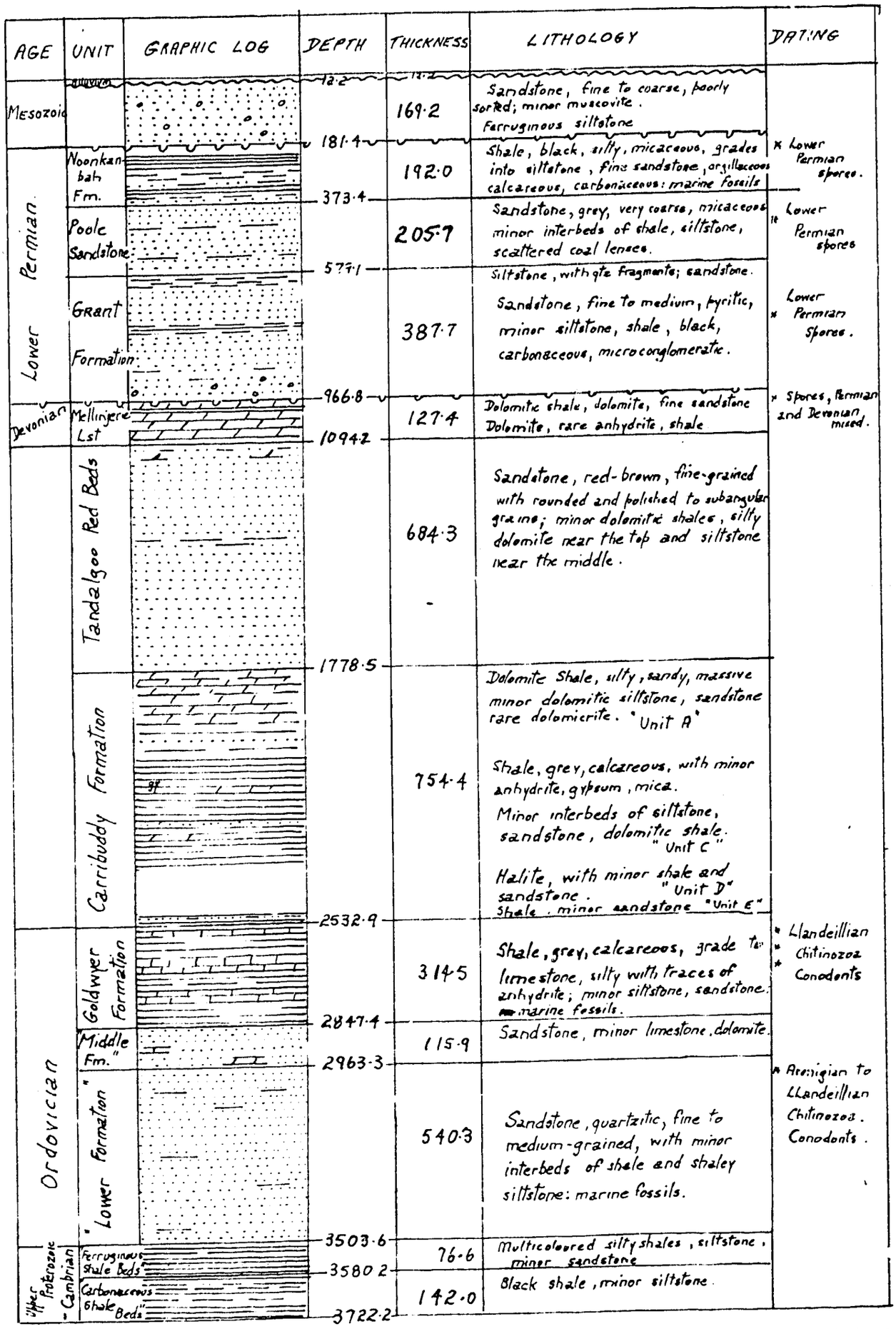


Record 1976/95

W/A/328

B3: AQUITAINE WILSON CLIFFS No 1

Scale: 1cm = 175m

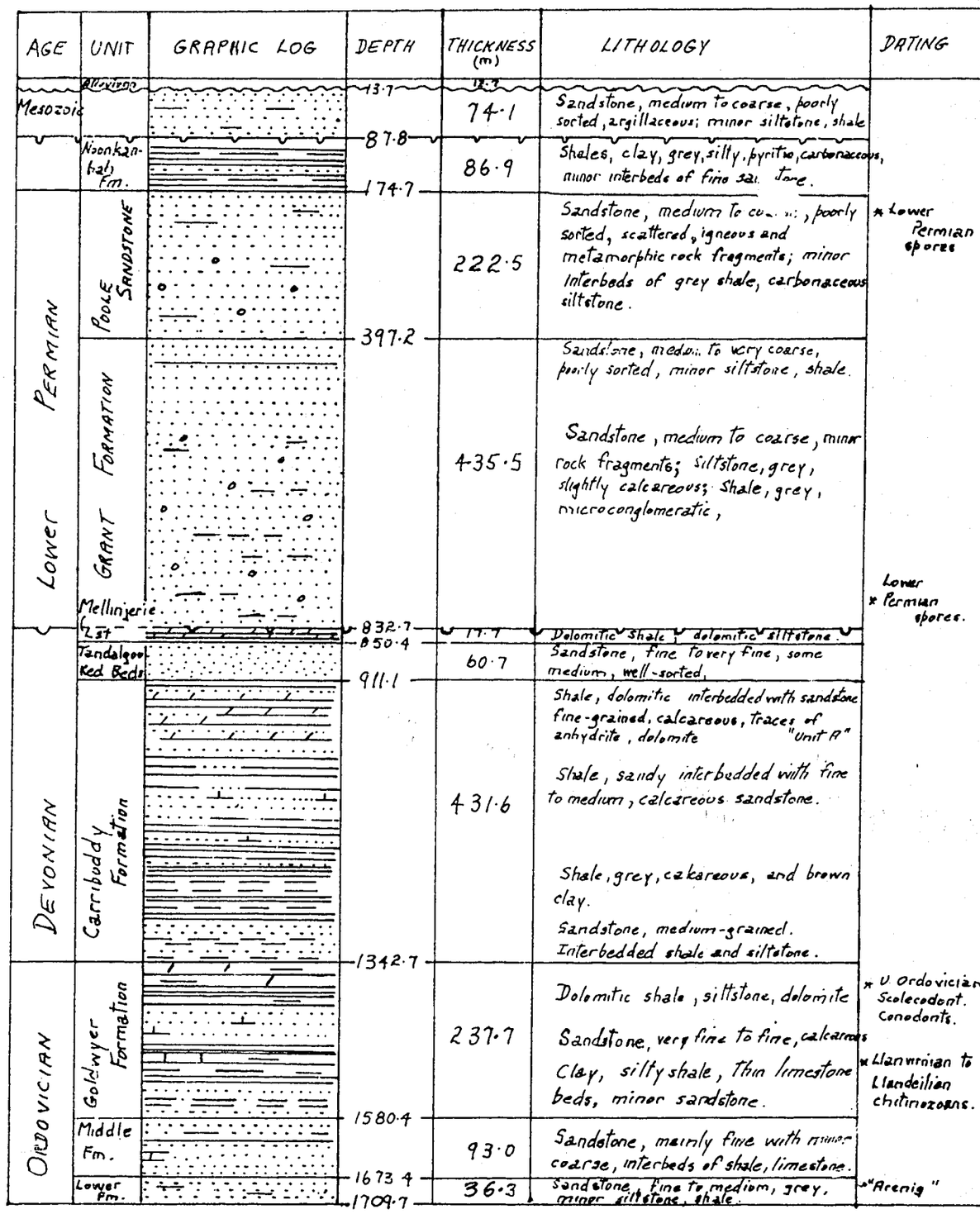


Record 1976/95

W/A/329

B4: AQUITAINE CONTENTION HEIGHTS No 1.

Scale: 1cm = 100m



APPENDIX C

PERMIAN FOSSILS FROM THE TABLETOP 1:250 000 SHEET AREA, WESTERN AUSTRALIA

by J.M. Dickins

ABSTRACT

Identifications of Permian marine invertebrate fossils are listed from the Cuncudgerie Sandstone now replaced by Poole Sandstone, the Triwhite Sandstone and possibly the Dora Shale now replaced by the Noonkanbah Formation from the Tabletop 1:250 000 Sheet area in the southwestern part of the Canning Basin, Western Australia. The fauna from the Cuncudgerie Sandstone is regarded as the time equivalent of the Nura Nura Member of the Poole Sandstone in the Fitzroy Trough and the Triwhite Sandstone as the equivalent of the upper part of the Noonkanbah Formation or the Lightjack Formation. The age of the intervening Dore Shale is unclear. The fauna of the Cuncudgerie Sandstone lived in part in a sublittoral environment and in part probably in slightly deeper water, and the fauna of the Triwhite Sandstone was probably sublittoral with, in places, a hard substrate.

INTRODUCTION

Permian fossils from this area are first referred to in an unpublished report by W.S. Dun (Jones, 1922). Dun's identifications were published by Glauert (1925) in a paper listing Western Australia fossils. Reeves (1949) also referred to fossils in an unpublished report.

Published identifications are given by Crespin and Dickins & Thomas in Traves, Casey & Wells (1956) and by Dickins in Veevers & Wells (1961). Further unpublished identifications have been given by Dickins and Thomas. All these identifications, except the early ones of Dun and Reeves, are consolidated in the present report together with those from the present (1975) survey.

IDENTIFICATIONS

CUNCUDGERIE SANDSTONE

T 16, Lat. 22°45' Long. 123°25'[1]. - Helen Hill, Canning Stock Route, 2½ miles (4 km) north-northwest of Well 27 (Veevers & Wells, 1961, pp. 287, 288).

Pelecypods

Myonia? sp. nov.[2].

Brachiopods (identified by G.A. Thomas)

Linoproductus sp. nov.

Pseudosyrinx sp. nov.

TK5A, Scott Bluff, east side of Lake Blanche, collected W.J. Koop of West Australian Petroleum Pty Ltd, 1963.

Pelecypods

Myonia subarbitrata Dickins 1963[3].

---

1. The latitude and longitude is that taken from Veevers & Wells. The correct position of Helen Hill is that shown for T81.
2. This identification can now be revised to *Myonia* cf. *subarbitrata* Dickins (1963).
3. Waterhouse (1969, p.321 has proposed a new name *Myofossa* with *M. subarbitrata* as type species.

Brachiopods

"Chonetes" sp.

Aulosteges or Taeniothaerus sp. indet.

Strophalosia cf. irwinensis Coleman 1957

Permorthetetes lindneri Thomas 1958

Pseudosyrinx sp. aff. nagmargensis (Bion) Identified by

Phricodothyris sp. nov. G.A. Thomas

T81, Helen Hill; 22°46'21"S; 123°39'18"E

Pelecypods

Oriocrassatella sp. (as in Callytharra Formation and Nura Nura Member of Poole Sandstone)

Stutchburia cf. variabilis Dickins 1957

Megadesmus sp. (as in Lyons Group)

Conulariid (unidentified)

T127, Scott Bluff, Lake Blanche; 22°31'06"S; 123°14'06"E

Pelecypods

Stutchburia cf. variabilis Dickins 1957

Etheripecten cf. tenuicollis (Dana) 1847

Gastropods

Mourlonia (*Pseudobaylea*) cf. *freneyensis* Dickins 1963

Brachiopods

Cancrinella sp.

Aulosteges and *Taeniothaerus*

Neospiriferid

Orthotetid

Fenestellids

DORA SHALE

Northern end of Lake Dora - 2 inches (5 cm) below the base of the salt crust (Registered No. MF 948). Crespin *in* Traves, Casey & Wells, 1956, pp. 54, 55.

Foraminifers

Ammodiscus nitidus Parr

Ammobaculites cf. *woolnoughi* Crespin & Parr

Hyperamminoides acicula Parr

Hyperamminoides cf. *expansus* Plummer

TRIWHITE SANDSTONE

T1, 4 miles (6.4 km) east of the central portion of Lake Dora, 1 mile (1.6 km) east-southeast of Dunn Soak (Traves, Casey & Wells, 1956, p. 51).

Pelecypods

Astartila blatchfordi (Hosking) 1931

Gastropods

Warthia cf. *micromphala* (Morris) 1845

Ptychomphalina maitlandi Etheridge Jnr 1903

T1141, 7 km southeast of Scott Bluff; 22°29'12"S; 123°16'19"E.

Pelecypods

Atomodesma mytiloides Beyrich 1865

Modiolus sp.

Etheripecten sp. (as in Balgo Hills)

Brachiopods

Indet. productid

Notospirifer? sp. nov. (surface pits and adminicula not characteristic of *Notospirifer*)

Wood and Bony plate.

T1148, 7.5 km NNW of Scott Bluff; 22°23'48"S; 123°11'06"E.

Pelecypods

Merismopteria sp.

Schizodus kennedyensis? Dickins 1956

Gastropods

Stachella sp.

Mourlonia (*Mourlonia*) sp.

T1153, 2.5 km southeast of Dunn Soak; 22°04'05"S; 123°10'12"E.

Pelecypods

Astartila cf. *blatchfordi* (Hosking) 1931

T1155, 20 km SSE of Triwhite Hills; 22°16'00"S; 123°17'42"E

Pelecypods

Astartila cf. *blatchfordi* (Hosking) 1931

Atomodesma mytiloides Beyrich 1865

CORRELATION OF FAUNAS

Cuncudgerie Sandstone

Evidence for correlation of the fauna of the Cuncudgerie Sandstone with that of the Nura Nura Member of the Poole Sandstone of the Canning Basin, the Callytharra Formation of the Carnarvon Basin and the Fossil Cliff Formation of the Perth Basin is substantial. *Myonia subarbitrata*, *Permorthotetes lindneri*, *Oriocrassatella* sp. and *Mourlonia* (*Pseudobaylea*) *freneyensis* occur also in the Nura Nura Member. *M.* (*Pseudobaylea*) *freneyensis*, *Strophalosia irwinensis* and *Myonia subarbitrata* occur in the Fossil Cliff Formation and *Oriocrassatella* sp. in the Callytharra Formation. *Pseudosyrinx* sp. aff. *nagmargensis* occurs also in the Lyons Group and Callytharra Formation of the Carnarvon Basin. The remaining elements of the fauna are

consistent with this correlation, and the part of the Cuncudgerie Sandstone bearing the marine fauna can be regarded as the time equivalent of the Nura Nura Member.

Dora Shale

Although the foraminifera recorded by Crespin were regarded as coming from the Dora Shale their source is not clear. The foraminifera might have been derived from the Triwhite Sandstone or even from the Cuncudgerie Sandstone, so the identifications give no certain indication of the correlation of the Dora Shale.

Triwhite Sandstone

Time equivalence with the upper part of the Noonkanbah Formation or the Lightjack Formation of the Liveringa Group is indicated by Astartila blatchfordi, Ptychomphalina maitlandi and Etheripecten sp. A. blatchfordi and P. maitlandi are characteristic of the Upper Noonkanbah rather than the Lightjack which perhaps indicates that the Triwhite Sandstone is equivalent to the Upper Noonkanbah rather that the younger Lightjack Formation.

PALAEOECOLOGY

Cuncudgerie Sandstone

Two somewhat different environments appear to be represented at Helen Hill (T16; T81) and Scott Bluff (TK5A, T127). At Helen Hill pelecypods predominate greatly in numbers - hundreds of individuals compared with a few specimens of each brachiopod species. The pelecypods Oriocrassatella, Stutchburia and Megadesmus are commonly associated with sand and are adapted to living in littoral or sublittoral turbulent conditions (see Dickins, 1963, p. 25).

At Scott Bluff, on the other hand, brachiopods predominate, and apparently this fauna lived in a less turbulent environment, possibly in slightly deeper water.

Triwhite Sandstone

The assemblages of the Triwhite localities are fairly similar to each other, suggesting a similar life environment/ Pelecypods of the sublittoral suite (Astartila, Schizodus) occur together with byssally attached forms such as Atomodesma, Modiolus and Merismopteria and the gastropods Stachella, Mourlonia and Ptychomphalina. A sandy, relatively shallow bottom with some hard substrate is suggested.

REFERENCES

DICKINS, J.M., 1963 - Permian pelecypods and gastropods from Western Australia. Bur. Miner. Resour. Aust. Bull. 63.

GLAUERT, L., 1925 - A list of Western Australia fossils. Geol. Surv. W. Aust., Bull. 88, 36-72.

JONES, L.J., 1922 - A geological reconnaissance of Locke Oil Co. lease 21H Canning Basin. Geol. Surv. W. Aust. File No. 121/22 (unpubl.).

JONES, L.J., 1922 - Report of a geological reconnaissance of portion of Bairds Oil Concession Area Block 23H, W.A. Geol. Surv. W. Aust. File No. 120/22 (unpubl.).

REEVES, F., 1949 - Geology and oil prospects of the Desert Basin, W.A. Unpubl. rep. for Vacuum Oil Co.

TRAVES, D.M., CASEY, J.N., & WELLS, A.T., 1956 - The geology of the south-western Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Rep. 29.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bur. Miner. Resour. Aust. Bull. 60.

WATERHOUSE, J.B., 1969 - The Permian bivalve genera Myonia, Megadesmus, Vacunella and their allies and their occurrence in New Zealand. Geol. Surv. N.Z. Pal. Bull. 41.

APPENDIX D

EARLY CRETACEOUS BIVALVES FROM MORRIS AND RUNTON 1:250 000 SHEETS, SOUTHERN CANNING BASIN, WESTERN AUSTRALIA

by S.K. SKWARKO

Four collections of impressions after bivalves from the southern Canning Basin, Western Australia, are of Aptian (Early Cretaceous) age. The assemblage is limited in genera and species and its preservation is indifferent, so definite identifications could not be made in every case. A fifth collection (M1072: 23°54'00"S; 125°52'24"E) has a problematicum, possibly a worm burrow, which cannot be dated but which somewhat resembles another problematicum from the Gibson Desert to the south, which may be of Permian age.

The lithology at all the sampled outcrops consists of silty quartz sandstone, massive or finely laminated, strongly leached, ironstained, and in places impregnated with silica.

Locality M21: 65 km north of Traegar Hills; 23°15'26"S, 124°43'18"E; Morris 1:250 000 Sheet. Collected by M.J. Jackson and R.W.A. Crowe. Formation: Samuel Formation.

This locality yielded the richest assemblage, consisting of ?Palaeomoera? mariaeburiensis (Etheridge Snr, 1872), Tancretella plana (Moore, 1870), Tatella maranoana (Etheridge Jnr, 1892) and also some bivalves which could not be identified. ?. mariaeburiensis is known from the Aptian strata at Maryborough, eastern Queensland. Because of unsatisfactory preservation it is not possible to positively compare our specimens with those at Maryborough, but they are certainly identical to those from the Aptian strata of the Gibson Desert to the south. T. plana has a wide distribution in Australia as it is known from Aptian strata in central Queensland, the Lake Eyre area of South Australia, and northwestern New South Wales, as well as

in the Bentley and Runton 1:250 000 Sheet areas in the Gibson Desert. T. maranoana is known from Aptian beds at Maryborough, central Queensland, Lake Eyre area, and at Rumbalara in the Northern Territory.

Locality M22: 48 km north-northeast of Traegar Hills; 23°27'42"S, 124°49'26"E; Morris 1:250 000 Sheet area. Collected by M.J. Jackson and R.W.A. Crowe.

Formation: Samuel Formation.

This locality yielded only some small specimens of ?P. mariaeburiensis.

Locality RN2006: 25 km east-southeast of Bejah Hills; 23°52'12"S, 124°22'12"E; Runton 1:250 000 Sheet area. Collected by A.N. Yeates and M.J. Jackson.

Formation: Samuel Formation

Locality RN2008: 40 km south-southeast of Bejah Hills; 23°57'00"S, 124°29'42"E; Runton 1:250 000 Sheet area. Collected by A.N. Yeates and M.J. Jackson.

Formation: Samuel Formation

These two localities yielded only shells which probably belong to Pseudavicula anomala (Moore, 1870) - one of the key Aptian fossils in Australia - previously identified from assemblages in Maryborough, central Queensland, Lake Eyre area, Rumbalara, northwest New South Wales and the Gibson Desert.

All the above bivalves further attest to the particularly uniform sedimentary and climatic conditions in the shallow seas covering much of the Australian continent in Early Cretaceous times, which allowed the individual species wide geographical distribution.

REFERENCE

SKWARKO, S.K., 1967 - Mesozoic Mollusca from Australia and New Guinea, 1. Lower Cretaceous Mollusca of the Great Australian Basin type in the Gibson Desert, Western Australia. Bur. Miner. Resour. Aust. Bull. 75.

RECORD 1978/8

PERMIAN AND MESOZOIC GEOLOGY OF THE DERBY AND MOUNT ANDERSON 1:250 000 SHEET AREAS, WESTERN AUSTRALIA

by

R.W.A. Crowe (Geological Survey of Western Australia),
R.R. Towner, and D.L. Gibson

CONTENTS

	Page
Summary	
Introduction	1
Part I; Stratigraphy and depositional environments of units	
Late Carboniferous to Early Permian	3
Grant Group	3
Betty Formation	3
Winifred Formation	4
Carolyn Formation	4
Tectonism between deposition of Grant Group and Poole Sandstone	11
Early to Late Permian	12
Poole Sandstone	12
Nura Nura Member	12
Tuckfield Member	14
Noonkanbah Formation	15
Liveringa Group	17
Lightjack Formation	18
Hardman Formation	19
Tectonism between deposition of Permian and Triassic	21
Triassic	21
Millyit Sandstone	21
Blina Shale	22
Erskine Sandstone	23
Tectonism between deposition of Triassic and Jurassic	24
Jurassic to Cretaceous	25
Wallal Sandstone	25
Jurgurra Sandstone 'Member'	25
Mudjalla Sandstone 'Member'	26
Alexander Formation	27
Barbwire Sandstone	28
Meda Formation	30
Jarlemai Siltstone	31

Mowla Sandstone 32
Jowlaenga Formation 34
Melligo Sandstone 35
Fitzroy Lamporite 36
Structural patterns in the Edgar Ranges Matches Springs area 36
Post Early Cretaceous tectonism 37
Part II; Geological history 38
Late Carboniferous to Early Permian 38
Early to Late Permian 39
Triassic 42
Jurassic to Cretaceous 43
Acknowledgements 45
References 46
Appendix I - Measured sections 58
Appendix II - Well sections 59

Enclosures

No. 1 Australian Inland Exploration Paradise Boreholes; composite log of Liveringa Group

No. 2 Conzinc Riotinto of Australia Alexander Creek and Meda River Bores; correlation of Liveringa Group

No. 3 Correlation of Jurassic units from the Edgar Ranges to King Sound

No. 4 Preliminary 2nd Edition of Derby 1:250 000 Sheet area

No. 5 Preliminary 2nd Edition of Mount Anderson 1:250 000 Sheet area

NOT IN MICROFICHE COPY.

Figures

1. Sketch map showing structural subdivision and main topographic features of DERBY AND MOUNT ANDERSON.
2. Diagram illustrating different weathering patterns in the same lithology.

3. Sketch map of small area in eastern Grant Range showing identification of reverse faults.
4. Sketch map of part of southern flank of Grant Range showing identification of post-Carolyn Formation pre-Poole Sandstone reverse fault.
5. Rose diagram of current directions in the Erskine Sandstone at Erskine Range.
6. Block diagram showing inferred stress pattern of ?Jurassic tectonic event.
7. Rose diagram of current directions in Mudjalla Sandstone 'Member' at Mudjalla Creek
8. Schematic diagrams showing two possible correlations of sequence at Camelgooda Hill.
9. Relations between Jowlaenga Formation and Melligo Sandstone at Dampier Hill.
10. Pre-Jurassic drainage pattern in Edgar Ranges Matches Springs are
11. Palaeogeographic maps for Carolyn Formation
    A. Showing area covered
    B. Carolyn Formation, pre-Wye Worry Member
    C. Lower Wye Worry Member
    D. Middle Wye Worry Member
    E. Lower Millajiddee Member
    F. Upper Millajiddee Member
12. Diagrammatic relations of facies within the Poole Sandstone between Grant Range and NOONKANBAH.
13. Diagrammatic relations of facies within the Liveringa Group between the study area and NOONKANBAH.
14. Schematic block diagrams showing relations between structure and sedimentation during Triassic (A) and Jurassic (B).
15. Interpreted facies correlations of Jurassic sequence.
16. Sketch map of DERBY and MOUNT ANDERSON showing locations of sections in Appendix I.
17. Sketch map of DERBY and MOUNT ANDERSON showing location of deep wells.

PLATES

1. Part of an intraformational breccia near Hawkstone Peak.
2. Intraformational unconformity in Carolyn Formation in east Grant Range.
3. Nura Nura Member of the Poole Sandstone in south Grant Range.
4. Interference, straight-crested, symmetrical ripple marks in the Tuckfield Member of the Poole Sandstone in south Grant Range.
5. Low-angle cross-bedding in the Tuckfield Member of the Poole Sandstone in south Grant Range.
6. Megaripples in Noonkanbah Formation in Geegully Creek.
7. Megaripple cross-bedding in Hardman Formation at Liveringa Ridge.
8. Thinly bedded and laminated sandy mudstone of the Blina Shale at Erskine Range.
9. Preserved dune in Jurgurra Sandstone 'Member' in Geegully Creek.
10. Concretions in the Jurgurra Sandstone 'Member' in Geegully Creek.
11. Stereo pair showing the origin of a load cast in the Alexander Formation at Mount Alexander.
12. Stereo pair showing a preserved megaripple in the Alexander Formation.
13. Stereo pair showing contact between Alexander Formation and Jarlemai Siltstone.
14. Stereo pair showing local disconformity between Jarlemai Siltstone and Mowla Formation.

SUMMARY

The Permian and Mesozoic geology of Derby and Mount Anderson Sheet areas is characterised by four major sedimentary cycles, each representing a marine transgression and regression with only minor continental deposition. The first cycle was deposited in the Late Carboniferous to Early Permian and was probably dominantly a glacial. A brief period of compressional tectonism preceded the second cycle, which occurred in a warmer climate during the rest of the Permian. Local tectonism then took place adjacent to the margins of the Fitzroy Trough and the third, Triassic cycle occurred, probably only to the north of the Fenton Fault. This was followed by a major period of compressional tectonism, probably during the Early or Middle Jurassic, which resulted in reverse movement along the margins of the Fitzroy Trough and folding within it. The fourth cycle of sedimentation started in the Middle Jurassic and continued until the Early Cretaceous. This was followed by minor faulting and gentle upwarping, probably during the Tertiary.

INTRODUCTION

The purpose of this report is to make available, a. quickly as possible, stratigraphic information, field interpretations, and hypotheses that result from the second-edition mapping of the Derby and Mount Anderson Sheet areas* in 1976. The report only covers the Permian and Mesozoic geology of the area, and the rest of the stratigraphy will be des in the Explanatory Notes that accompany the maps (Towner & Gibson, in prep.; Gibson & Crowe, in prep.).

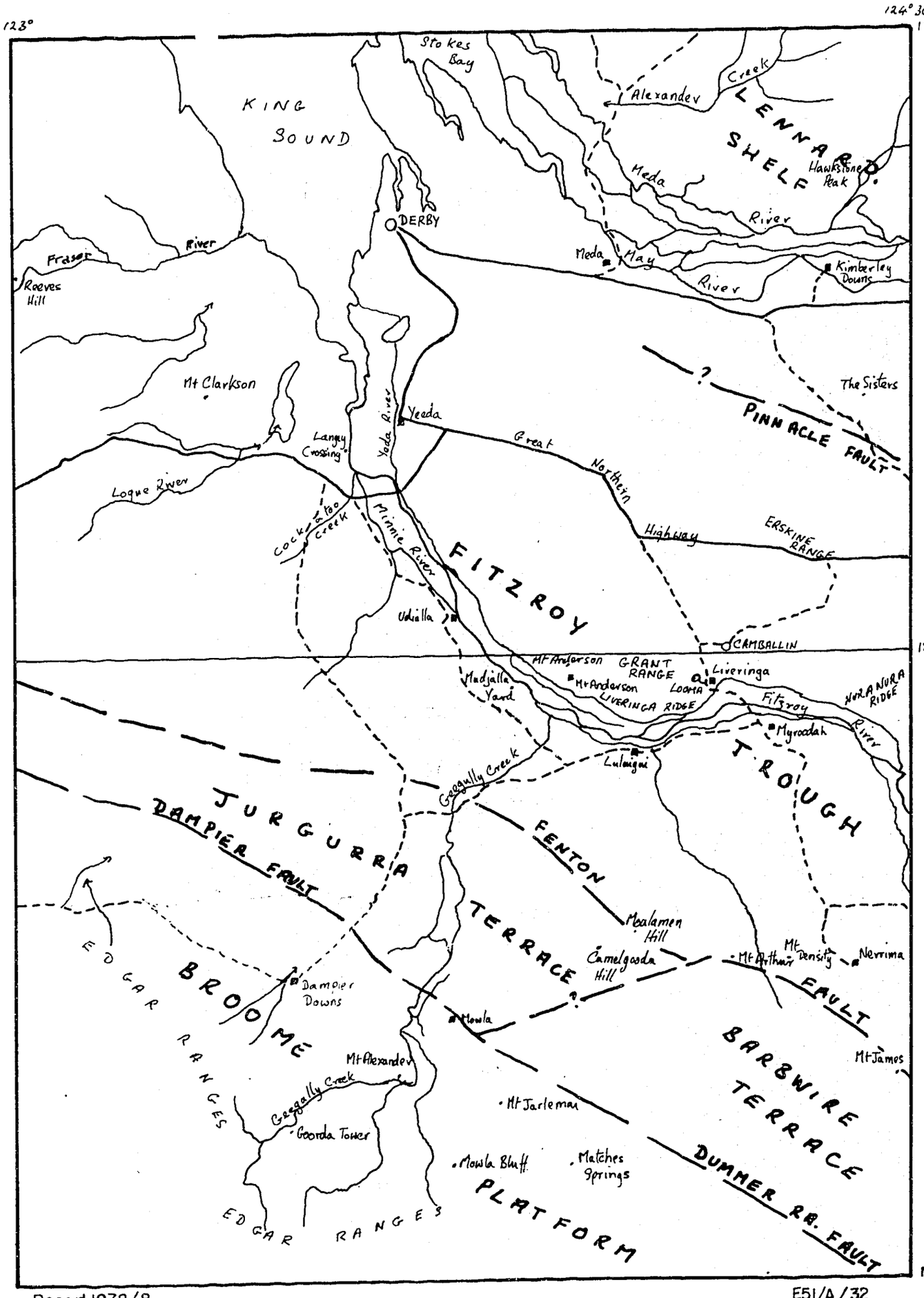
In many respects the work is a continuation of that carried out in adjoining NOONKANBAH in 1974 (Crowe & Towner, 1976c). Although time limitations did not allow the same amount of detailed work as that done in NOONKANBAH, many of the interpretations and hypotheses are the same. Most of the stratigraphic units recognized in NOONKANBAH were traced into the area though they were not recognizable everywhere. The Jurassic section only just extends into NOONKANBAH and was therefore not covered by Crowe & Towner (1976c). However, in the present study area it is well exposed. A problem with the Jurassic section is that the exposures are widely sep separated and correlation is therefore difficult. In previous mapping (Brunnschweiler, 1957; Guppy and others, 1958; Veevers & Wells, 1961) this' resulted in the definition of a large number of units with indefinite or unknown relations. However, since that time there has been a large increase in the amount of subsurface data available and this has enabled useto simplify the earlier interpretation of the stratigraphy. In making these simplifications, some nomenclature changes have been necessary and in some cases (Langey Shale, Jurgurra Sandstone, Mudjalla Sandstone) these changes have not yet been formally defined.

*Hereafter 1:250 000 Sheet area names are shown in capitals (NOONKANBAH) to distinguish them from place names.

The report is organized differently from previous reports (Yeates and others, 1975b; Crowe & Towner, 1976c; Towner and others, 1976) as much of the information is given in tabular form. Part I of the text concentrates on the interpretation of the depositional environment and unusual or important features of each lithostratigraphic unit and the relevant information is summarized in tables. Part II is an account of the Permian and Mesozoic geological history of the area. Environmental models are used to explain the facies distributions and although there is only slight evidence for some of these models, it is felt that such suggestions are worth recording as they should form a basis for future work in the area.

The rocks are described according to the classification of Gilbert (in Williams and others, 1958). Grainsize is classified on the Wentworth scale, and terms used for bedding thickness are those of Ingram (1954). The classification of cross-bedding follows Potter & P Pettijohn (1963) and Reineck & Singh (1973), and that of flaser and lenticular bedding follows Reineck & Wunderlich (1968). Other terms used are referenced in the text.

All place names referred to are shown on the 1:250 000 geological maps (Enclosure 4). Most can be found on the existing 1:250 000 topographic maps, although for the latest topographic information the 1:100 000 maps should be used (topographic maps are available from the Division of National Mapping, Canberra or from the Department of Lands and Surveys, Perth). The more important place names are shown in Figure 1 together with the names of the structural subdivisions that are used in the text.



Record 1978/8

E51/A/32

Fig. 1 Sketch map showing structural subdivisions and main topographic features of DERBY and MT ANDERSON

O Town or settlement ■ Station homestead ~ Creek or river — — Road

SCALE 1:1 000 000

PART I

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF UNITS

LATE CARBONIFEROUS TO EARLY PERMIAN

GRANT GROUP

The Grant Group (Crowe & Towner, in press) consists of three formations, the lower Betty Formation, the middle Winifred Formation, and the upper Carolyn Formation. The upper part of the Carolyn Formation also contains two subdivisions, the Wye Worry Member and the uppermost Millajiddee Member (Crowe & Towner, 1976a). All these units are recognized in the area, although the two Carolyn Formation members are not everywhere recognizable (Tables 4 & 5). The Betty and Winifred Formations are not thought to crop out in the area but are recognized in bores (Appendix II).

BETTY FORMATION (Table 1)

The Betty Formation unconformably overlies Early Carboniferous, Early Palaeozoic, and Devonian rocks in the area. It progressively overlies younger rocks from the centre of the Fitzroy Trough outwards, and the basal boundary is a seismic reflecting horizon which has been mapped in many areas of the basin.

Little is known about the depositional environment of the Betty Formation. The one record of marine fossils in the southeastern part of the basin implies that it is at least partly marine. If the environment is marine, then such large thicknesses of sandstone are, in the absence of turbidite indicators, difficult to explain except in a shallow-water environment. The possible presence of dropstones within the sequence suggests a glacial climate. This is supported by the fact that the formation is thought to interfinger with parts of the glacial Paterson Formation in the southern part of the basin (Crowe & Towner, in press).

Unit Betty Formation	Symbol Pb	Defined by Crowe & Towner (in press)

Distribution In subsurface the unit occurs throughout the area except in DERBY. It is not thought to crop out.

Lithology Dominantly white to light grey sandstone, very fine to coarse-grained; minor conglomerate. Unit contains some calcareous and pyritic zones and some shale intervals. Fragments of various Precambrian rock types are reported from many wells (and may represent glacial dropstones).

Facies variations Facies appears to vary laterally and vertically although the facies have not been separately mapped.

Thickness Maximum thickness recorded in basin is 1714 m in WAPET Grant Range No.1 (Appendix II)	**Type section locality** Between 1058 and 1657 m in WAPET Lake Betty No.1 (MOUNT BANNERMAN: Lat.19°34'10"S, Long.126°19'52"E).

Age and criteria Late Carboniferous to Sakmarian based on palynological evidence (Gorter, in prep.). On Broome Platform and Jurgurra Terrace the unit is probably mostly Permian.

Fossils The only macrofossils are unspecified marine fossils in Aquitaine Wilson Cliffs No.1 (Aquitaine, 1969) (Wilson).

Relations Unconformably overlies pre-Permian rocks and is conformably overlain by the Winifred Formation.

Subdivisions None defined although there are fine-grained parts of the sequence that may be mappable in the subsurface.	**Nature of exposure** None. **Remarks** A prospective reservoir for petroleum.

The formation contains a basal Late Carboniferous section which appears to be largely confined to the Fitzroy Trough (except in western parts of the area). This implies that deposition started in the Fitzroy Trough before spreading throughout the area in the Early Permian.

WINIFRED FORMATION (Table 2)

Little is known about the depositional environment of the Winifred Formation. The unit contains marine fossils in the southern part of the basin and so is at least partly marine. It may have been laid down in a glacial climate as a few clasts of Precambrian rock types are reported from some wells, and Towner and others (1976) believe parts of the unit' are varved. The fine grainsize of the unit suggests deposition in deeper or quieter water than the Betty and Carolyn Formations.

CAROLYN FORMATION (Table 3)

The Carolyn Formation occurs throughout the Canning Basin except where it is cut out by the Jurassic unconformity. From work in adjoining NOONKANBAH, Crowe & Towner (1976c) were able to show that the formation is, at least locally, unconformably overlain by the Poole Sandstone. In one area this unconformity cuts out the uppermost Millajiddee Member (Crowe & Towner, 1976c) and a similar situation exists in DERBY and MOUNT ANDERSON.

Grant Range area

The best exposures of the Carolyn Formation in the area occur in the Grant Range (Section 1) and at nearby Mount Anderson and Mount Wynne (northern MOUNT ANDERSON). The formation is exposed in cliffs which are partly obscured by scree. Examination of the sedimentary structures is made difficult by the presence of a siliceous weathering skin on the rock surface and the structures can normally only be seen in caves and overhangs where the skin is eroded (Fig. 2).

Table 2

Unit Winifred Formation	Symbol Pw	Defined by Crowe & Towner (in press)

Distribution Not exposed. Intersected in the subsurface throughout the area except in NE DERBY and near Matches Springs where it is cut out by the Jurassic unconformity.

Lithology Predominantly grey shale, carbonaceous, pyritic; grading to siltstone, with thin interbeds of very fine-grained sandstone. Unit is coarser-grained towards base.

Facies variation The unit is difficult to recognize in some bores within the Fitzroy Trough, indicating that it may contain lithological variations.

Thickness Max. intersection is 278 m in AFO Sisters No. 1 (Appendix II).	Type section locality Lat.22°52'40"S, Long. 123°36'20"E (TABLETOP)

Age and criteria Sakmarian (sensu lato) based on palynological determinations (Gorter, in prep.).

Fossils Some unidentified crinoid, bryozoan, and echinoid fragments are recorded from the unit from WAPET Sahara No. 1 (SAHARA) to the south of the area (WAPET, 1966b).

Relations Interpreted to be conformably overlain by Carolyn Formation in bore sections. However Carolyn Formation overlaps the Winifred Formation in the northern part of the area. The lower boundary with the underlying Betty Formation is also interpreted to be conformable.

Subdivisions None.	Nature of exposure None.
	Remarks Not easily recognized in bores within the Fitzroy Trough in this area. May be a cap rock for petroleum.

Unit Carolyn Formation	Symbol Pc	Defined by Crowe & Towner (in press)

Distribution Throughout area; exposed in NE DERBY, in Grant Range and at Mount Arthur (MOUNT ANDERSON). Unit is cut out by unconformities in Edgar Range area.

Lithology Fine to coarse-grained quartz wacke and quartz arenite; minor feldspathic and lithic wacke, bedding poorly preserved, mainly planar-bedded, some large-scale trough cross-bedding, ripple marks, and scour-and-fill structures. Contains large-scale slump structures at Hawkstone Peak and in east Grant Range. Contains grey calcareous mudstone sequences ascribed to Wye Worry Member. See text for description of individual areas.

Facies variations Towards the top of the formation marked lateral facies variations are common and are difficult to map. There appears to be some lateral (as well as vertical) changes between Wye Worry and Millajiddee Member in central Grant Range. Sections at Mount Arthur and Hawkstone Peak are different again (see text).

Thickness 366 m in AFO Sisters No. 1 (Appendix II)

Type section locality Composite section at Lat.18°44'20"S, Long.124°55'52" E, and Lat. 18°41'53"S, Long.124°54'30"E (NOONKANBAH).

Age and criteria Late Sakmarian (sensu late) based on marine macrofossils (Dickins and others, in press). Palynological determinations indicate a Sakmarian (sensu lato) age (WAPET, 1973).

Fossils *Eurydesma*? sp. ind., *Deltopecten lyonensis*, *Etheripecten* cf. *tenuicollis*, *Streblopteria* sp., *Keenia*? sp. ind. in Wye Worry Member outside area.

Relationships Lower boundary with Winifred Formation is believed to be conformable in well sections in area. Unconformably overlain by Poole Sandstone in Grant Range; unconformity not seen elsewhere in area but may be present. Unit is cut out by unconformities in Edgar Range area.

Subdivisions

Millajiddee Member
Wye Worry Member
Undivided lower part

Nature of exposure High straight-sided cliffs or smooth scree slopes; appears rugged on aerial photographs.

Remarks Identification of members within Carolyn Formation could only be made in north-central and south-central Grant Range.

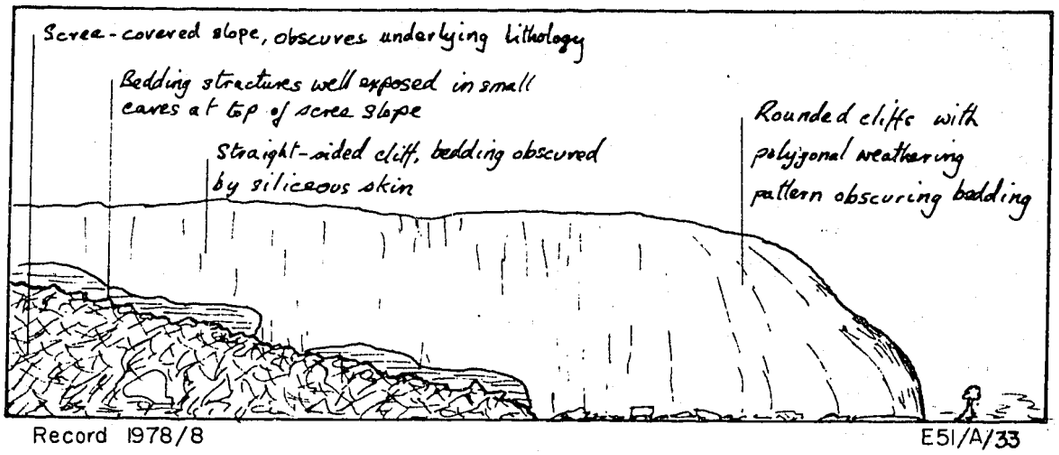


Fig. 2 Diagram illustrating how different weathering patterns occur in the same lithology. The small caves at the top of the scree slopes are the only places where the sedimentary structures can be seen. The polygonal weathering pattern that occurs on the rounded cliffs is illustrated in Crowe & Toomer (1976c; plate 2)

In mapping the Carolyn Formation in adjoining NOONKANBAH (Crowe & Towner, 1976c; in prep.) the fine-grained shaly Wye Worry Member (Table 4) was found to be a useful marker. Typically the member crops out as smooth scree slopes due to its fine-grained shaly nature and this gives the unit a characteristic tone on the aerial photographs.

The photo-pattern was found to be a reliable identifying criteria in NOONKANBAH and it was consequently also used in the Grant Range area. In fact, identification of the Wye Worry Member by air-photo interpretation was commonly found to be more reliable than ground identifications. The reason is that, on the ground, complex structures, and the presence of scree and unusual weathering patterns tend to complicate the overall picture (Fig. 2). However, mapping of the Carolyn Formation members was only possible in the central and western parts of Grant Range and at Mount Anderson. In the eastern part of Grant Range, the structures are so complex that identification and mapping of the Wye Worry Member marker (at air-photo scale; 1:80 000) was not possible (see section below).

Another complication of the Grant Range sequence is the presence of vertical repetition of the Wye Worry and Millajiddee Members. In NOONKANBAH, Crowe & Towner (1976c) interpreted the Wye Worry and Millajiddee Member sequence s a single regressive cycle of deposition. In Grant Range, however, the sequence is repeated several times (at least three cycles were recognized) and the value of the Wye Worry Member as a marker is largely lost. Moreover, the Wye Worry and Millajiddee Members lens in and out over distances of a kilometre or so. As the whole sequence is complexly faulted, identification of the Carolyn Formation members is rather tentative in the Grant Range area. On the geological map (Gibson & Crowe, in prep.) only the uppermost members are shown for simplicity and the tongues of Millajiddee Member within the Wye Worry Member are not differentiated.

In the Mount Wynne area, shaly Wye Worry Member is exposed underneath laterite but other exposures of mainly sandstone could not be assigned to any of the members of the Carolyn Formation.

Mount Arthur area

In the Mount Arthur area (west central MOUNT ANDERSON) the Grant Group sequence consists of fine to medium and minor coarse-grained quartz wacke. There are large-scale trough cross-bedded parts which pass up into planar-bedded sections with current lineation. These, in turn, pass up into ripple cross-laminated beds and then the whole sequence is repeated. The cycles are about 10 m thick and some contain intraformational conglomerate beds at their bases, with abundant fossil wood fragments.

This facies could be correlated with either the Millajiddee Member or parts of the Carolyn Formation below the Wye Worry Member. However, the absence of the Wye Worry Member in such a thick section (probably several hundred metres) suggests that the latter correlation is more likely. It is nevertheless possible that the Wye Worry Member has been faulted out by strike faults which are known to exist in the area. More detailed mapping in the vicinity of Mount Arthur would probably solve this problem.

Hawkstone Peak area

In the Hawkstone Peak area (northeast DERBY) the exposures consist mainly of fine to medium-grained, well-rounded, moderately to well-sorted quartz arenite and minor quartz-pebble conglomerate. The conglomerate occurs as crudely graded lenses at the base of trough cross sets which are mostly 0.5 m thick although some are thicker. Within this sequence there are steep-sided channels containing intraformational breccias (Plate 1) set in a poorly sorted lithic-wacke matrix. Some blocks are up to 3 m across. In places the larger blocks protrude into the underlying sediment and can be seen to have deformed it. Parts of the sequence are contorted by rheotropic deformation of the order of 10 m thickness.

This lithology is believed to be part of the Millajiddee Member. Although the sequence is not very similar to exposures of the Millajiddee Member in Grant Range, it does correlate with the upper part of the Millajiddee Member section exposed in the Lauris Range in NOONKANBAH (Section 18 of Crowe & Towner, 1976c).

G.S.W.A. F. 19. No. 3

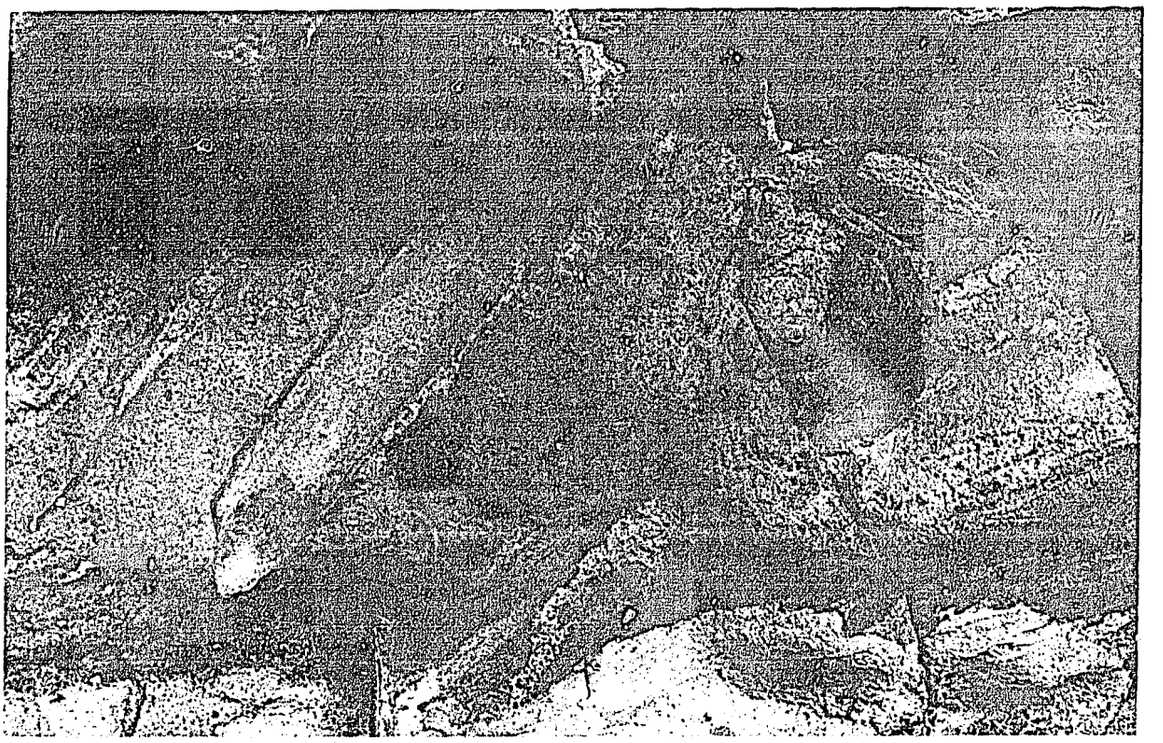


Plate 1. Part of an intraformational breccia in an exposure of the Millajidee Member near Hawkstone Peak at Lat. 17°14' 30" S, Long. 124°09'00" E.

G.S.W.A. F. 18. No. 15



Plate 2. Intraformational unconformity in Carolyn Formation in east Grant Range (Lat. 18°02' 00" S, Long. 124°09'00" E). The underlying dipping beds are interpreted to be part of a large slump which has been planed off before deposition of the overlying horizontal sequence.

It seems as if the Hawkstone Peak and Lauris Range sections of the Millajiddee Member represent a facies variation of the Millajiddee Member that is not generally seen in the Fitzroy Trough. This is probably the reason why early workers in the area separated the Grant Group exposures on the Lennard Shelf from those in the Fitzroy Trough (Kraus, 1941; Findlay, 1942; see Guppy and others, 1958 for discussion). An explanation of this facies variation is given in the section on depositional environment and geological history.

Structures in eastern Grant Range

The structures in eastern Grant Range (referred to above) are of two types: tectonic post-depositional structures, and syn-depositional sedimentary structures.

As stated above, the detailed stratigraphy of eastern Grant Range could not be mapped at air-photo scale. However, at certain localities (e.g. Fig. 3) the Wye Worry Member marker was identified and this enabled some of the detailed stratigraphy to be mapped. Attempts to trace these stratigraphic levels around the range to the west failed because of structural complexities. In particular, very large-scale (several tens of metres) slump structures occur and have been planed off before deposition of the overlying beds (Plate 2). Such intraformational unconformities are thought to be partly responsible for the lateral discontinuities which make it difficult to trace the units.

Mapping in eastern Grant Range suggests that some faults have much greater throws than previously imagined (Guppy and others, 1958). The mapping suggests that some of the north-trending faults may have throws of at least 500 m. However, where these faults are traced southwards into exposures of the Poole Sandstone there is no displacement. Even allowing for differences in displacement across the crest of the Grant Range Structure (anticlinal) this anomaly cannot be explained unless' faulting between deposition of the Carolyn Formation and Poole Sandstone is inferred. This inference could not be established on the more major faults but at Lat. 18° 04'00", Long. 124°08'05"E there is firm evidence of such faulting (see following section).

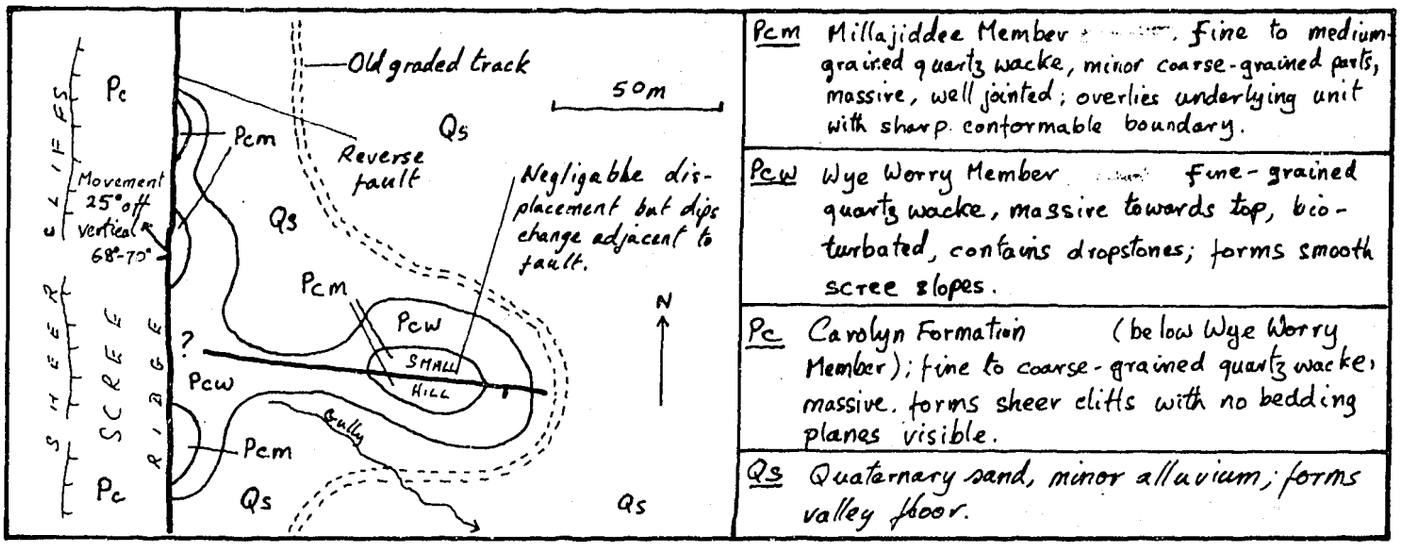
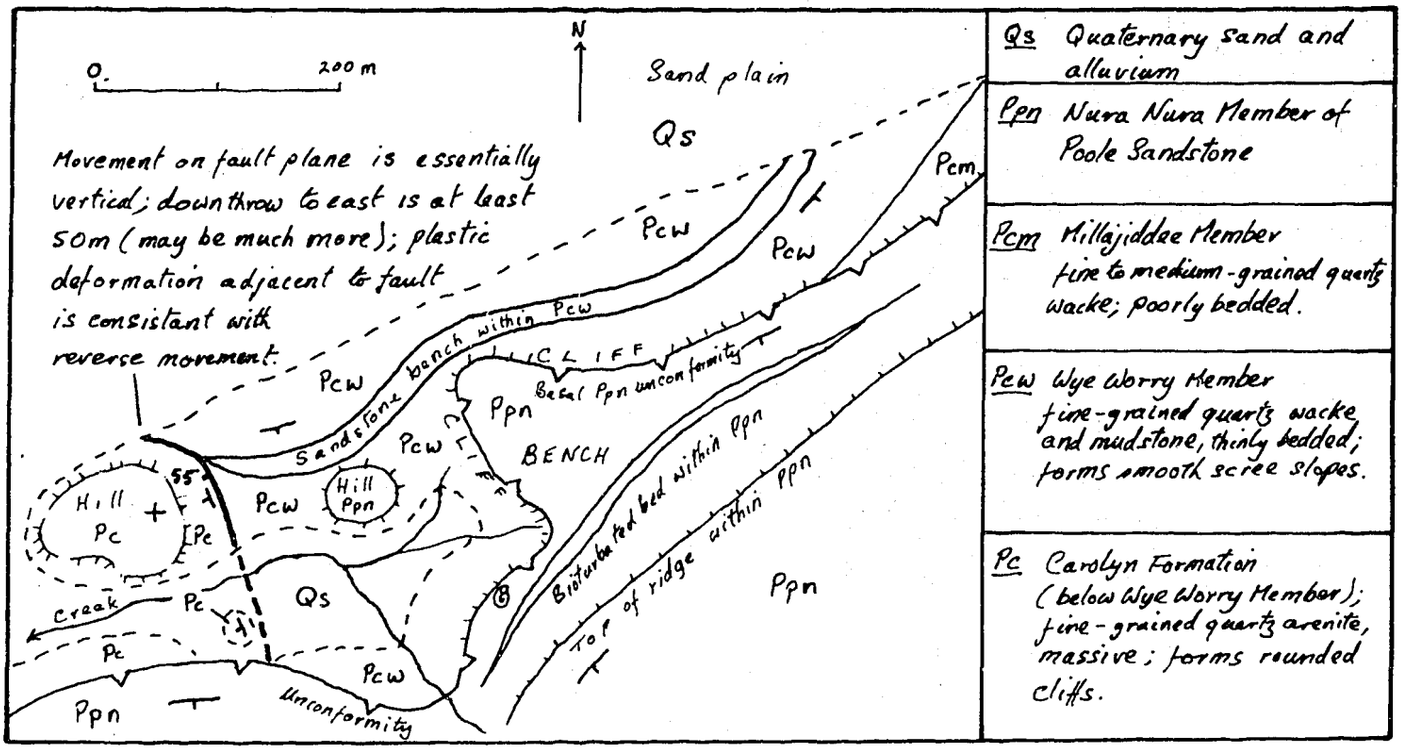


Fig. 3 Sketch map of small area in eastern Grant Range (Lat. 18° 01' 30"S, Long. 124° 08' 00"E) showing identification of reverse fault.



Record 1978/8 E51/A11/6

Fig. 4 Sketch map of part of southern flank of Grant Range (Lat. 18°04' 00"S, Long. 124° 08' 05"E) showing identification of post-Carolyn-Formation pre-Poole-Sandstone reverse fault.

Most of the faults within the Fitzroy Trough have previously been described as normal. This is compatible with the tectonic model proposed by Rattigan (1967) and Smith (1968) where the faults within the trough are tensional and part of an en echelon fold pattern related to Middle Triassic/Early Jurassic right lateral wrench movement on the major faults that bound the trough (Fenton Fault and Pinnacle Fault; see Fig. 6). However, the rare occurrence of reverse faults was noted by Crowe & Towner (in prep.) in NOONKANBAH and further examples of reverse movement were discovered during this survey in the Grant Range (Figs. 3 & 4). The occurrence of these reverse faults in a tensional regime may therefore indicate that there was a separate period of compressional tectonism' within the Fitzroy Trough. The mapping suggests that this compressional movement occurred between deposition of the Carolyn Formation and the Poole Sandstone (see Figs. 3 & 4) as none of the reverse faults, so far identified, appear to displace the Poole Sandstone.

Another complication of the geology in the eastern Grant Range is the occurrence of wrench faulting. Horizontal slickensides occur in a fault zone at Lat. 18°01'30"S, Long. 124°08'20"E but the amount of movement could not be determined.

Depositional environment

Grant Range area: In the Grant Range area there is little evidence to indicate the depositional environment of the Carolyn Formation below the Wye Worry Member. Where the siliceous weathering skin is absent, sections are seen to be composed of thin-bedded, bioturbated, fine to medium-grained quartz wacke, quartz arenite, and minor feldspathic wacke (possibly theuupper part of the sequence). The lateral continuity of bedding in these sections suggests deposition in a large body of water. Scour-and-fill structures, flaser bedding, and mega-ripple cross-bedding are also present suggesting fairly shallow water (?above wave base) deposition from bedload. However, the bulk of the sequence below the Wye Worry Member in the Grant Range is composed of structureless, massive poorly sorted coarse-grained quartz wacke, the origin of which is problematical. A shallow-water marine environment appears to be the most likely environment capable of depositing such a thick homogenous sequence.

The Wye Worry Member in the Grant Range area consists of mainly fine-grained, grey, partly calcareous lithic wacke, mudstone, and quartz wacke. The sections are mainly thin-bedded or laminated with vertical burrows, bioturbated zones, and bedding-surface trace fossils. This lithology is very similar to the marine part of the Wye Worry Member in NOONKANBAH (Crowe & Towner, 1976c) and a similar depositional environment is inferred. The general absence of ripple marks, channel structures, and the poor sorting suggest deposition below wave base. The basal varved sequence that occurs in the Wye Worry Member in NOONKANBAH does not appear to be present in the area although faceted and striated dropstones occur sporadically throughout the sequence. The dropstones' are interpreted as glacial in origin.

The Millajiddee Member in the Grant Range is similar to the 'Lower' Millajiddee Member sequence in NOONKANBAH (Crowe & Towner, 1976c). It is composed of well-sorted quartz arenite with minor quartz wacke and contains scour-and-fill structures, ripple cross-lamination, flaser bedding, and minor large-scale trough and planar cross-bedding. The boundary between the Wye Worry Member and Millajiddee Member is gradational and represents an upwards increase in grainsize and sorting, indicating a shallowing of water depth. The structures within the Millajiddee Member are typical of sediment laid down above wave base, suggesting near-shore conditions.

The Wye Worry Member-Millajiddee Member sequence is repeated several times in the Grant Range area (Section 1) and one explanation for this is that there was an oscillating shoreline in the area. An alternative explanation is that the intervals of Millajiddee Member represent offshore sand bars and that the final regression is not preserved. The lenticularity of some of these intervals suggests this is the most likely alternative.

In the Mount Arthur area, sections of the Carolyn Formation are different from those in the Grant Range. The upward progression from trough cross-bedding to planar bedding to ripple cross-bedding is typical of channel point-bar deposits. These sequences are repeated several times and this supports the interpretation. Such sequences are often interpreted as fluviatile but they may also represent tidal or

Table 4

Unit Wye Worry Member	Symbol Pcw	Defined by Crowe & Towner (1976a)

Distribution Only recognized at Mount Anderson and in the central Grant Range. Possibly cut out by Poole Sandstone/Grant Group unconformity in Mount Arthur area and is probably overlapped by Millajiddee Member at Hawkstone Peak. Not recognizable in subsurface sections.

Lithology Fine to medium-grained quartz and lithic wacke and mudstone, grey, calcareous; contains rare faceted and striated dropstones. Sedimentary structures are not well preserved because unit is normally covered by scree. Where unit passes up into Millajiddee Member it contains conglomerate lenses, small scour-and-fill structures, and some ripple marks and flaser and lenticular bedding. See Section 1 (Appendix I).

Facies variations Appears to alternate with Millajiddee Member in cyclical fashion. Also appears to pass laterally into Millajiddee Member or Carolyn Formation.

Thickness At least 110 m in Grant Range.	Type section locality Lat.18°46'30"S, Long.125°18'50"E (NOONKANBAH).

Age and criteria Late Sakmarian (sensu lato) based on marine macrofossils (Dickins and others, in press).

Fossils See under Carolyn Formation.

Relations The lower contact with the underlying part of the Carolyn Formation was not definitely identified. The upper boundary with the Millajiddee Member is conformable. The sequence of Wye Worry Member going up to Millajiddee Member appears to be repeated several times owing to interfingering in the central Grant Range.

Subdivisions	Nature of exposure Rather poor, due to cover of scree over most exposures.
	Remarks Difficult to recognize.

Table 5

Unit Millajiddee Member	Symbol Pcm	Defined by Crowe & Towner (1976a)

Distribution Only recognized at Mount Anderson, in central Grant Range, and tentatively at Hawkstone Peak (NE DERBY). Not recognized in subsurface sections.

Lithology Mainly medium-grained, moderately sorted, quartz wacke; also fine and coarse-grained and mudstone parts; contains ripple marks and large-scale (mainly planar) cross-bedding; scour-and-fill structures and minor flaser bedding; forms resistant cliffs, and bedding is commonly masked by a thin siliceous skin produced by weathering. See Section 1 (Appendix I).

Facies variations Extensive pinching out of Millajiddee Member indicates interfingering with Wye Worry Member. Section at Hawkstone Peak contains intraformational breccia and large-scale slump structures which do not correlate directly with Grant Range exposures.

Thickness Probably at least 75 m in Grant Range.	Type section locality Lat.18°45'00"S, Long.124°55'25"E (NOONKANBAH)

Age and criteria Late Sakmarian (sensu lato) based on the late Sakmarian age of the underlying Wye Worry Member and the age of the overlying Nura Nura Member which appears to be late Sakmarian to early Artinskian (Thomas & Dickins, 1954; Glenister & Furnish, 1961).

Fossils Contains indeterminate wood fragments and trace fossils.

Relations The lower boundary with the underlying Wye Worry Member is conformable although the Wye Worry Member interfingers with the Millajiddee Member in the central Grant Range. The Millajiddee Member is overlain unconformably by the Poole Sandstone.

Subdivisions The threefold subdivision of the unit that was possible in NOONKANBAH could not be made in the exposures in DERBY and MOUNT ANDERSON.	Nature of exposure Forms rounded cliffs often covered by a siliceous skin or polygonal weathering pattern.
	Remarks The unit is an excellent aquifer. Owing to the structural and stratigraphic complexities in the eastern Grant Range the unit cannot be confidently identified. The Millajiddee is difficult to recognize where the underlying Wye Worry Member is absent.

delta channel deposits in a near-shore environment. As correlation of this sequence with other parts of the Carolyn Formation is not possible at present, the exact nature of the meandering channels in the Mount Arthur area has not been established.

The exposures in the Hawkstone Peak area are assigned to the upper part of the Millajiddee Member. The sequence mainly consists of large-scale trough cross-bedded sandstone with pebble conglomerate at the base of the cross-sets. The conglomerates are interpreted as channel lags and the cross-sets are also believed to be channel deposits of possible fluvial origin. Intraformational breccias occur in steep-sided channels cut into this general lithology and their association with soft-sediment deformation structures suggests that they were deposited as mudflows. The association between mudflows and fluviatile deposits is characteristic of an alluvial fan environment.

The unconformity in the Grant Range area between the Carolyn Formation and the Poole Sandstone indicates that after deposition of the Carolyn Formation, the Grant Range area was uplifted, folded and faulted before deposition of the Poole Sandstone (see following section). The upper and middle parts of the Millajiddee Member that are believed to represent a regression in NOONKANBAH (Crowe & Towner, 1976c) do not appear to be present in the Grant Range and are probably cut out by this unconformity.

Unit Poole Sandstone	Symbol Pp	Defined by Guppy and others (1952)

Distribution Exposed on the flanks of the Grant Range, in the Mount Wynne/Nura Nura Ridge area, and in the Mount Arthur area. Subsurface information indicates the formation is present in all but the northeastern part of the area and where it has been cut out by the Jurassic unconformity.

Lithology Mainly fine-grained quartz and lithic wacke, thin-bedded, laminated; abundant ripple cross-bedding and trace fossils. Contains some medium to coarse-grained quartz wacke and arenite in the lower part. Flaser and lenticular bedding, wavy bedding and some large-scale, mainly planar, cross-bedding is present. Lenses of ferruginized clay pellet conglomerate, with abundant fossil wood fragments occur throughout. See Section 2 (Appendix I).

Facies variations See under Nura Nura Member and Tuckfield Member.

Thickness At least 250 m exposed in Grant Range. Maximum is 350 m in AFO Nerrima No.1(Appendix II).	Type section locality Southeast Grant Range (MOUNT ANDERSON: Lat.18°04'30"S, Long.124°08'30"E).

Age and criteria Late Sakmarian (sensu lato) to ?early Artinskian. The oldest limit is based on macrofossils from the Nura Nura Member (Glenister & Furnish, 1961; Dickins in Crowe & Towner, 1976c) and the younger limit is based on microfossils (Paten in Yeates and others, 1975b) and the age of the overlying Noonkanbah Formation.

Fossils Macrofossils from the Nura Nura Member are listed by Guppy and others (1958). Wood fragments and plant fossils are listed by Guppy and others (1958).

Relations Unconformably overlies the Grant Group. Upper boundary is not exposed but in subsurface sections it is sharp and is therefore thought to be a disconformity.

Subdivisions Christmas Creek Member (does not occur in area) Tuckfield Member Nura Nura Member	Nature of exposure Forms smooth, scree-covered hills and strike ridges. Remarks Unit is a moderately good aquifer if sandstone sections are intersected.

TECTONISM BETWEEN DEPOSITION OF GRANT GROUP AND POOLE SANDSTONE

Guppy and others (1958) were the first to recognize an angular unconformity between the Grant Group and the Poole Sandstone. Later workers (e.g. Veevers & Wells, 1961) believed the boundary was only disconformable, but Crowe & Towner (1976b, 1976c) showed that in NOONKANBAH there was corroborating evidence of uplift, erosion and tilting between deposition of the two units, in addition to planed off slump structures which mark the unconformity.

The evidence given by Crowe & Towner was of two types. Firstly, from measured sections, they were able to show that in certain areas the upper part of the Carolyn Formation (their 'Upper Sandstone Unit') was missing, suggesting an unconformity. Secondly, a small lensoid between the two units was interpreted as a mudflow deposit and so was compatible with an environment where uplift was producing steep topography.

In MOUNT ANDERSON there is also good evidence of an unconformable relation between the Grant Group and the Poole Sandstone. In several places in Grant Range, beds of the Carolyn Formation are cut out by the unconformity at the base of the Poole Sandstone. In one area (Fig. 4) a fault exhibits significant (probably reverse) displacement in the Carolyn Formation but does not displace the overlying Poole Sandstone. Apparently this is the first recording of faulting between these two units and it supports Crowe & Towner's evidence of tectonism at this time in NOONKANBAH (Crowe & Towner, 1976c).

Crowe & Towner (1976c) suggested that in NOONKANBAH, the areas that are now anticlines acted as both positive and negative features at various times during Permian deposition and it could be that the Grant Group/Poole Sandstone unconformity is restricted to these major anticlines.

EARLY TO LATE PERMIAN

POOLE SANDSTONE

The Poole Sandstone was defined by Guppy and others (1952). The type area was designated in the Poole Range (NOONKANBAH) but later Guppy and others (1958) defined a type section in the Grant Range (Section 2). The basal Nura Nura Member was also defined by Guppy and others (1952) but their definition was inadequate and has therefore been expanded here. Crowe & Towner (in press) have named the widespread middle section of the formation the Tuckfield Member. The uppermost Christmas Creek Member (Crowe & Towner, 1976a) that occurs in NOONKANBAH does not occur in the area.

In some parts of the area (e.g. Mount Arthur) the members could not be reliably recognized and the exposures were therefore mapped as Poole Sandstone undivided.

NURA NURA MEMBER (Table 7)

The Nura Nura Member was defined by Guppy and others (1952) as consisting of 'calcareous sandstone, sandy limestone, and limestone, with bands of unsorted, coarser sediments' at Nura Nura Ridge (northeast MOUNT ANDERSON). In NOONKANBAH, Crowe & Towner (1976b; in prep.) extended this unit to include a wider variety of facies. Further more detailed work should allow these facies to be subdivided but at 1:250 000 scale mp mapping the member was taken to include the rocks between the distinctive boundaries of the post-Grant Group unconformity and the conformable, often sharp upper boundary with the Tuckfield Member ('middle Poole Sandstone' of Crowe & Towner, 1976b). In western NOONKANBAH, the upper part of the Nura Nura Member consists of a poorly bedded, well-sorted quartz arenite unit interpreted as a barrier bar deposit. A similar sandstone unit forms a distinctive marker (forming rugged terrain) along the northern and southern flanks of the Grant Range and although it occurs much higher in the section, it is correlated with the NOONKANBAH sandstone unit and is taken as the topmost part of the Nura Nura Member in the Grant Range area.

Table 7

Unit Nura Nura Member	Symbol Ppn	Defined by Guppy and others (1958)

Distribution Exposed at Nura Nura Ridge/Mount Wynne area and on the northern and southern flanks of Grant Range. Possibly exposed in Mount Arthur area. In the subsurface the unit occurs throughout the area except in northeast and where cut out by Jurassic unconformity.

Lithology In the Grant Range area the basal 10 m consists of fine-grained poorly laminated quartz arenite with abundant trough cross-bedding with some bioturbation and macro-fossils. Middle part consists of thin-bedded ferruginized, fine-grained quartz wacke and mudstone with lenses of clay-pellet conglomerate, ripple marks, wavy and flaser bedding. Top 25 m consists of moderately to well-sorted quartz wacke and quartz arenite with abundant trough and planar cross-bedding and rippled cross-lamination. Sorting and grainsize increase towards top. Intense ferruginization of some parts suggests they may have been calcareous before weathering. See Section 2.

Facies variations Unit is thinner and calcareous in Nura Nura Ridge area. Exposures in northern Grant Range appear to contain more abundant poorly bedded quartz arenite sections than in southern flank of range. Guppy and others (1958) point out that the unit exhibits marked changes in thickness over short distances.

Thickness 110 m in Grant Range..

Type section locality Nura Nura Ridge (MOUNT ANDERSON: Lat.18°02'S, Long.124°28'E).

Age and criteria Late Sakmarian based on macrofossils (Glenister & Furnish, 1961; Dickins in Crowe & Towner, 1976c).

Fossils Macrofossils from the unit are listed by Guppy and other (1958) and include brachiopods (Thomas, 1954; Coleman, 1957), Bryozoa (Crockford, 1957), foraminifera, ammonoids, molluscs (Thomas & Dickins, 1954), conodont fragments, crinoid ossicles, and ostracods.

Relations Lies unconformably on Carolyn Formation (Plate 3) and is conformably overlain by the Tuckfield Member.

Subdivisions Some characteristic subdivisions can be recognized in Grant Range;

25 m-thick cross-bedded, poorly laminated, fine to medium-grained quartz wacke and quartz arenite.

Thin-bedded, ripple-marked, poorly sorted quartz wacke and mudstone with lenses of clay pellet conglomerate.

Local, 10 m thick, cliff-forming well-sorted cross-bedded quartz arenite.

Nature of exposure Well exposed as small cliffs and scree-covered slopes in Grant Range. Poorly exposed at Nura Nura Ridge.

Remarks Basal part of member is easily confused with top of Carolyn Formation as weathering pattern is similar.

G.S.W.A. F. 17 No. 13

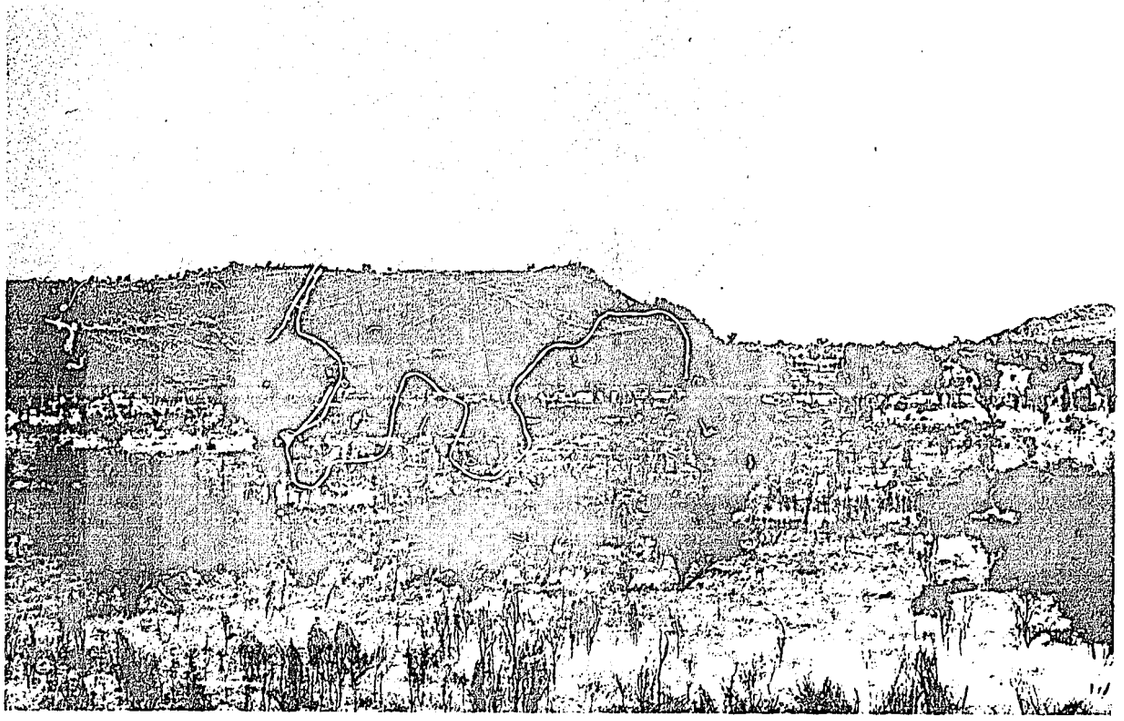


Plate 3. Thin - bedded (scree-forming) Nura Nura Member of the Poole Sandstone showing the massive bench at the base of the unit. The contact with the underlying Carloyn Formation is exposed in the scree at the base of the hill. South flank of Grant Range (Lat. 18°02'50" S, Long. 124°09'00" E).

In the Nura Nura Ridge area some of the original exposures described by Guppy and others (1952; 1958) are now covered by the waters of Lake Josceline. The parts that are still exposed consistoof basal calcareous sandstone and fossiliferous limestone overlain by ferruginized sandstone which forms a small ridge near the lake. The ferruginization suggests that this sandstone was originally calcareous (this is a common weathering effect in the area) and the ridge is tentatively correlated with the sandstone marker that occurs at the top of the Nura Nura Member on the flanks of the Grant Range. Because there is a difference between the sections of the Nura Nura Member at Nura Nura Ridge and in the Grant Range it is herein proposed that the Grant Range section (Section 2) be taken as a reference section.

In the Mount Arthur area, the exposed section is not thick enough to confidently identify the Nura Nura Member. However, the ridges of Poole Sandstone at the western end of the Mount Arthur group of hills are lithologically similar to the Nura Nura Member in the Grant Range. The section at Mount Arthur itself is more like the Tuckfield Member. Complex strike faulting makes it difficult to establish the vertical sequence in the Mount Arthur area.

Depositional environment

The basal quartz arenite part of the Nura Nura Member that is seen in the Grant Range is interpreted as a transgressive sand body deposited as the sea moved over the pre-existing land surface. The clean, very well-sorted (with rounded grains) nature of the sedimentsis characteristic of intense re-working by wave action which would be expected in such an environment.

Such sand bodies can be deposited either as beaches or as off-shore sand bars. The abundance of large-scale trough cross-bedding in the unit suggests sand bars because trough cross-bedding is not common in beach deposits. As Visher (1965) has pointed out, rather special conditions are necessary for transgressive sand bodies to be preserved because as the transgression continues the sea tends to rework its own deposits. This would explain why the unit is only locally developed.

The middle part of the Nura Nura Member in the Grant Range contains ripple-marked, poorly-sorted interbedded sandstone and mudstone interpreted to have been deposited in a shallow sea (above wave base). The interbedding of sand and silt in such an environment is common because of the alternations between fast-moving and slack water due to tidal action.' Small scour-and-fill and bioturbation structures are also common and are compatible with the interpretation. Larger sccurs containing clay-pellet, intraformational conglomerate are associated with large-scale planar cross-sets and these are interpreted as channel deposits of tidal origin.

Towards the upper part of the Nura Nura Member in the Grant Range, there is an overall upward increase in grainsize and sorting to coarse-grained well-sorted quartz arenite at the top. This indicates that shallower-water conditions returned to the area. The abundance of large-scale planar and trough cross-bedding in this part of the sequence indicates deposition in channels and as mega-ripples. This, and the fact that the sequence passes upwards into further shallow-water deposits (of the Tuckfield Member) suggests that the upper part of the Nura Nura Member represents an offshore sand-bar deposit possibly of the barrier-bar type. This fits in with the interpretation placed on the similar sandstone unit which occurs at the top of the member in western NOONKANBAH (see above).

Visher (1965) states that a common physical characteristic of a transgressive sequence is that, above the basal beds, the sequence commonly passes sharply up into carbonates. This could be the situation in the Nura Nura Ridge area where the member contains limestone and calcareous sandstone near its base.

TUCKFIELD MEMBER (Table 8)

Exposures of the Tuckfield Member (Section 2) are lithologically similar to the exposures of the member in adjoining NOONKANBAH. However, in the Grant Range there appear to be more clay-pellet conglomerate lenses in the sequence.

Table 8

Unit Tuckfield Member	Symbol Ppt	Defined by Crows & Towner (in press)

Distribution Exposed in the Grant Range and Mount Wynne areas. Possibly present at Mount Arthur. In the subsurface it occurs throughout the area except in the north-east and where it is cut out by the Jurassic unconformity.

Lithology Consists mainly of fine-grained quartz wacke, lithic wacke, and mudstone, well and poorly-sorted, thin-bedded, laminated; minor flaser bedding, abundant wavy bedding; some large-scale planar cross-bedding and abundant ripple cross-bedding. Ripple marks are mainly straight-crested and both symmetrical and asymmetrical. Lenses of clay pellet conglomerate up to 0.5m thick and 10m long occur throughout the sequence and contain abundant fossil wood fragments. Parts of sequence consist of laminated, fine-grained, well-sorted quartz arenite with current lineation and large-scale, low-angle planar cross-bedding. See Section 2.

Facies variations The unit is laterally and vertically homogeneous although the middle part appears to contain a greater proportion of mudstone than the rest.

Thickness At least 140 m present in Grant Range. Maximum subsurface intersection is 271 m in AFO Nerrima No. 1 (Appendix II).	Type section locality Mount Tuckfield (NOONKANBAH: lat.18° 42'15"S, Long.124°53' 35"E).

Age and criteria Probably Artinskian as it is overlain by the Artinskian Noonkanbah Formation (Guppy and others, 1958) and it overlies latest Sakmarian Nura Nura Member (Glenister & Furnish, 1961).

Fossils Contains abudant fossil wood fragments. Plants found in the unit are recorded in Guppy and others (1958). The only other fossils recorded are bedding-surface trace fossils and some burrows.

Relations Conformably overlies the Nura Nura Member and is overlain by the Noonkanbah Formation. Lower boundary is not seen on surface in the area but farther east Crowe & Towner (1976c) postulate that it may be disconformable.

Subdivisions None.	Nature of exposure Forms smooth rounded hills and strike ridges.
	Remarks A good aquifer.

Depositional environment

Crowe & Towner (1976b, c) suggested that the Tuckfield Member was deposited in a lagoonal environment on the basis of the abundance of shallow-water indicators (wave-formed ripple marks, etc.), the presence of plant material, and the lack of open-marine indicators. They suggested that the sandstone unit at the top of the Nura Nura Member in the west St George Range was a barrier-bar deposit and the this may have acted as the barrier responsible for restricting open-marine circulation during deposition of the Tuckfield Member.

This suggestion is extended here (Fig. 12) and the Tuckfield Member in DERBY AND MOUNT ANDERSON is similarly interpreted as a possible lagoonal deposit.

The member contains similar shallow-water indicators (e.g. Plate 4) as it does farther east with the exception of root-bearing beds which occur in NOONKANBAH. The greater abundance of clay-pellet conglomerate lenses is thought to be due to greater channel activity within the postulated lagoon. The conglomerate contains abundant fossil wood fragments, presumably derived from the vegetation that is indicated by the root horizons in NOONKANBAH.

Another difference between the NOONKANBAH and Grant Range sequences is that the exposures in Grant Range contain intervals of very well-sorted, laminated, fine and very fine-grained quartz arenite with current lineation on the bedding surfaces and which is arranged in low-angle planar cross-sets (Plate 5). These intervals are interpreted as beach deposits, suggesting that there may have been local emergence.

NOONKANBAH FORMATION (Table 9)

In MOUNT ANDERSON several exposures south of the Fitzroy Trough have been assigned to the Noonkanbah Formation by previous workers (Guppy and others, 1958). These exposures areedifferent to outcrops of the unit in the Fitzroy Trough.

Unit Noonkanbah Formation	Symbol Pn	Defined by Wade (1938) Guppy and others(1952)

Distribution Underlies much of the black-soil plains north of the Meda River and occurs as floaters. Occurs in gullies south of Jimbulara Ridge, and south and north of Grant Range. Identified in float southeast of Sandfly yard and around Mount Arthur and Nerrima Ridge.

Lithology Mainly mudstone, black, micaceous, partly pyritic, calcareous; interbedded with limestone, fossiliferous, grey, thin-bedded, finely crystalline, argillaceous in parts; and quartz wacke, very fine to medium-grained, scattered coarse grains and granules, moderate to poorly-sorted, thin-bedded, and calcareous matrix, contains lenses of very coarse-grained shelly sandstone.

Limestone interbeds occur throughout unit but sandstone appears more common towards base.

Facies variations In Nerrima Ridge area a well-defined marker bed is present; the Strophalosia kimberleyensis marker bed (Guppy and others, 1950). Located 23 m below top of formation, it occurs as a line of boulders and rubble on north and south flanks of Nerrima Dome. Facies changes are rare in the Noonkanbah Formation though outcrops south of the Fenton Fault appear coarser-grained and contain a large amount of terrigenous material.

Thickness Average in area is about 300 m; maximum is 410 m in AFO Sisters No. 1 (Appendix II).	Type section locality Near Fruten Hill (NOONKANBAH: Lat. 18°44'35"S, Long. 125°37'30"E)

Age and criteria Macrofossils indicate the unit is Artinskian (Guppy and others, 1958) Palynomorph assemblages confirm this date (Balme, 1967).

Fossils Very rich fauna consisting of brachiopods, bryozoans, corals, crinoids, foraminifera, molluscs, ostracods. Balme (1967), from examination of samples from Wapet Blackstone No. 1, believes the formation contains the Vittatina I, II, and III palynomorph zones.

Relations Lower contact with Poole Sandstone not exposed but thought to be conformable in bore sections. Farther east Crowe & Towner (1967c) postulated a disconformable relation.

Upper contact with Lightjack Formation is conformable and gradational as observed at Lower Liveringa Ridge (Section 3).

Subdivisions None.	Nature of exposure Very poor; occurs as soil float and is exposed in erosion gullies.
	Remarks Unit has a characteristic air-photo pattern of light-coloured (clayey) patches with bedding trends visible as out-crops or vegtation lines. A poor aquifer although it may contain or confine artesian aquifers particularly in faulted areas.

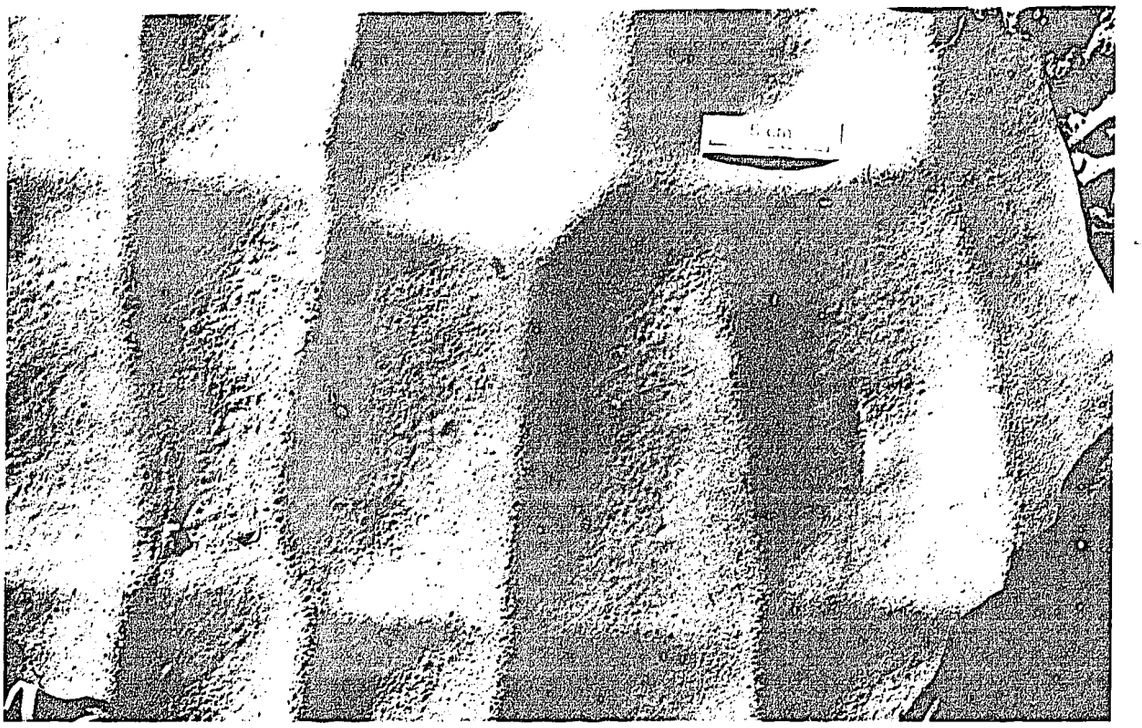


Plate 4. Interference, straight-crested, symmetrical ripple marks in the Tuckfield Member of the Poole Sandstone. South flank of Grant Range (Lat. 18° 03'00" S, Long. 124° 09'40" E).

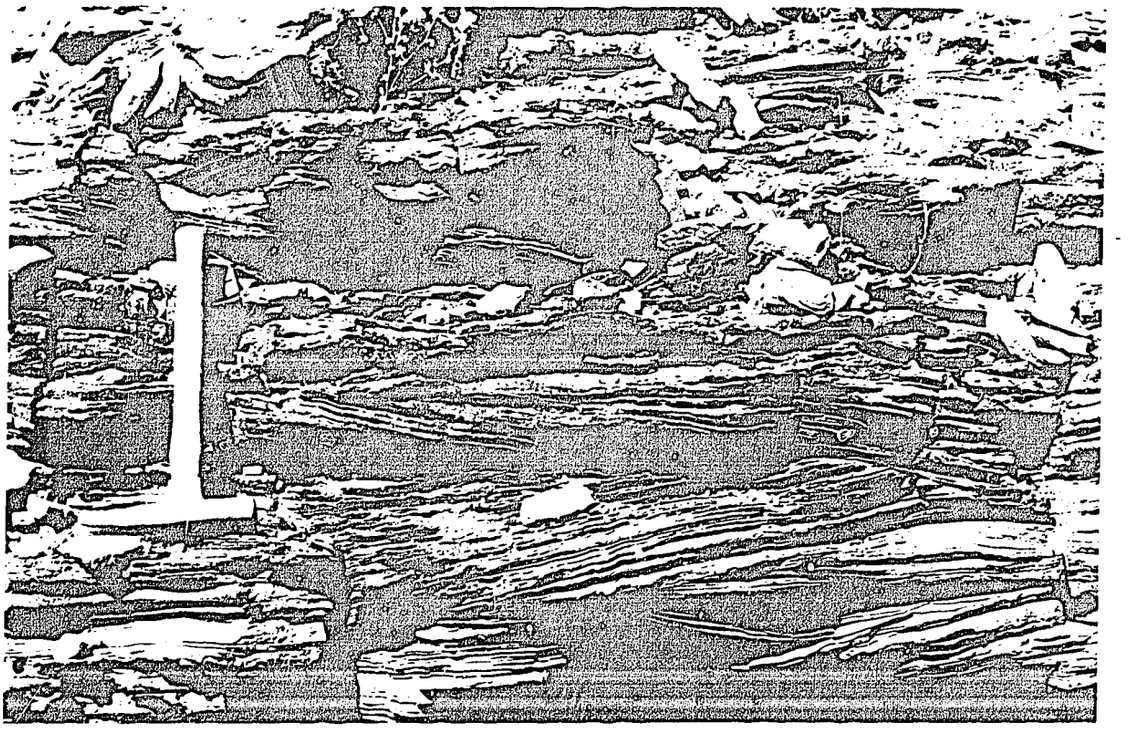


Plate 5. Low-angle cross-bedding in the Tuckfield Member of the Poole Sandstone. Note that foresets dip in opposite directions. Southern flank of Grant Range (Lat. 18°04'30" S, Long. 124°08'30" E).

Exposures south of the Fenton Fault on Nerrima station contain a typical Noonkanbah Formation fauna but the lithology is different in that it contains lenses (up to a metre thick) composed of intraformational conglomerate with a few quartzite and hematitic extraclasts. The conglomerate lenses also contain abundant abraded fossil fragments.

Another atypical exposure of Noonkanbah Formation occurs in Geegully Creek at Lat. 18°19'00"S, Long. 123°43'35"E. It consists of mega-ripples of coarse-grained quartz wacke and granule conglomerate set in more typical grey calcareous mudstone (Plate 6). Although no fossils were found in this exposure it is assigned to the Noonkanbah Formation on the basis that nearby BMR Jurgurra Creek No.1 bore spudded in that unit.

Depositional environment

The Noonkanbah Formation contains a rich marine fauna which indicates an unrestricted marine depositional environment. The lithology of the unit in the Fitzroy Trough and Lennard Shelf is mainly laminated calcareous mudstone, suggesting deposition from suspension. The presence of pyritic zones indicate that quiet reducing conditions periodically prevailed. Cross-bedded sandstone beds near the base of the unit suggest shallow-water or near-shore conditions but the lack of current structures in the rest of the unit suggests that it was deposited below wave base (?30 m). Palaeontological evidence supports this interpretation as the mainly 'brachiopodal' assemblage was thought by Thomas (1958a) to indicate a water depth of 30-55 m.

The lenses of intraformational conglomerate that occur south of the Fenton Fault were probably deposited in channels which suggest shallower-water conditions in this area. The large amount of terrigenous material in mega-ripples in the Geegully Creek exposure also indicates shallow-water conditions with strong currents.

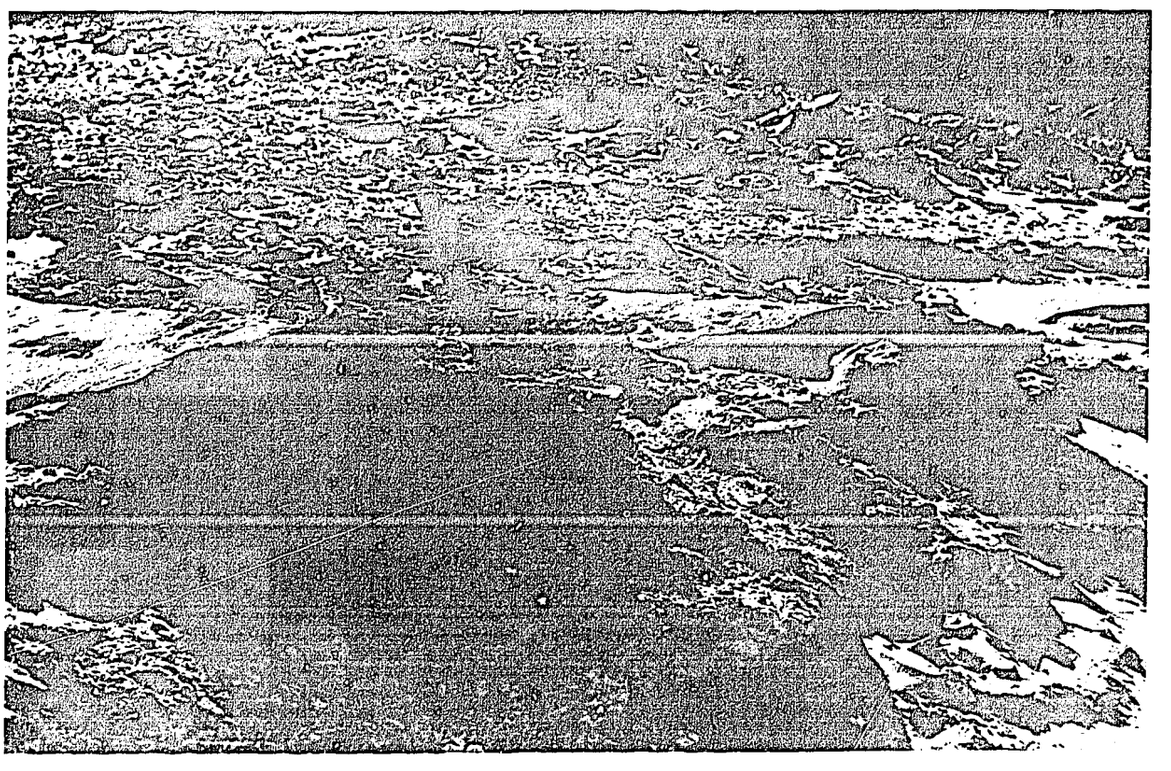


Plate 6. Mega ripples in an exposure in Seegully Creek (Lat. 18°19'00" S, Long. 123°43'35" E), which is assigned to the Noonkanbah Formation. There is good separation between the finer-grained lithic wacke on the ripple surfaces and the coarse-grained quartz wacke that forms the foresets.

LIVERINGA GROUP

The term 'Liveringa Group' was first used by Guppy and others, (1952) who later formally defined the sequence as the Liveringa Formation with three member subdivisions (Guppy and others, 1958). The sequence was then redefined as the Liveringa Group by Yeates and others (1975a) and they named the previous members as formations; the basal Lightjack Formation, the middle Condren Sandstone, and the upper Hardman Formation. The Hardman Formation was further subdivided into the lower, Kirkby Range Member; the middle, Hicks Range Sandstone Member; and the upper, Cherrabun Member (Yeates and others, 1975a).

The Condren Sandstone wedges out in NOONKANBAH (Crowe & Towner, 1976c) and is not thought to be present within DERBY and MOUNT ANDERSON However, the other subdivisions of the Liveringa Group have been mapped in the area. Each of the units within the Liveringa Group is characteristically a coarsening upwards cycle. The present mapping has suggested that further cycles may be developed in the area, but poor exposure, lack of distinctive markers, and little reliable subsurface control did not allow these cycles to be separated.

In DERBY and MOUNT ANDERSON there are no detailed and representative bore sections through the Liveringa Group and consequently a section from the northwestern corner of NOONKANBAH has been enclosed (Enclosure 1). The section is a composite of six continuous coreholes that were drilled by Australian Inland Exploration in 1971 in the Paradise station area. The section is herein proposed as a reference section for the Liveringa Group. It has been compiled from various sources which are acknowledged in the enclosure.

Enclosure 2 shows a correlation of bores drilled in DERBY by Conzinc Riotinto of Australia in 1973, for coal. The identifications of the units and the correlations are mainly ours.

LIGHTJACK FORMATION (Table 10)

Intersection in Derby Town Bore

The interval between 536.4 and 722.4 m in Derby Town Bore (Lat. 17°19'00"S, Long. 123°38'30"E) consists of silty, fine-grained, micaceous sandstone containing brachiopods, overlying sandy, micaceous, laminated to unbedded siltstone with thin beds of oolitic chamositic ironstone (Playford, 1957). Thomas (in Playford, 1957) identified the brachiopods, though not specifically and suggested that they might belong to the Hardman Formation. However, as he pointed out, the two forms also range down into the Noonkanbah Formation.

The oolitic ironstone from the bore is similar to oolite found in exposures of Lightjack Formation although the surface samples are replaced by limonite. It is therefore suggested that the Liveringa Group rocks in the Derby Town Bore belong to the Lightjack Formation.

Depositional environment

The upward overall increase in grainsize and sorting to the top of the middle sandstone unit indicates a regressive sequence.

In the lower part of the unit, large-scale cross-sets occur in association with scour-and-fill structures and fossiliferous clay-pellet conglomerates at the bases of the scours. These deposits are interpreted as channel deposits. At Mount Marmion (DERBY), wave-formed ripple marks occur in the deposits, indicating shallow-water deposition (above wave base) and it is therefore thought that the sequence is tidal. The presence of burrows and bioturbated zones within this part of the sequence is compatible with such an interpretation.

The middle sandstone unit (referred to as the 'middle plant-bearing member' by Guppy and others, 1958) consists mainly of laminated medium-grained quartz wacke which because of its position in the vertical sequence is interpreted as a barrier bar or beach deposit (see also Crowe & Towner (1976c).

The upper part of the formation, although not recognized on the surface, is inferred to be present in the southern part of the Fitzroy Trough. Crowe & Towner (1976c) suggested that this part was deposited in a lagoonal environment.

Table 10

Unit Lightjack Formation	Symbol Pj	Defined by Guppy and others (1958); Yeates and others (1975a)

Distribution In DERBY crops out as long strike ridges at Jimbulara, Willumbah, and Lower Liveringa Ridges and at Mount Marmion. In MOUNT ANDERSON, exposed at Liveringa Ridge, southeast of Mount Wynne and at Nerrima Ridge. Penetrated in eight wells in area.

Lithology Brown, fine to very fine-grained quartz wacke and mudstone, interbedded; with small lenses of coarse-grained quartz wacke commonly containing fossils; laminated to thin-bedded with wavy bedding and ripple marks. This passes up into middle part of medium-grained quartz wacke and quartz arenite, moderate to well-sorted, laminated to thin-bedded; trough cross-bedding and ripple cross-laimination; contains abundant plant fossils and thin sandy coal seams in subsurface. Top part of unit consists of interbedded mudstone and fine-grained quartz wacke with abundant ripple marks. However, this upper part is probably only present in southern part of area. See Section 3.

Facies variations Appears to contain more coarse-grained quartz wacke and granule conglomerate in areas adjacent to Fenton Fault.

Thickness Thickest section is 167 m at Liveringa Ridge.

Type section locality Lightjack Hill (NOONKANBAH: Lat.18°59'S, Long.125°50'E)

Age and criteria Lower part is dated as late Artinskian to Kungurian based on macro and microfossils. Upper part is imprecisely dated as Permian by plant macrofossils and Late Permian by palynomorphs (WAPET, 1967b).

Fossils Contains a rick fauns including pelecypods, gastropods, brachiopods, bryzoans, foraminifera and rare ammonoids (Guppy and others, 1958; Thomas, 1954) from lower part of unit. Middle sandstone part of unit contains rich floras of Glossopteris and Gangamoptoris. Basal part of unit is assigned to the Vittatina III Assemblage of Balme (1967) and rest of unit is part of his Dulhuntyspora Assemblage.

Relations Conformably overlies Noonkanbah Formation. Probably disconformably overlain by Hardman Formation (Section 3). To southeast, overlain conformably by Condren Sandstone but this unit is missing in the area. Subsurface information (Galloway & Howell, 1975) suggests top part of Lightjack Formation is also missing in most of area.

Subdivisions Crowe & Towner (1976c) identified upper, middle, and lower parts of the formation to the east of the area. These subdivisions can be recognized in DERBY and MOUNT ANDERSON although subsurface information (Galloway & Howell, 1975) suggests that the upper part is absent in north.

Nature of exposure Poor, but is generally better exposed than other parts of Liveringa Group. Trend lines visible through soil cover in many areas.

Remarks Contains colitic ironstone (Edwards, 1953) in MOUNT ANDERSON and in Derby Town Bore (Playford, 1957). Middle sandstone unit is probably a good aquifer.

J.M. Dickins (pers. comm.) has suggested that the fauna from exposures of Lightjack Formation in the western Fitzroy Trough may be slightly younger than the fauna from the same stratigraphic level in the Gregory Sub-basin. If correct, this evidence of diachronism supports the interpretation of the Lightjack Formation as a regressive sequence.

Subsurface information from the Kimberley Downs area (see Enclosure 2) shows that the Lightjack Formation may contain two coarsening-upward cycles. Without more detailed information it is difficult to interpret these cycles but it is suggested that the lower sandstone unit may represent another sand-bar deposit. The identifications of the boundaries of the Lightjack Formation in these bores is based on the electric-log characteristics.

HARDMAN FORMATION (Table 11)

The members of the Hardman Formation are poorly exposed and difficult to map in the area. With the mapping on NOONKANBAH, Crowe & Towner (1976c) were able to reliably establish the bio- and litho- stratigraphy of the Hardman Formation. This has enabled identification of the Hardman Formation members by their photo patterns and faunas, and by using the aerial photographs it has been possible on MOUNT ANDERSON to trace the units away from the identified localities. In this way, most of the Hardman Formation members beneath the gravel plains south of the Fitzroy River and within the Fitzroy Trough have been mapped.

Kirkby Range Member (Table 12)

Fossils in the Kirkby Range Member indicate marine deposition. The basal part of the unit consists of coarse-grained, medium-grained, and fine-grained sandstone beds interbedded with mudstone. The separation between the different grainsizes is good and indicates alternating current conditions so that the lower part of the unit was probably laid down in a tidal environment.

Unit Hardman Formation	Symbol Ph	Defined by Guppy and others (1958); Yeates and others (1975a)

Distribution Extensively exposed south of Fitzroy River but crops out less north of the river where it is largely covered by Triassic rocks. In the subsurface the unit is confined to the Fitzroy Trough and southwestern Lennard Shelf except where cut out by Jurassic unconformity.

Lithology Interbedded sandstone and mudstone, ripple marks, scour-and-fill structures; lenses of coarse-grained sandstone and granule conglomerate; intervals of sandstone with large-scale cross-bedding. Unless fossils are found or a thick vertical sequence is exposed, the members of the Hardman Formation are difficult to recognize; in many areas the exposures can be traced several kilometres along strike because the trend lines show up as vegetation patterns. See Section 3.

Facies variations See under various members.

Thickness See under members.	**Type section locality** Mount Hardman (NOONKANBAH: Lat. 18°18'45"S, Long. 124°38'52"E)

Age and criteria See under members.

Fossils See under members.

Relations Unit is believed to disconformably overlie the Condren Sandstone (which is probably not present in this area) and the Lightjack Formation. The formation is largely conformably (but locally unconformably) overlain by Triassic rocks.

Subdivisions	**Nature of exposure** Exposed beneath gravel plains and as low strike ridges.
Three Members; Cherrabun Member Hicks Range Sandstone Member Kirkby Range Member	**Remarks**

Table 12

Unit Kirkby Range Member	Symbol Phk	Defined by Yeates and others (1975a)

Distribution Very poor exposure in area but can be identified as a lighter photopattern stratigraphically beneath the Hicks Range Sandstone Member and above the relatively prominent ridges of Lightjack Formation. Occurs throughout Fitzroy Trough and southwest Lennard Shelf except where cut out by Jurassic unconformity.

Lithology Basal parts consist of fine-grained quartz wacke and mudstone; slightly calcareous; laminated to thin-bedded, ripple-marked; lenses of granule conglomerate. Middle part is not exposed and probably consists mainly of mudstone. Upper part consists of fine-grained, laminated to thin-bedded quartz wacke with occasional pebbles; u-shaped burrows and concretions common; low-angle large and small-scale cross-bedding present. See Section 3.

Facies variations The unit is probably finer-grained (more mudstone) than in NOONKANBAH. It could not be separated from the overlying Hicks Range Sandstone Member in bore sections on the Lennard Shelf (see Enclosure 2), suggesting that there is a different facies present in that area.

Thickness 230 m at Liveringa Ridge appears to be maximum thickness in area.

Type section locality Millyit Range (CROSSLAND: Lat. 19°09'39"S, Long. 125° 34'24"E).

Age and criteria The fauna collected from the unit in NOONKANBAH has not been fully studied but it indicates a Late Permian age (Dickins *in* Crowe & Towner, 1976c).

Fossils A poorly preserved marine fauna was collected from the unit but has not yet been studied.

Relations At Liveringa Ridge, the lower boundary of the Kirkby Range Member with the Lightjack Formation is marked by a conglomerate bed suggesting a disconformable relation. This agrees with the regional relations as the Condren Sandstone and upper part of the Lightjack Formation are absent in this area. The upper boundary with the Hicks Range Sandstone Member was not seen but from subsurface data is believed to be conformable.

Subdivisions The unit becomes coarser-grained towards the top so that the upper part consists mainly of sandstone whereas the lower part is predominantly mudstone.

Nature of exposure Extremely poor in area. Occurs as scattered lines of calcareous float in soil. Some exposure at Liveringa Ridge.

Remarks Mainly a poor aquifer although upper sandstone part has moderate potential.

The upper part of the unit is composed of relatively better-sorted sandstone with no mudstone interbeds. The sandstone contains large and small-scale cross-bedding and small scour structures suggesting deposition in small channels. There is a general upward increase in sorting and grainsize which indicates a regressive sequence and following Crowe & Towner (1976c), the upper sandstone part of the member is interpreted as an offshore sand bar of the barrier type.

Hicks Range Sandstone (Table 13)

The lower and middle parts of the Hicks Range Sandstone Member consist of interbedded sandstone and minor mudstone which are thinly bedded and contain abundant wave-formed ripple marks. This indicates shallow-water deposition in a wave-dominated environment. The vertical position of this sequence above the interpreted barrier-bar deposits (of the Kirkby Range Member) caused Crowe & Towner (1976c) to interpret a lagoonal environment of deposition and this interpretation is extended into the present survey area. The lack of marine macrofossils and the presence of plant fossils in the unit is compatible with this interpretation.

At Liveringa Ridge (Section 3) the uppermost part of the Hicks Range Sandstone Member that is preserved (the top of the section is eroded) consists of mega-ripples of coarse-grained quartz wacke and granule conglomerate interbedded with fine-grained quartz wacke and mudstone (Plate 7). Trough cross-bedding and ripple marks are also present, and some ripples contain opposing foresets (Plate 7) which suggests deposition in tidal channels. These deposits probably correlate with the channel deposits that Crowe & Towner (1976c) recognized at the top of the member in NOONKANBAH. They believed that these channel deposits represented the uppermost part of the regression that started during the deposition of the underlying Kirkby Range Member.

Unit Hicks Range Sandstone Member	Symbol Phh	Defined by Yeates and others (1975a)

Distribution Exposed over large areas south of the Fitzroy River in the Fitzroy Trough but only one exposure in DERBY (northeast flank of Grant Range Structure) is assigned to the unit. In the subsurface the unit probably occurs throughout the Fitzroy Trough and southwestern Lennard Shelf except where it is cut out by the Jurassic unconformity.

Lithology Lower part (30 m) consists mainly of fine-grained quartz wacke, moderately to well-sorted, laminated to thin-bedded, contains wave-formed ripple marks and bioturbation structures. This passes gradationally up into interbedded mudstone and fine-grained quartz wacke which becomes coarser-grained towards the top. Planar and trough cross-bedding is present, both large and small scale; wavy bedding, bioturbation and trace fossils also present. Top part consists of 10 m-thick, medium-grained quartz arenite and quartz wacke (exposed in Dry Corner Syncline); contains fossil roots, trough cross-bedding, current lineation and cobbles of quartz and quartzite. See Section 3.

Facies variations The unit appears to be generally coarser-grained than in NOONKANBAH. Poor exposure makes facies variations difficult to recognize though subsurface information indicates that variations are present (see also under 'Facies variations' for Kirkby Range Member).

Thickness Incomplete section at Liveringa Ridge is 80 m thick. Unit reaches a thickness of as much as 325 m in NOONKANBAH.

Type section locality Hicks Range (CROSSLAND: Lat. 19°13'48"S, Long. 125° 53'42"E).

Age and criteria Late Permian based on the ages of the underlying and overlying units.

Fossils No macrofossils have been found in the unit. Plant fossils and trace fossils occur but are not age-diagnostic.

Relations Subsurface information shows that the lower boundary of the unit with the underlying Kirkby Range Member is gradational and that the upper boundary with the overlying Cherrabun Member is a disconformity.

Subdivisions The uppermost sandstone part of the unit forms a strike ridge around the Dry Corner Syncline and forms a useful marker.

Nature of exposure Exposed as dark-coloured gravel plains and low strike ridges. Relatively well exposed at Liveringa Ridge.

Remarks The upper part of the unit is expected to be moderately good aquifer.

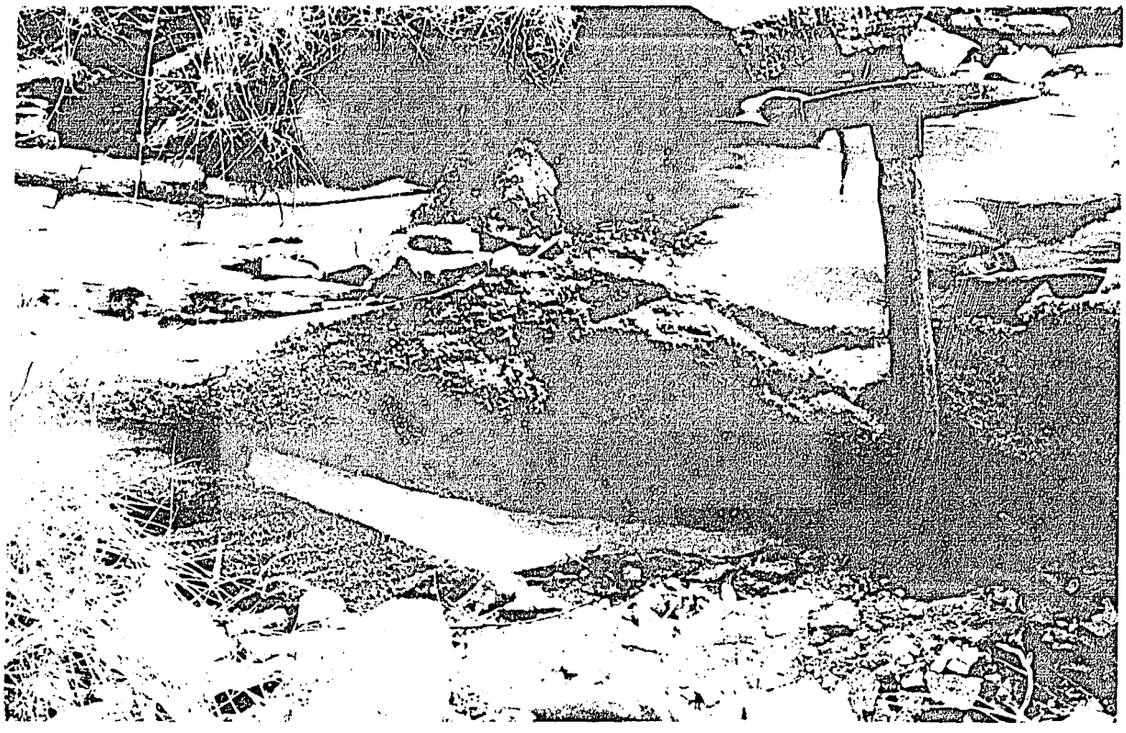


Plate 7. Mega ripple cross-bedding in the upper part of the section at Liveringa Ridge (Lat. 18°04'40" S, Long. 124°03'00" E). The exposure is assigned to the Hicks Range Sandstone Member of the Hardman Formation. Note the clear separation of mudstone and granule conglomerate and the fact the foresets dip in opposite directions within the same ripple.

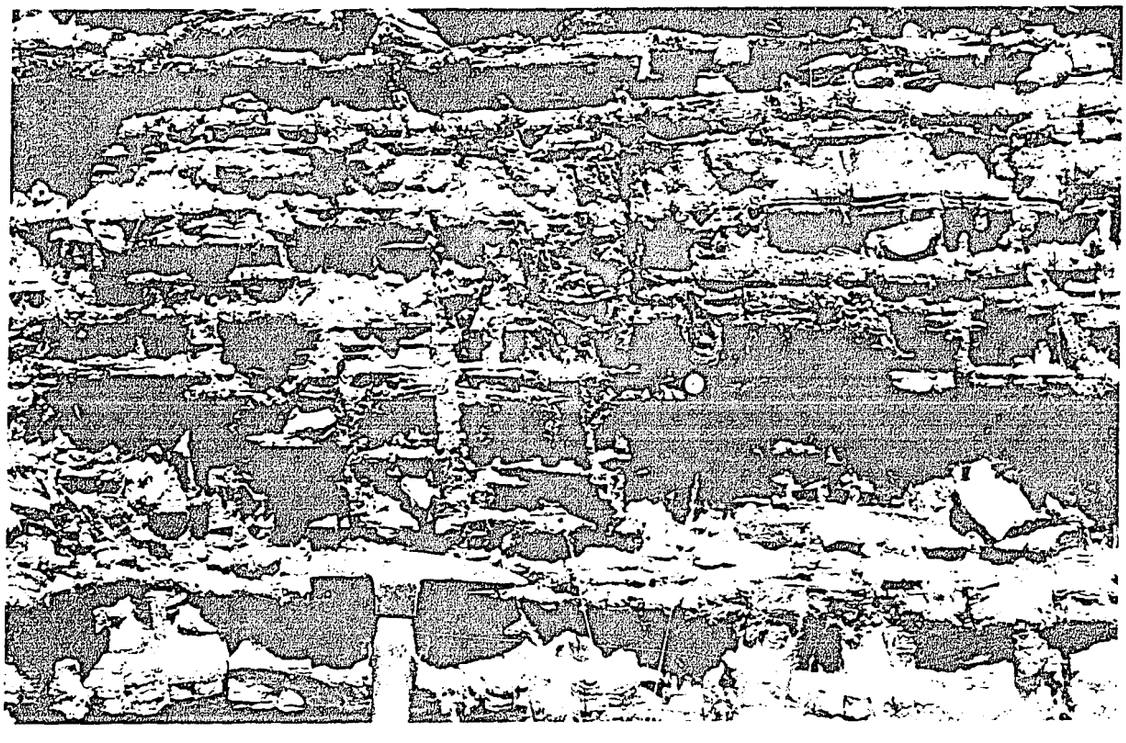


Plate 8. Thinly bedded and laminated sandy mudstone of the Blina Shale at Erskine Range (Lat. 17°51'30" S, Long. 124°21'10" E). Note the abundant vertical burrows.

Cherrabun Member (Table 14)

Crowe & Towner (1976c) interpreted the Cherrabun Member as a regressive sequence disconformably overlying the Hicks Range Sandstone Member. Lack of exposure in the present survey area does not allow this interpretation to be expanded but there appears to be an overall upwards increase in grainsize which supports this interpretation.

In exposures adjacent to the Fenton Fault there is some evidence to suggest that the unit contains several coarsening-upwards cycles. It is suggested that this is due to additional fluctuation in the relative sea level (i.e. shoreline) in this area.

TECTONISM BETWEEN DEPOSITIO. OF PERMIAN AND TRIASSIC

The Millyit Sandstone overlies the Permian Hardman Formation with a slight angular unconformity (see under Millyit Sandstone) in the McLarty Syncline, adjacent to the Fenton Fault. On the Lennard Shelf, mapping suggests that the Triassic sequence also unconformably overlies the Permian in the Sisters Plateau/Warrawadda Structure area, adjacent to the Pinnacle Fault. However in the middle of the Fitzroy Trough (e.g. Myroodah Syncline) and on the northern part of the Lennard Shelf the Triassic rocks appear to conformably overlie the Permian. This indicates that there was local tectonism between deposition of the two sequences. The association of these local unconformities and the faults bounding the Fitzroy Trough suggests that the unconformities were caused by movement of these faults. The surrounding areas probably remained relatively stable.

TRIASSIC

MILLYIT SANDSTONE (Table 15)

The only exposure of Millyit Sandstone in the area occurs in the middle of the McLarty Syncline and consists of a low, scree-covered strike ridge. In adjoining NOONKANBAH this strike ridge diverges from the trend lines of the underlying Hardman Formation,

Table 14

Unit Cherrabun Member	Symbol Phc	Defined by Yeates and others (1975a)

Distribution The unit crops out widely on the gravel plains south of the Fitzroy River but only one exposure is identified in DERBY (between Cockatoo Creek and Minnie River). In the subsurface, the unit occurs in the Fitzroy Trough and southwestern part of the Lennard Shelf except where it is cut out in the west by the Jurassic unconformity.

Lithology Poor exposure makes description difficult. In NOONKANBAH the sections show that the unit contains a lower, commonly calcareous, mudstone part which contains a rich marine fauna. This passes up into an upper sandstone part which is cross-bedded (see Section 20 of Crowe & Towner, 1976c).

In this area the lithologies are consistent with the section described in NOONKANBAH.

Facies variations The exposure is too poor to enable recognition of lateral facies variations. However, exposures near to the Fenton Fault which are assigned to the unit on palaeontological grounds may contain additional coarsening-upwards cycles. Poor exposure, lack of distinct markers, and little subsurface control make mapping in this area difficult.

Thickness	Type section locality
No surface sections measured. In AIE Paradise No. 4 (NOONKANBAH) unit is 100 m thick (enclosure 1).	Spring Creek (CROSSLAND: Lat.19°11'00"S, Long.125°33'06"E).

Age and criteria Late Permian (possibly Tartarian) based on the fauna (Thomas 1954; Coleman, 1957; Dickins, 1963).

Fossils The Hardman Formation fauna listed by Guppy and others (1958, called Hardman Member by them) comes from the Cherrabun Member. Additional collections made in 1974 and 1976 have not yet been studied.

Relations The lower boundary with the Hicks Range Sandstone Member is thought to be disconformable. The unit is unconformably overlain by the Millyit Sandstone and the 'Mudjalla Sandstone Member'. The Blina Shale also overlies the unit and although the contact is not exposed there does not appear to be any angular relation.

Subdivisions	Nature of exposure
The upper sandstone part of the unit could probably be separated from the lower mudstone part in bore sections.	Crops out as gravel plains and low strike ridges. No good section exposed in the area.
	Remarks The top sandstone part of the unit may be a good aquifer where present.

Table 15

Unit Millyit Sandstone	Symbol Rm	Defined by Elliot (in McWhae and others 1958); Yeates and others 1975a)

Distribution Tentatively identified in one area (the middle of the McLarty Syncline). The unit occurs more extensively to the southeast of the area (Yeates and others 1975a).

Lithology Consists of fine-grained, micaceous, quartz wacke and minor mudstone, thinly bedded, minor low-angle cross-bedding, ripple marks; bioturbation is common; base is marked by a quartz-pebble conglomerate.

Facies variations To the southeast of the area the unit is lithologically more variable and contains a higher proportion of large-scale cross-bedding.

Thickness 10 m exposed in McLarty Syncline but may be 25 m present.	Type section locality Millyit Range (CROSSLAND: Lat. 19°12'00"S, Long.125°33'30"E).

Age and criteria Earliest Triassic based on microflora. The unit contains a microflora belonging to Stage R1b of Evans (1966) (Paten & Price, in Yeates and others, 1975b). Plant macrofossils indicate a Permian or Triassic age.

Fossils Contains plant macrofossils (White & Yeates, 1976), wood fragments, and a microflora described by Paten & Price (in Yeates and others, 1975b).

Relations Overlies the Hardman Formation with slight angular unconformity (based on air-photo evidence) in McLarty Syncline. Outside area the unit is overlain disconformably by the Blina Shale.

Subdivisions None.	Nature of exposure Poor, low strike, ridges.
	Remarks Identified in area by lithology and stratigraphic position.

indicating a slight angular unconformity. This was the basis on which the exposure was considered to be Millyit Sandstone by Crowe & Towner (in prep.) as the Millyit Sandstone has the same relations in CROSSLAND.

Depositional environment

The poor exposure of Millyit Sandstone in the area does not allow the depositional environment to be interpreted. The position of the unit at the base of the marine Triassic sequence may indicate it is a transgressive sand body. However, farther southeast, Yeates and others (1975b) believed the unit had been deposited in channels and was possibly fluviatile.

BLINA SHALE (Table 16)

Depositional environment

Sedimentological evidence. The laterally continuous thin bedding in the Blina Shale suggests deposition in a large body of water. The fine grainsize (mudstone and sandy mudstone) indicates deposition from suspension, suggesting quiet conditions. In the upper part of the unit in Section 4 there are small vertical fissures filled with fine-grained quartz wacke. These are similar to structures described by Coneybeare & Crook (1968, plate 69b & c) and are interpreted as infilled fossil mudcracks. Similar structures are illustrated by Yeates and others (1975b, fig. 25) and they suggest periodic subaerial exposure. Also in Section 4, the Blina Shale becomes coarser-grained towards the top and contains small scour-and-fill structures and current ripple marks, suggesting some deposition by currents.

Mineralogical evidence. The presence of disseminated pyrite in subsurface sections of the unit indicates anaerobic, stagnant, reducing conditions. Organic matter is also well preserved in subsurface samples and this suggests poorly oxygenated bottom conditions. Glauconite is reported from the section in WAPET Meda No. 1 (WAPET, 1962a) and according to Porrenga (1967) this probably indicates slow sedimentation.

Table 16

Unit Blina Shale	Symbol Rb	Defined by Reeves (1951); Brunnschweiler (1954)

Distribution Occurs in low-lying synclinal areas such as the Dry Corner and Myroodah Synclines. Also occurs in Erskine Range/Sisters Plateau area. Intersected in many bores in the Fitzroy Trough and Lennard Shelf.

Lithology Consists mainly of buff-coloured, sandy mudstone and very fine quartz wacke, laminated to thinly bedded. Contains ripple marks and small scour-and-fill structures near the top. Characteristic closely-spaced vertical burrows occur throughout (Plate 8). Subsurface information shows that sandstone becomes predominant towards the base (WAPET 1967a, 1967). Several phosphatic bone beds occur, particularly near the base. Pyrite, glauconite, and organic matter reported from subsurface sections. See Section 4.

Facies variations Characteristically the unit contains remarkably little lateral variation.

Thickness Thickest section is 311 m in WAPET Blackstone No.1; (Appendix II) Erskine Range Section (No.4) is 32 m thick.

Type section locality Erskine Range (DERBY: Lat.17°51'S, Long.124°22'E).

Age and criteria Early Triassic (Scythian) based on palynological evidence (Balme, 1963, 1964, 1969) and on vertebrate evidence (Cosgriff, 1965, 1974).

Fossils Amphibians including Deltasaurus pustulatus and Blinasaurus lenwoodi (Cosgriff, 1965, 1969), the conchostracan Isaura (which occurs in thin coquinas), the brachiopod Lingula, bivalves (including cf. Pseudomonontis), fish (including Ceratodus and Saurichthys) and other vertebrate remains. Plant fossils also quite common. Contains rich microfloral assemblage (Taeniaesporites Assemblage of Balme, 1964).

Relations On field evidence Crowe & Towner (1976c) believe the Blina Shale overlies the Millyit Sandstone conformably and overlies the Permian either disconformably or with slight angular unconformity. The Blina Shale is overlain by the Erskine Sandstone. The contact is erosional and probably represents a slight time break.

Subdivisions None.

Nature of exposure Very poor, except in Erskine Range. Overlain by black-soil plains.

Remarks Can often be identified by light (clayey) colour on aerial photographs. Trend lines are visible as a streaky pattern on photos.

Fossil evidence. The presence of marine acritarchs in the microfossil assemblages and marine pelecypods indicates a marine influence in the environment. However, forms such as the conchostracan Isaura and the brachiopod Lingula are more suggestive of brackish-water conditions. McKenzie (1961) suggests that the amphibian remains and Dipnoan teeth recovered from the unit may represent death assemblages flushed into the environment by freshwater. According to Balme (1969), the unusually high proportion of vascular-plant spores within the formation suggests that they were derived from coastal marsh plants 'occupying a similar ecological niche to modern mangroves'.

Summary. The Blina Shale appears to have been deposited in a shallow, low-energy, near-shore environment of deposition with intermittent subaerial exposure. The unit probably represents deposition in a mud flat.

We agree with McKenzie (1961) who did not accept the lagoonal interpretation of Brunnschweiler (1954). However the paucity of open-marine indicators and the presence of brackish-water indicators in the fauna suggest that the area over which the Blina Shale was deposited was not directly connected to the ocean.

ERSKINE SANDSTONE (Table 17)

Depositional environment

In the underlying Blina Shale there is some evidence of an increase in sandstone content towards the top of the unit. This suggests that, if the Blina Shale and Erskine Sandstone are considered together, they may represent a regressive sequence. As the contact between the two units is erosional it is suggested that the regression may have been of the deltaic type (Selley, 1970).

The abundance of large-scale trough cross-bedding in association with intraformational conglomerate and ripple cross-lamination indicates deposition by currents in channels possibly of the distributary type. Current readings obtained by McKenzie (1961; see Fig. 5) suggest that the channels flowed towards the north or northwest. The upper part of the Erskine Sandstone contains intervals of planar-bedded mudstone and very fine-grained sandstone which are interpreted as overbank deposits laid down on the hypothetical delta plain.

Unit Erskine Sandstone	Symbol Re	Defined by Brunnschweiler (1954)

Distribution Occurs in MOUNT ANDERSON in Myroodah Syncline. Covers a wide area on the Lennard Shelf and Fitzroy Trough in DERBY. Best exposed in the Erskine Range and Sisters Plateau.

Lithology Consists mainly of fine and very fine-grained quartz wacke and quartz arenite, laminated to thin-bedded; contains large-scale trough and planar cross-bedding, clay pellet conglomerate and current ripple marks with some climbing-ripple cross-bedding. The upper part of the unit contains some parallel-laminated, very fine-grained quartz wacke and mudstone, interbedded. See Section 4.

Facies variations On a small scale, local facies variations are abundant but on a regional scale the unit is homogeneous although it may be slightly finer-grained at Derby than in the Erskine Range area.

Thickness 30 m exposed in Erskine Range Maximum recorded thickness is 269 m in Myalls bore south of Derby, (Appendix II).

Type section locality Erskine Range (DERBY: Lat.17°50'S, Long.124°22'E)

Age and criteria Early to early Middle Triassic (Smithian to early Anisian) on the basis of microfossils (see Balme, 1969 ; Dolby & Balme, 1976). Macroflora agrees with this date (see Brunnschweiler, 1954 ; Helby, 1973).

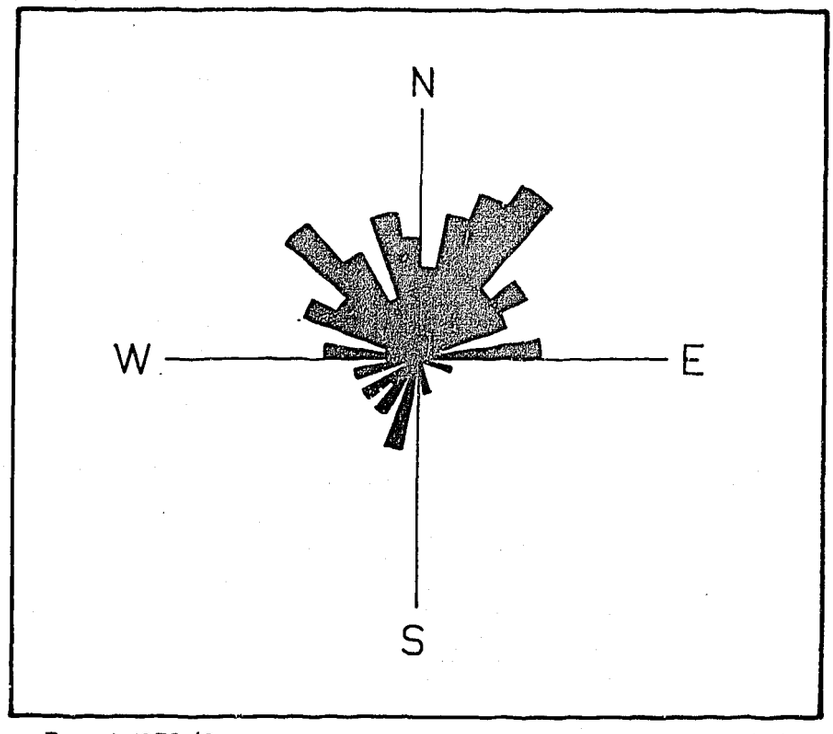
Fossils Brunnschweiler (1954) lists the macroflora from the unit which includes Thinnfeldia (Dicroidium), and Gleichenites. Fossil wood is common in the unit and burrows are recorded from the upper part of the unit in Derby Town Bore (Playford,1957). No marine acritarchs are recorded from the microfossil assemblages.

Relations Overlies the Blina Shale disconformably and overlaps it and rests unconformably on Permian rocks on the Lennard Shelf. Erskine Sandstone is disconformably overlain by the Meda Formation although the upper surface is usually an erosion surface.

Subdivisions None.

Nature of exposure Forms low scarps in Sisters Plateau and more isolated mesas elsewhere.

Remarks Despite the fine grainsize of parts of the unit, the Erskine Sandstone is a remarkably good aquifer (P. Whincup, GSWA, pers. comm.).



Record 1978/8 E51/A7/6

Fig. 5 Rose diagram of current directions in the Erskine Sandstone at Erskine Range. Readings from 81 cross-sets. Adapted from McKenzie (1961).

Fossil evidence supports this interpretation. Pleuromeia occurs in the flora (Brunnschweiler, 1954) and is thought by Balme & Helby (1973) to be a plant group which rapidly colonized new areas formed by retreat of the sea.

In conclusion, we agree with McKenzie who believed that the Erskine Sandstone was deposited by a delta which debouched into the sea that deposited the Blina Shale.

TECTONISM BETWEEN DEPOSITION OF TRIASSIC AND JURASSIC

The main structural features exposed in the areasare the result of tectonism that occurred between deposition of the Triassic that this tectonism produced, can be dated as post-Middle Triassic and pre-? Middle Jurassic; however, the precise age limits of the formations that overlie and underlie the unconformity are not known. For simplicity the hiatus is referred to as the Jurassic unconformity in this report. It is possible that intrusion of the ?Jurassic Fitzroy Lamproite was related to this period of tectonism.

Rattigan (1967) and Smith (1968) have described the structural pattern in the Fitzroy Trough. The main features are that after the period of mainly tensional tectonics that produced growth movement along the major faults during the Palaeozoic and Triassic, the area underwent a major period of compressional tectonism. The mainly westerly-trending folds in the Fitzroy Trough are believed by Rattigan (1967) to be the result of compression between the northerly Kimberley Block and the southern part of the Canning Basin (including the Broome Platform). This compression resulted in right-lateral regional coupling which produced reverse movement along the previously normal faults and this in turn generated the en echelon pattern of major folds (Fig. 6). The predominantly north-trending faults that cut these folds fit in with the en echelon pattern and are believed to be tensional release features produced by the folding.

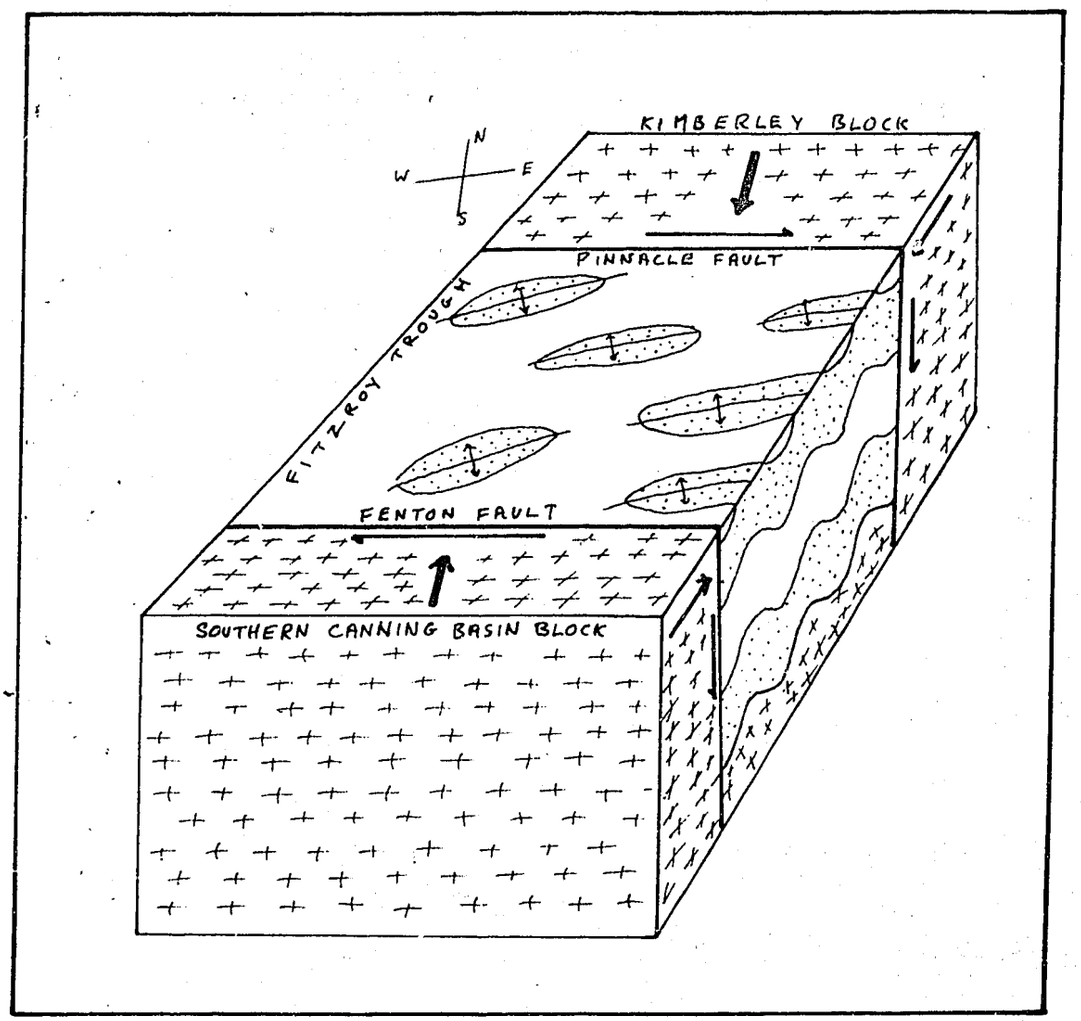


Fig. 6 Block diagram showing inferred stress pattern of ? Jurassic tectonic event. Modified from Rattigan (1967).

JURASSIC TO CRETACEOUS

WALLAL SANDSTONE (Table 18)

The term Wallal Sandstone was introduced by McWhae (in Johnstone, 1961), for the basal Jurassic sandstone unit that had been intersected in petroleum exploration wells in the western part of the basin. The formation was thought to correlate with the Jurgurra Sandstone (Table 19) which occurs in the area. More recent sursurface data have since confirmed this correlation and also shown that the unit' can be correlated with another unit, the Mudjalla Sandstone (Table 20). The present mapping has shown that both the Jurgurra and Mudjalla Sandstones probably only represent local facies and it is therefore proposed that they be considered members of the Wallal Sandstone. Because this nomenclature change has not been formally defined the Jurgurra Sandstone and the Mudjalla Sandstone are herein referred to as the Jurgurra Sandstone 'Member' and the Mudjalla Sandstone 'Member'.

McWhae (in Johnstone, 1961) believed that the Wallal Sandstone was deposited in a paralic, largely shallow-water, marine environment although parts of the unit may also be continental in origin. Because the formation is a subsurface unit, a detailed interpretation of its depositional environment is not attempted.

JURGURRA SANDSTONE 'MEMBER' (Table 19)

The present survey has shown that the Jurgurra Sandstone is probably at least partly of 2 aeolian origin (see below). It is likely that this facies is fairly restricted both laterally and vertically and it is therefore desirable at this stage to assign all subsurface intersections to the Wallal Sandstone, unless the 2 aeolian facies can be confidently recognized.

Table 18

Unit Wallal Sandstone	Symbol Jl	Defined by McWhae (in Johnstone, 1961.

Distribution Occurs south of the Fenton Fault and in western DERBY and MOUNT ANDERSON.

Lithology Sandstone, with subordinate siltstone, conglomerate, and lignitic beds.

Facies variations In this report the Jurgurra and Mudjalla Sandstone 'Members' are considered facies of the Wallal Sandstone.

Thickness Maximum recorded thickness in area is 168 m in WAPET Dampier Downs No.1; probably thicker in WAPET Fraser River No1

Type section locality Between 279 and 587 m in BMR Stratigraphic Well No.4A (Wallal) (MANDORA: Lat.19°44'12"S, Long. 120°44'25"E)

Age and criteria Microfossil evidence suggests a Toarcian to Oxfordian age (Passmore, in prep.). However Playford and others (1975) believe that a Bathonian to Oxfordian age seems most likely on stratigraphic grounds.

Fossils Microflora and microplankton are described by Balme (1961).

Relations Unconformably overlies various Palaeozoic units. Apparently conformably overlain by Alexander Formation.

Subdivisions Jurgurra and Mudjalla Sandstone 'Members' are considered local facies of the Wallal Sandstone.

Nature of exposure Not exposed except as separately-named 'members'.

Remarks The unit is an important artesian aquifer in southern part of basin and can be expected to be a good aquifer in this area.

Table 19

Unit Jurgurra Sandstone 'Member'	Symbol Jlj	Defined by Brunnschweiler (1954)

Distribution Exposed in southern part of Jurgurra Creek and in scattered localities in the north-central part of the Edgar Range (MOUNT ANDERSON).

Lithology Mainly quartz arenite and wacke, medium to coarse-grained, in places poorly sorted and micaceous; contains abundant large-scale trough cross-bedding and small-scale anastomosing ripple cross-lamination; contains minor mudstone beds and clay-pellet conglomerate at the bases of troughs. Unit contains abundant concretions in some areas (Plate 10). See Section 5.

Facies variations As defined, the Jurgurra Sandstone 'Member' refers to one characteristic facies association so any marked variations should be termed Wallal Sandstone. Burne & Crowe (1977) recognize two major facies within the unit, a cross-bedded quartz arenite and a planar-bedded quartz wacke.

Thickness 20 m exposed in Section 5.

Type section locality In Geegully Creek near Mount Alexander (Section 5, Lat.18°41'00"S, Long.123°39'20"E, MOUNT ANDERSON).

Age and criteria Bathonian to Oxfordian based on the age of the overlying unit and the age of the Wallal Sandstone.

Fossils Brunnschweiler (1954) reported rare indeterminate marine pelecypods and Guppy and others (1958) recorded poorly preserved plant fossils. Root moulds and fragmentary plant fossils were found during the present survey.

Relations The lower boundary of the unit with either part of the Wallal Sandstone or Palaeozoic rocks is not exposed. The upper boundary with the Alexander Formation was believed to be slightly disconformable by Brunnschweiler (1954), although our mapping shows that the two units may locally interfinger.

Subdivisions Burne & Crowe (1977) recognize two main facies (see above).

Nature of exposure Exposed in gullies and at the bases of some small hills.

Remarks Can be expected to be an excellent aquifer.

Depositional environment

Burne & Crowe (1977) have described an exposure of the Jurgurra Sandstone (at Lat. 18°32'30"S, Long. 123°40'55"E) in detail and conclude that it was deposited in an aeolian environment. Their interpretation is based on the fact that the original shape of the fossil dunes is preserved beneath an interdune (planar-bedded) facies (Plate 9) containing root moulds and some lenses of water-laid deposits. The dune facies consists of large-scale trough cross-bedded quartz arenite with fairly high foreset angles (up to 31°) and with some convex-upward foresets, a good indicator of an aeolian origin. This dune facies is very similar to the Jurgurra Sandstone at its type section and it is on this basis that it is considered wise to restrict the unit to deposits of probable aeolian origin.

The upper part of the Jurgurra Sandstone in Section 5 contains abundant sand-filled anastomizing holes which are interpreted as weathered-out fossil roots. They suggest that the dunes may have become stabilized by vegetation before being buried and transgressed by the sea which deposited the overlying Alexander Formation.

MUDJALLA SANDSTONE 'MEMBER' (Table 20)

Depositional environment

Abundant broad and shallow trough cross-bedding with basal conglomerate lenses and associated lenses of ripple-marked and planar-bedded mudstone suggest that the lower part of the unit was laid down in a fluviatile environment. The cross-bedded parts were deposited in channels and the fine-grained lenses probably represent overbank deposits. Figure 7 shows that the rivers that deposited the unit flowed westward.

The upper part of the unit consists of lower-energy deposits. It lacks any marine indicators and the ripple marks in it are all of the current type. The mainly conformable nature of the boundary with the underlying facies suggests that the planar-bedded facies may have been deposited in a floodplain or delta plain. There is an overall upward decrease in grainsize and sorting throughout the whole unit and this also suggests a floodplain interpretation.

G.S.W.A. F. 18 No. 4 Neg.



Plate 9. Exposure in Jurgurra Sandstone 'Member' in floor of Geegully Creek (Lat. 18°32'30" S, Long. 123°40'55" E) showing preserved dune which is overlain by thin-bedded interdune deposits (see Burne & Crowe, 1977).

G.S.W.A. F. 18, No. 1



Plate 10. Concretions in the Jurgurra Sandstone 'Member' in the floor of (Lat. 18°32'30" S, Long. 123°40'55" E). The creek waters have selectively weathered out the concretions. Creek flow is from bottom left to top right part of photograph.

Table 20

Unit Mudjalla Sandstone 'Member'	Symbol Jlm	Defined by Guppy and others (1958)

Distribution Occurs west of Grant Range on southwest bank of Fitzroy River between Geegully and Cockatoo Creeks. A small exposure in Geegully Creek north of Wilsons Yard is also assigned to the unit, and outcrops at and near Frome Rocks may belong to the

Lithology Mainly medium to coarse-grained quartz wacke and arenite, poorly sorted; contains abundant large-scale, trough and apparently planar cross-bedding with lenses of conglomerate and siltstone. Also contains some small-scale ripple cross-lamination associated with the trough cross-bedding. Upper part conformably (and disconformably) overlies cross-bedded sequence and consists of mainly planar-bedded very fine to medium-grained quartz wacke which contains current ripple marks, wavy bedding and small scour-and-fill structures.

Facies variations Only the lower coarse-grained, cross-bedded facies and upper planar-bedded facies are known. Restricted area of exposure does not allow lateral facies variations to be recognize.

Thickness 41 m exposed but subsurface information (Russell, 1966a,b) suggests a maximum thickness of 80m (Enclosure 3)

Type section locality Near Mudjalla Yard (MOUNT ANDERSON:Lat.18°03'05"S, Long.123° 47'40"E).

Age and criteria Plant fossils indicate a Jurassic age (Guppy and others, 1958). The unit is interpreted to be overlain by the Oxfordian Alexander Formation. As the unit is considered a facies of the Wallal Sandstone it may be as old as Bathonian.

Fossils Rare plant fossils, including conifers, are known from the unit (Guppy and others, 1958). Wood fragments are also common.

Relations The unit overlies probable Hardman Formation with an angular unconformity. It is thought to be overlain by the Alexander Formation (Enclosure 3). The unit may correlate with the Meda Formation as the two units contain similar conglomerate clasts.

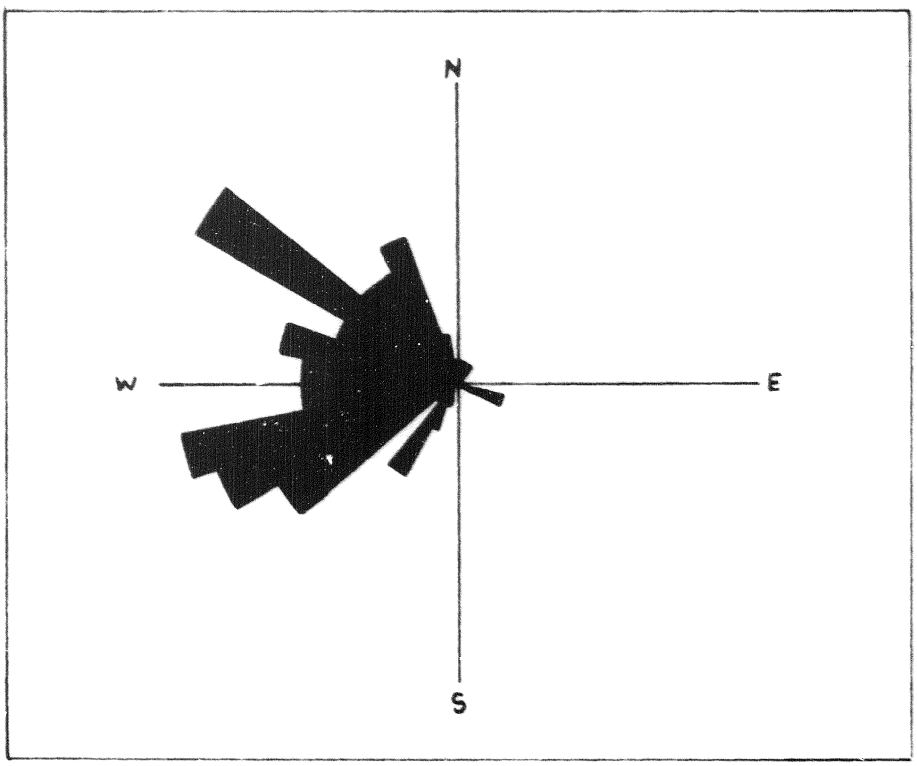
Subdivision

Upper fine-grained, mainly planar-bedded quartz wacke.

Lower coarse-grained, cross-bedded and conglomeratic quartz arenite and wacke.

Nature of exposure Well exposed in gullies in and around Mudjalla Gully.

Remarks Upper fine-grained part is recognizable by its lighter tone on the aerial photographs.



Record 1978/8 E51/A/35

Fig 7 Rose diagram of current directions in the Mudjalla Sandstone 'Member'. Readings from 50 cross-sets.

ALEXANDER FORMATION (Table 21)

The mapped distribution of the Alexander Formation differs considerably from that shown on the first edition maps (Guppy and others, 1958). One of the most important changes is that rocks that underlie the Barbwire Sandstone (previously James Sandstone in the area) in the Mount James area are now assigned to the the Alexander Formation. The presence of Alexander Formation in this general area was demonstrated by Crowe & Towner (in prep.) when they discovered Jurassic fossils in a deeply weathered exposure near Mount Fenton (NOONKANBAH). Williams & McKellar (1958) had previously mapped, on lithological grounds, some Alexander Formation underlying the Barbwire Sandstone at hills 5 km south of Mount James. However, they showed the gravel plains in that area as Liveringa Group. Our mapping suggests that there is no Liveringa Group exposed south of the Fenton Fault but that Williams and McKellar were correct in showing Barbwire Sandstone overlying Alexander Formation. The boundary is erosional and marked by a basal conglomerate in the Barbwire Sandstone. The exposures assigned to the Alexander Formation consist of interbedded mudstone and fine-grained quartz wacke containing wave-formed ripple marks and lenticular bedding.

Another change to the original mapping is that small exposures in the west bank of the Fitzroy River at Langey Crossing, which were originally considered Mudjalla Sandstone, are now assigned to the Alexander Formation.

These outcrops consist of interbedded laminated mudstone and fine-grained quartz arenite. Large, shallow scour-and-fill structures with foreset slip planes are present together with lenticular bedding containing wave-formed ripple marks. Bio- turbation is common and in some gravel pits adjacent to the river there are ?lenses of very coarse-grained quartz wacke which contains possible mega-ripple cross-bedding and indeterminate shelly fossils. The interpretation of the depositional environment (below) also suggests that this sequence is part of the Alexander Formation and not the Mudjalla Sandstone'Member'.

Unit Alexander Formation	Symbol Ja	Defined by Brunnschweiler, 1954

Distribution Exposed mainly in Edgar Ranges, at Matches Springs and scattered exposures south of the Fenton Fault. An exposure along the west bank of Fitzroy River at Langey Crossing is also assigned to the unit. In the subsurface the unit occurs in western DERBY and MOUNT ANDERSON and south of the Fenton Fault in central and eastern MOUNT ANDERSON.

Lithology Consists mainly of fine to medium-grained quartz arenite and wacke; interbedded with mudstone and minor granule conglomerate, thin-bedded, wave and current ripples, flaser and lenticular bedding, wavy bedding, megaripples (Plate 12) and some large-scale trough cross-bedding. Some cross-bedded fining-upwards sequences with ripple-marked tops identified near top of unit. Bioturbation is common and fossils occur in lenses. Root moulds occur at one level in the southeastern Edgar Ranges. See Section 5.

Facies variations There are many local lateral and vertical changes in facies but the overall lithology is fairly uniform.

Thickness Maximum known thickness is 72 m in the Edgar Ranges. The unit thins to the north.

Type section locality Mount Alexander (Section 5; MOUNT ANDERSON:Lat.18°41'00"S, Long.123°39'20"E)

Age and criteria Late Oxfordian to early Kimmeridgian in the area on the basis of the macrofauna (Brunnschweiler, 1960) and microfossils (B Ingram, GSWA, pers. comm.).

Fossils Ammonoids, bivalves, brachiopods, ophiuroids (Brunnschweiler, 1954). Microfossils are known from petroleum and phosphate exploration wells (e.g. WAPET, 1962b). Trace fossils are also abundant in the unit.

Relations The unit is believed to conformably overlie the Wallal Sandstone in bore sections and to locally interfinger with the Jurgurra and possibly the Mudjalla Sandstone 'Members'. It is conformably overlain by the Jarlemai Siltstone (Plate 13). The formation is partly overlain by and is probably partly equivalent to the Barbwire Sandstone, south of Mount James.

Subdivisions None.

Nature of exposure Forms mesas and buttes with smooth, scree-covered slopes.

Remarks

These outcrops consist of interbedded laminated mudstone and fine-grained quartz arenite. Large, shallow scour-and-fill structures with foreset slip planes are present together with lenticular bedding containing wave-formed ripple marks. Bio-turbation is common and in some gravel pits adjacent to the river there are ?lenses of very coarse-grained quartz wacke which contains possible mega-ripple cross-bedding and indeterminate shelly fossils. The interpretation of the depositional environment (below) also suggests that this sequence is part of the Alexander Formation and not the Mudjalla Sandstone 'Member'.

Depositional environment

The presence of marine fossils in the Alexander Formation shows that it was deposited under marine conditions. The abundance of wave-formed ripples (e.g. see Plate 11) indicates it was deposited mainly above wave base. The presence of flaser, lenticular and wavy bedding suggests deposition during periods of slack and fast-moving water such as occurs in the tidal zone. Cross-bedded, fining-upwards sequences are interpreted as channel deposits of tidal origin. The interpreted root moulds in the southeastern Edgar Ranges indicate temporary emergence in that area.

The formation exposed near Langey Crossing is similarly believed to have been deposited in a tidal environment. The scours are interpreted as tidal channels and the wave-formed ripple marks suggest deposition in water probably not more than 30 m deep. The occurrence of quartz arenite in the sequence is also typical of near-shore deposition where wave action is responsible for a high degree of sorting.

BARBWIRE SANDSTONE (Table 22)

The Barbwire Sandstone was previously mapped as James Sandstone in the area. However, Crowe & Towner (in press) have extended the term Barbwire Sandstone to include the James Sandstone as the two units are similar.

Unit Barbwire Sandstone	Symbol Jb	Defined by Guppy and others (1958)

Distribution Occurs in isolated exposures along Fenton Fault. Exposures south of Mount James and at Camelgooda Hill are also assigned to the unit.

Lithology Fine to coarse-grained quartz wacke and conglomerate, poorly sorted; contains large-scale planar and trough cross-bedding. Conglomerate contains intra-formational clasts in places, but characteristically consists of quartz and quartzite pebbles. contains minor beds of mudstone and is normally intensely ferruginized, in places converted to ferricrete.

Facies variations Exposure at Camelgooda Hill are tentatively assigned to the unit and if the correlation is correct then the Camelgooda Hill sequence could be considered a fine-grained facies of the Barbwire Sandstone.

Thickness 33 m thick at Mount James.	Type section locality Barbwire Range (NOONKANBAH: Lat.18°58'S, Long.125°01'E).

Age and criteria Plant fossils indicate a Jurassic or Early Cretaceous age (White & Yeates, 1976).

Fossils Only some trace fossils recorded from area. Yeates and others (1975b) record plant fossils from the unit.

Relations Unconformably overlies Permian rocks. Appears to overlie, and is possibly partly laterally equivalent to the Alexander Formation. Top of unit is everywhere eroded. May correlate with the Mowla Sandstone, Meda Formation and/or the Wallal Sandstone (see Fig. 15).

Subdivisions	Nature of exposure Occurs as very ferruginized cappings to hills along Fenton Fault.
	Remarks Includes James Sandstone (Crowe & Towner, in press).

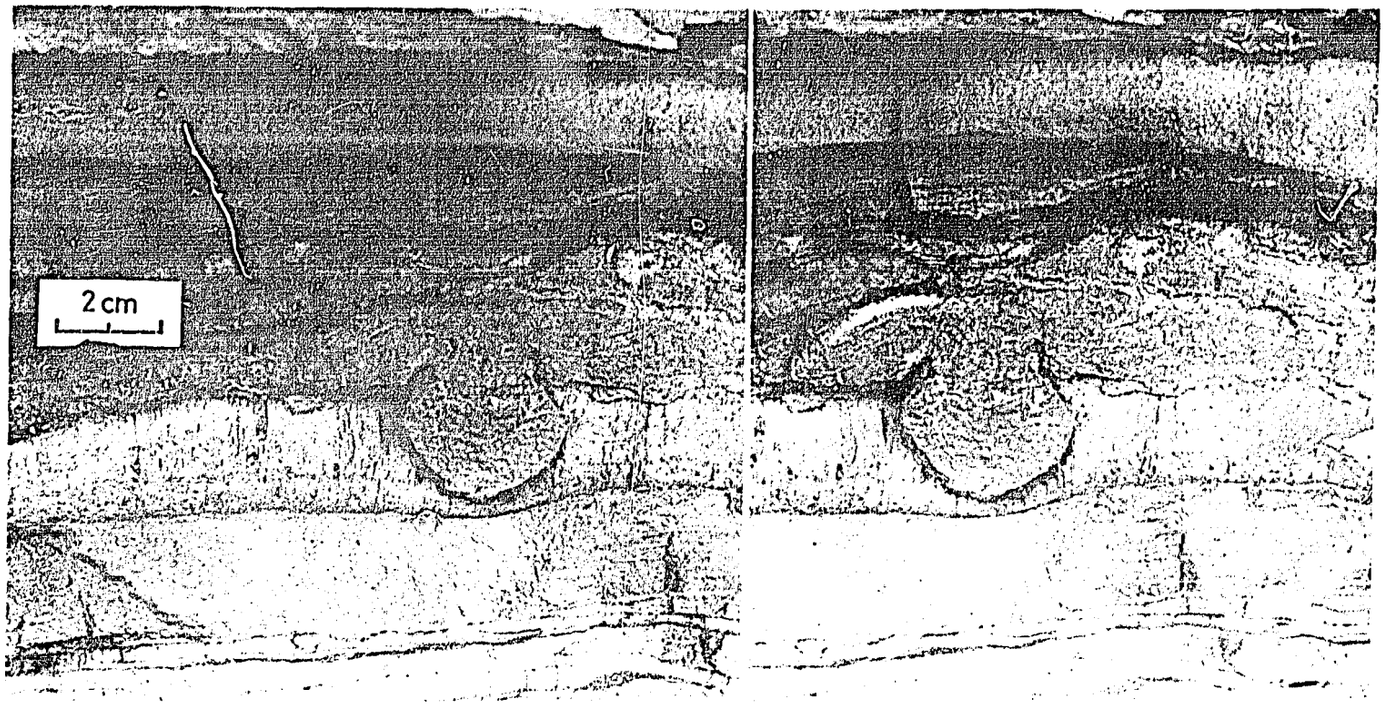


Plate 11. Stereopair showing the origin of a load cast in the Alexander Formation at Mount Alexander (Lat. 18°41'00" S, Long. 123°39'20" E). The sandstone forming the load cast is derived from the wave-formed ripple above and has squeezed into the underlying soft mudstone.

G.B/1531 & 1544

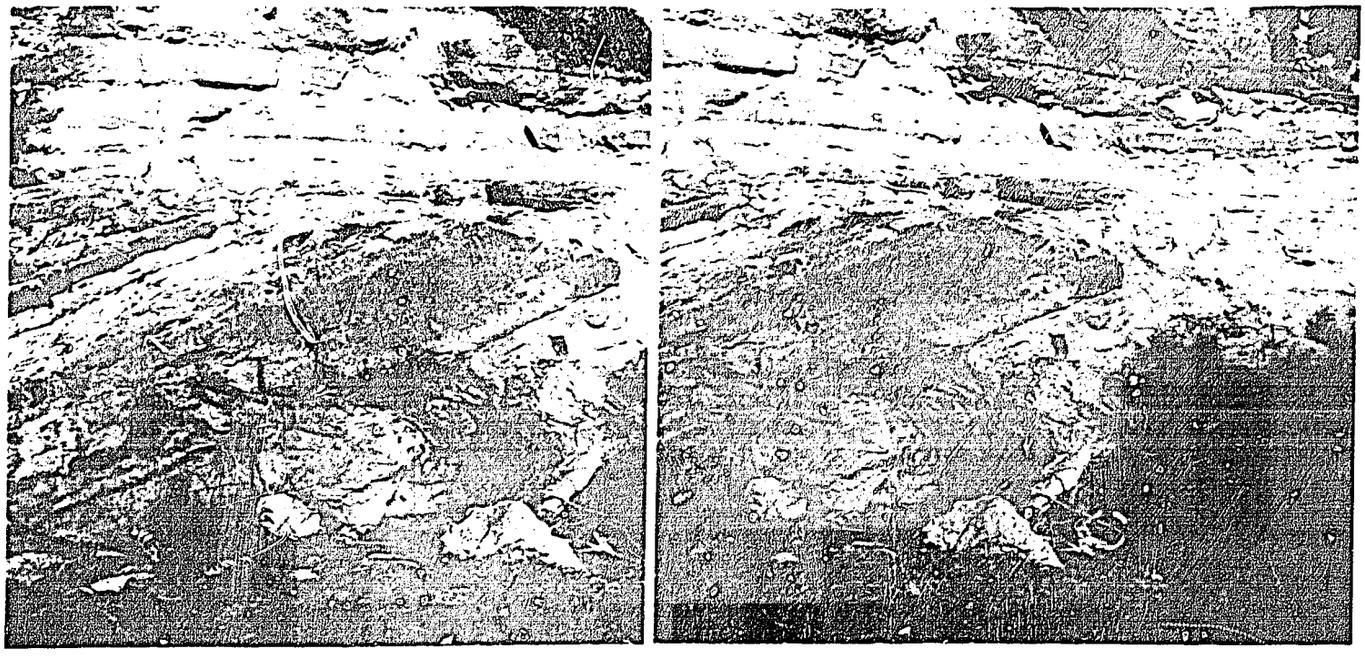


Plate 12. Stereopair showing a preserved megaripple overlain by draped sediments in the Alexander Formation exposed in a gully at Lat. 18°49'00" S, Long. 123°38' 45" E. Hammer is inked in on left-hand print.

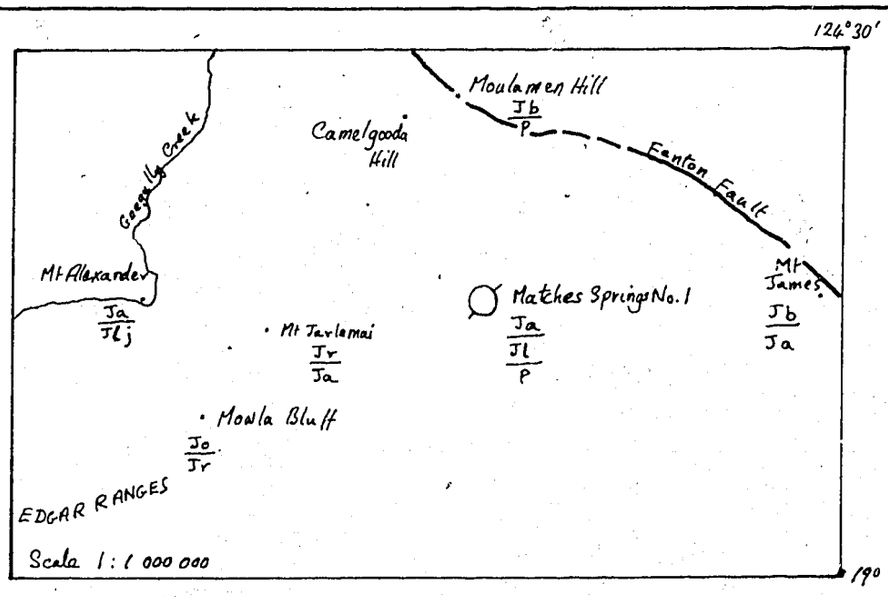
The Barbwire Sandstone may be correlated with the Meda Formation which only crops out in DERBY. The correlation is based on the fact that the two units contain similar pebbles of quartzite that are not commonly found in units older than Jurassic. On the gravel plains south of the Fitzroy River, many patches of gravel contain similar quartz and quartzite pebbles. Such pebbles are not common in the underlying Permian rocks and so it is thought that they represent deflation material from a thin veneer of Jurassic sediment that has been eroded away. This interpretation is supported in NOONKANBAH where Crowe & Towner (in prep.) mapped several exposures in this veneer. The inference of this interpretation is that the extensive gravel plains represent sediments that may have been continuous between the Barbwire Sandstone and Meda Formation.

Camelgooda Hill

The section exposed at Camelgooda Hill does not correlate well with any of the defined units.

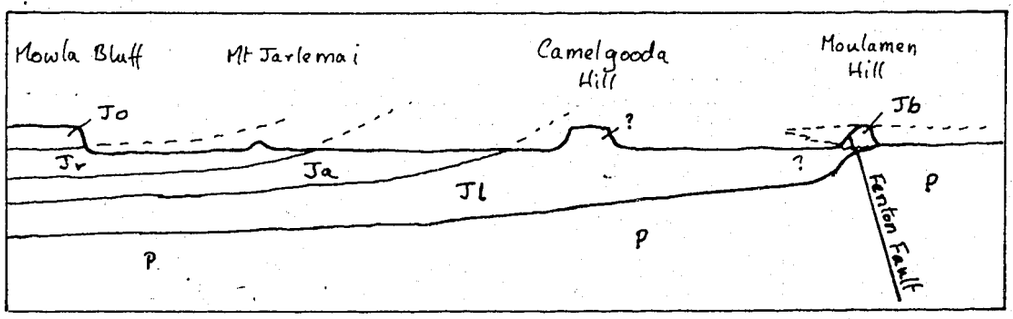
The sequence consists of fine-grained quartz wacke and quartz arenite with minor mudstone. Large troughs (2 m wide and 1 m deep) occur within the unit and contain poorly laminated foresets which pass upwards into climbing ripple cross-lamination. Minor intraformational conglomerate occurs at the bases of the troughs together with a few plant and wood fragments. Other parts of the sequence are mainly planar-bedded but they contain abundant current ripple marks.

On lithological grounds the unit could correlate with any of the non-marine Jurassic units (except the Jurgurra Sandstone 'Member'). Figure 8 shows two alternative correlations of the Camelgooda Hill sequence. We prefer alternative B because it appears to better explain the environmental interpretations for the units and it is on this basis that the Camelgooda Hill sequence is tentatively assigned to the Barbwire Sandstone. More subsurface information is needed before our correlations can be verified.

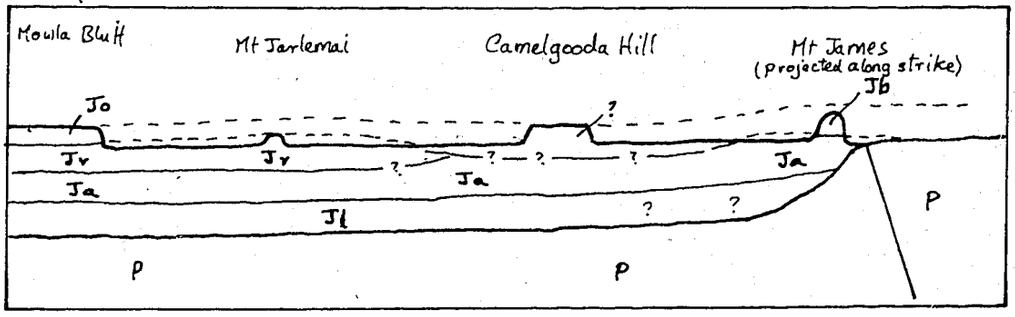


Locality sketch showing units identified.

P - Permian; Jl - Wallal Sandstone; Jlj - Jurgurra Sandstone 'Member'; Ja - Alexander Formation; Jr - Jarlemai Siltstone; Jb - Barbwire Sandstone; Jo - Mowla Sandstone.



A CORRELATION OF CAMELGOODA HILL SEQUENCE WITH WALLAL SANDSTONE (This correlation ignores relation seen at Mount James).



B CORRELATION OF CAMELGOODA HILL SEQUENCE WITH BARBWIRE AND MOWLA SANDSTONES (This correlation projects relation at Mt James along strike)

Record 1978

E51/A11/7

Fig. 8 Schematic diagrams showing two possible correlations of sequence at Camelgooda Hill.

Depositional environment

Exposures of the Barbwire Sandstone at Mount James (and at hills 5 km south of there) are considered fluviatile. This interpretation is based on the abundance of trough cross-bedded units which commonly fine upwards. Current ripple marks also occur in the finer-grained parts of the sequence and are interpreted as overbank deposits. There is an overall upward reduction in grainsize in the unit in exposures farther east and this supports the fluviatile interpretation. The presence of conglomerate in the sequence suggests moderate to high-energy deposition.

Sections of the Barbwire Sandstone to the northwest, along the Fenton Fault, are too poorly exposed to allow interpretation of theiroorigin but the sections visited are lithologically similar to the section at Mount James.

The section at Camelgooda Hill is also interpreted as a fluviatile (or possibly delta-plain) deposit. The large scours are typical of channel deposits. Abundantly ripple-marked planar beds in the sequence are interpreted as overbank or levee deposits laid down on a flood or delta plain. The fine grainsize and the predominance of planar-bedded units in the sequence suggests lower-energy deposition than occurred in the Barbwire Sandstone. If the correlation shown in Figure 8B is correct then the facies at Camelgooda Hill can be considered transitional between the Mowla Sandstone and Barbwire Sandstone at Mount James.

MEDA FORMATION (Table 23)

The Meda Formation only occurs in DERBY and as stated above (under Mudjalla Sandstone 'Member' and Barbwire Sandstone) the unit could be correlated with either the Mudjalla Sandstone 'Member' or the Barbwire Sandstone. Such correlations are based on the fact that the Jurassic continental facies (excluding the Jurgurra Sandstone 'Member') contain similar pebbles of quartz and quartzite. This is an admittedly slender line of evidence but it is on this basis that we consider the unit is probably Jurassic. The possibility that the unit is younger cannot, however, be ruled out.

Unit Meda Formation	Symbol Jd	Defined by Guppy and others (1958)

Distribution Only occurs in DERBY at Erskine Range and in isolated exposures on Meda and Kimberley Downs stations and to the south of Derby.

Lithology Consists mainly of fine to coarse-grained quartz wacke and granule and pebble conglomerate; contains large-scale trough cross-bedding and some current ripple marks. Conglomerate clasts include rock types from the underlying Erskine Sandstone but mainly consist of white quartz and quartzite. Overall the unit is poorly sorted although individual beds are graded and some are well sorted. Most exposures are very ferruginized. See Section 4.

Facies variations None.

Thickness A maximum thickness of about 7 m is exposed in the Erskine Range.

Type section locality Erskine Range (DERBY: Lat.17°51'S, Long.124°22'E).

Age and criteria Believed to be Jurassic as it contains a similar range of extraclasts to other Jurassic units (e.g. Barbwire Sandstone and Mudjalla Sandstone 'Member'). If this correlation is correct then the Meda Formation is probably Late Jurassic.

Fossils Wood fragments are the only fossils recorded from the unit.

Relations Disconformably overlies the Erskine Sandstone and the top is eroded. The lower boundary is strongly erosional and if it is an angular relation then this was not recognized in the small areas of exposure.

Subdivisions None.

Nature of exposure Good at tops of hills.

Remarks

Depositional environment

The generally poorly-sorted nature of the sediment and the presence of abundant large-scale trough cross-bedding with associated current ripple marks suggest deposition in channels. The strongly erosional base of the unit and the occurrence of wood fragments is compatible with this interpretation. It is thought that the unit is probably fluviatile.

JARLEMAI SILTSTONE (Table 24)

Since the area was originally mapped by Guppy and others, (1958) and Brunnschweiler (1957) there has been a substantial increase in the knowledge of the subsurface Jurassic geology. This has enabled correlations to be made so that some surface-defined units can now be discarded.

The Langey Shale (Guppy and others, 1952; Playford and others, 1975) was originally defined from gravel pits near the now-abandoned Langey Crossing at the mouth of the Fitzroy River. The gravel pits are now filled in and the only unit exposed is the Alexander Formation. As the Langey Shale can now be shown to be equivalent to the Jarlemai Siltstone (Enclosure 3) it is proposed to discard the term Langey Shale. Drilling in the area has shown that the base of the Jarlemai Siltstone contains a glauconitic, phosphatic bed (Russell, 1966a, b, reported in Playford and others, 1975) and if this should prove to be a useful marker it would be possible to restrict the term Langey Shale to this unit. As the glauconitic bed no longer appears to crop out this has not been attempted here.

Another unit that is now assigned to the Jarlemai Siltstone is the Fraser River Limestone (Guppy and others, 1952). Although this unit was never defined, it was mapped as a separate unit and correlated with the Langey Shale (Brunnschweiler, 1957). Our mapping showed this unit to be mainly shale containing marine fossils with only minor 'limestone' (calcareous mudstone) intervals. Although Brunnschweiler (1957) probably visited different exposures to ours we have little hestiation in equating the unit with the

Unit Jarlemai Siltstone	Symbol Jr	Defined by Brunnschweiler (1954)

Distribution Occurs in southern MOUNT ANDERSON in Edgar Ranges and isolated exposures. Exposures of shale in Fraser River area (DERBY) are also assigned to unit.

Lithology Consists mainly of white, red, yellow, and purple mudstone which is commonly sandy. Contains scattered coarse grains of sand and granules. Bedding is very poor so the unit appears massive. Upper 30 to 50 m in eastern Edgar Ranges consists predominantly of quartz wacke. Whole of unit appears bioturbated and this may explain the lack of bedding. In subsurface the unit is glauconitic and phosphatic. Selenite and pyrite are common accessory minerals. The unit contains rare pebbles. See Sections 6 & 7 (Appendix I).

Facies variations The upper part of the unit in the eastern Edgar Ranges is mainly sandstone and considered a local facies.

Thickness About 90 m thick in Edgar Ranges and possibly more than 160 m thick in Fraser River area.

Type section locality Mount Jarlemai (MOUNT ANDERSON: Lat.18°42'55"S,Long.123°48'40"E).

Age and criteria Middle Oxfordian to early Tithonian on palynological grounds (Balme in Cranwell, 1964). However basal part of unit in Langey Crossing area is only Kimmeridgian (B Ingram, pers. comm.).

Fossils Includes pelecypods, belemnites, ammonites, and brachiopods (Brunnschweiler, 1954, 1957; includes 'Langey Crossing Marl' fauna). Palynomorphs are described by Balme (in Cranwell, 1964).

Relations Overlies Alexander Formation conformably (Plate 13). Is overlain ?conformably by the Jowlaenga Formation and possibly disconformably by the Melligo Sandstone. Mowla Sandstone interfingers with upper part of unit and overlies with local disconformity.

Subdivisions In eastern Edgar Ranges the unit contains a fine-grained (mudstone) lower part and a coarser-grained (sandstone) upper part. The upper sandstone part appears to wedge out to west.

Nature of exposure Forms mesas and buttes with sheer sides and scree slopes.

Remarks Mowla Bluff is proposed as a reference section. It covers the upper part of the formation which is not exposed in the type section. Streaky air-photo patterns in southwest DERBY are believed to indicate Jarlemai Formation subcrop.

Jarlemai Siltstone. The correlation is also supported by the identification of Jarlemai Siltstone at the top of the section in WAPET Fraser River No. 1 (BMR Basin Studies Group, pers. comm.).

Depositional environment

The Jarlemai Siltstone was deposited in a marine environment as indicated by the marine fossils. The fossils are haphazardly arranged in the unit, indicating that they do not represent a death assemblage that has been washed into the unit. The whole unit is characteristically very poorly bedded or massive and this may be due to the loss of bedding structures by intense bioturbation. Such bioturbation has certainly occurred because the rock (particularly at Mowla Bluff) is filled with clay-marked burrows and trails.

The unit lies above the transgressive tidal deposits of the Alexander Formation (Plate 13) and beneath the regressive sequences of the Mowla Sandstone (in the Mowla Bluff area) and the Jowlaenga Formation and Melligo Sandstone (in the western DERBY area). This suggests that the Jarlemai Siltstone was deposited at the peak of the Jurassic transgression probably in a fairly shallow shelf sea. The lack of any well-defined current structures suggests deposition below wave-base with little influx of terrigenou material.

Palynological datings from bores in the Langey Crossing area indicate that the palynological time zones are compressed (B. Ingram, pers. comm.). This may be explained by the presence of intraformational unconformities or by slow deposition. As no major disconformities appear to be present in the area, we prefer the latter explanation.

In conclusion, most of the evidence indicates that the Jarlemai Siltstone was laid down in a stable shelf sea and that a slow rate of deposition may be responsible for intense organic reworking resulting in the destruction of bedding structures.

MOWLA SANDSTONE (Table 25)

Brunnschweiler (1954) believed the boundary between the Mowla Sandstone and the underlying Jarlemai Siltstone was disconformable in places and transitional in others and on this basis he assigned the unit to the Jurassic. McWhae and others (1958) disregarded Brunnschweiler's field evidence of local transitions and, seeing only the disconformity, argued that an Early Cretaceous age was more likely.

Unit Mowla Sandstone	Symbol Jo	Defined by Brunnschweiler (1954) and Guppy and others (1958)

Distribution Occurs in small areas in centres of synclines in area at Matches Springs, Mowla Bluff, and to the east of Mounts Jarlemai and Troy.

Lithology Basal part consists of poorly-sorted pebble conglomerate which fills channels cut into the underlying Jarlemai Siltstone (Plate 14). The conglomerate passes into fine to coarse-grained, medium to thin-bedded, trough cross-bedded quartz arenite with occasional pebbles. This in turn passes up into partly bioturbated, arenite and wacke with some clay pellet conglomerate. At the top, the unit contains ripple-marked, fine-grained micaceous quartz wacke and mudstone with some plant fragments and climbing ripples. See Section 7.

Facies variations None observed.

Thickness Maximum recorded thickness is 15 m near Matches Springs (Smith & Williams, 1955).

Type section locality Mowla Bluff Section 7; MOUNT ANDERSON: Lat.18°49' 20"S, Long. 123°38'50"E).

Age and criteria Probably Tithonian on the basis that it interfingers with the middle Oxfordian to early Tithonian Jarlemai Siltstone.

Fossils Fragmentary indeterminate plant fossils found in upper part of unit.

Relations Erosional and interfingering lower boundary with the Jarlemai siltstone. Top of unit is everywhere eroded.

Subdivisions Bottom of unit is conglomeratic.

Nature of exposure Good; forms small hills with scree slopes.

Remarks

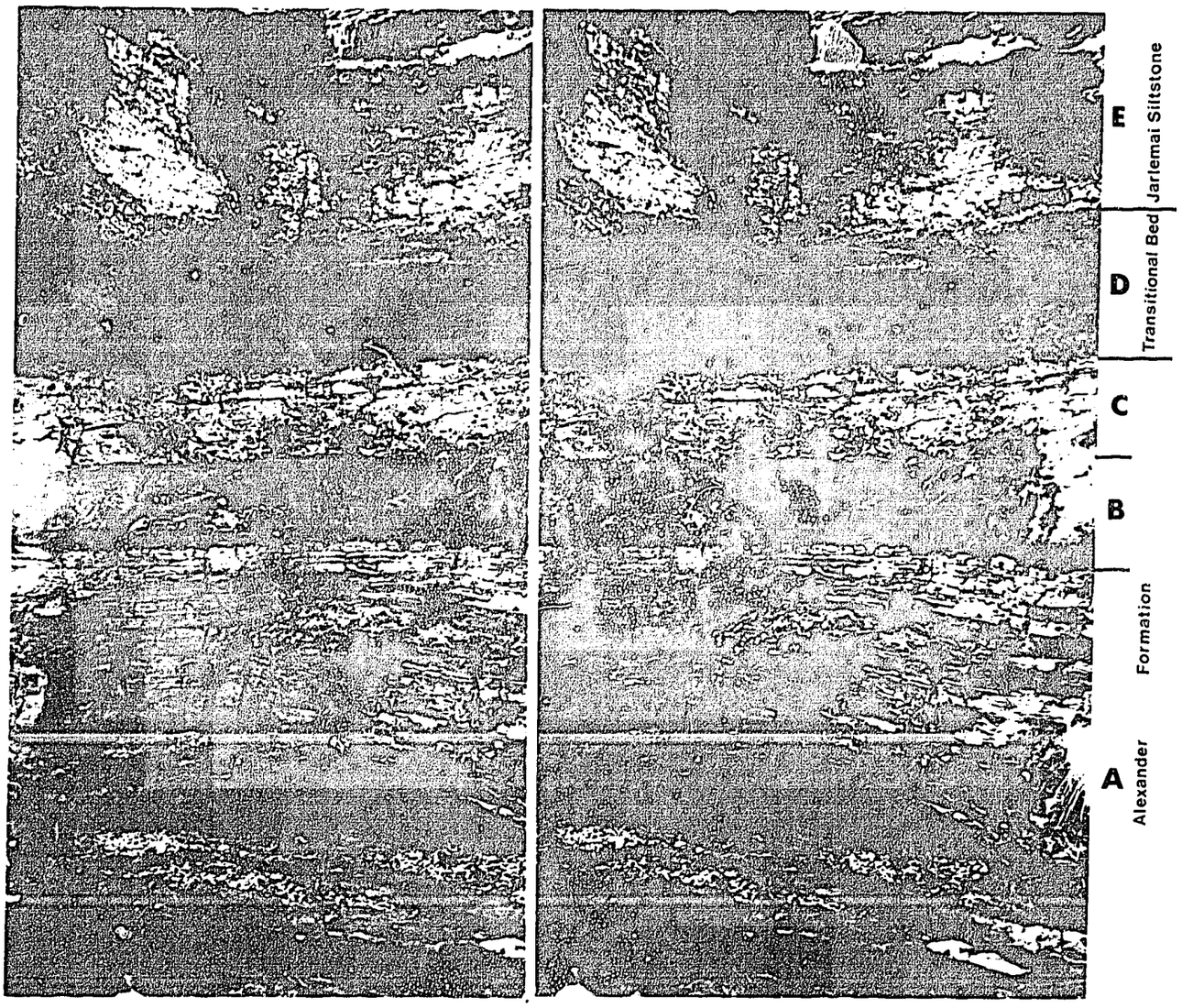


Plate 13. Stereopair showing contact between Alexander Formation and Jarlemai Siltstone at Lat. 18°55'30" S, Long. 123°40'00" E. A: Interbedded sandstone and sandy mudstone with a rich but poorly preserved fauna of bivalves and rare ammonoids and ophiuroids. B: Massive fine to medium-grained quartz wacke. C: Well-bedded, rippled mudstone with lenticular beds of sandstone. D: Massive fine to medium-grained quartz wacke. E: Poorly bedded to massive, sandy mudstone; bioturbated.
BMR Negative Nos. GB/1539 & 1540

Our mapping shows that Brunnschweiler (1954) was correct and werrecognize the boundary as an interfingering relation with small channels of Mowla Sandstone facies becoming increasingly abundant towards the top of the Jarlemai Siltstone (see Section 7 and Plate 14). Consequently the Mowla Sandstone is again considered Jurassic.

Possible Mowla Sandstone in the western Edgar Ranges

At Lat. 18°50'00"S, Long. 123°17'00"E in the western Edgar Ranges there is a thin unit of clean, well-sorted medium-grained quartz arenite. The unit occurs as boulders overlying the Jarlemai Siltstone and so it may correlate, on stratigraphic grounds, with either the Mowla Sandstone or the Jowlaenga Formation/Melligo Sandstone sequence.

The boulders contain large-scale planar cross-bedding with some interlaminated coarse-grained quartz arenite and a few pebbles. The lithology best resembles the Mowla Sandstone and so the unit is tentatively assigned to this formation.

Depositional environment

The lower part of the Mowla Sandstone contains abundant large scours with conglomeratic bases associated with trough cross-bedding. These sequences are interpreted as channel deposits (Plate 14) and they pass upwards into finer-grained sediment which is predominantly planar-bedded and which contains abundant current ripple marks.interpreted as overbank or levee deposits.

The upper part of the Jarlemai Siltstone in the eastern Edgar Ranges becomes increasingly coarser-grained towards the top. This suggests that it marks the start of the Late Jurassic marine regression from the area. The Mowla Sandstone is believed to represent the top part of this regressive sequence and the nature of the erosional contacts between the two units and the presence of channel deposits suggest that the regression was of the deltaic type in this area. Consequently the lower part of the Mowla Sandstone is interpreted as predominantly a distributary deposit and the upper parts as delta-plain or inter-distributary deposits.

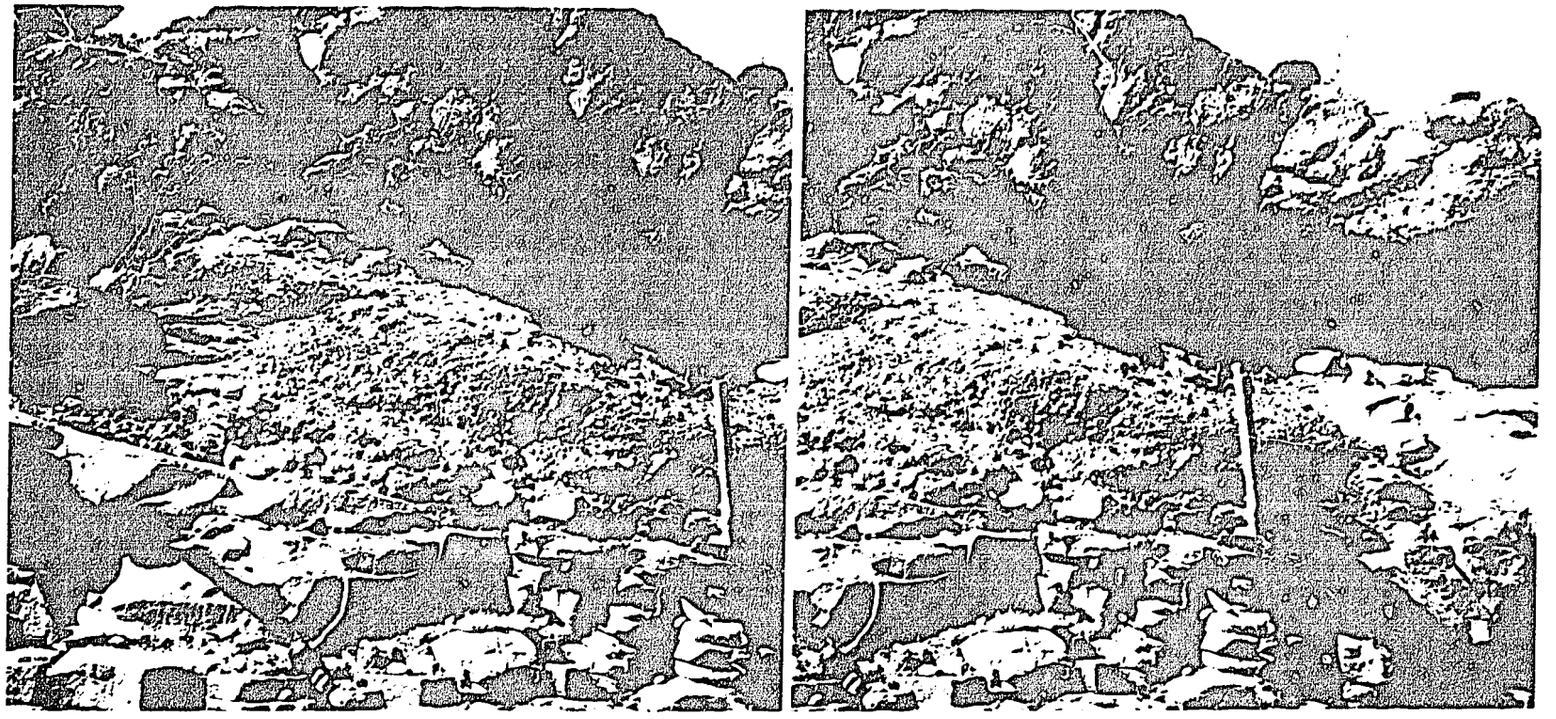


Plate 14. Stereopair showing local disconformity between sandy mudstone of the Jarlemai Siltstone (at base) and channel - fill conglomerate of the Mowla Formation at Lat. 18°47' 45" S, Long. 123°44'20" E, near Mowla Bluff. BMR Negative Nos GB/1519.

This interpretation allows the Mowla Sandstone to be tentatively correlated with the section exposed at Camelgooda Hill (see under Barbwire Sandstone). As the Mowla Sandstone is regarded as representing the retreat of the Jurassic sea from the area, it can also be correlated with the Jowlaenga Formation/Melligo Sandstone sequence exposed in DERBY. However there is good evidence to suggest that the regression from DERBY occurred much later than it is thought to have occurred in MOUNT ANDERSON. Further palaeontological work is needed on this part of the sequence before the diachronous nature of the Jurassic rocks can be fully understood.

JOWLAENGA FORMATION (Table 26)

Previous reports show that there has been some doubt about whether the Jowlaenga Formation is Late Jurassic or Early Cretaceous. Brunnschweiler (in Guppy and others, 1952; and Brunnschweiler 1954; 1957; 1960) believed the unit to be Neocomian on palaeontological grounds. Later reports by Stevens (1965) and Skwarko (1970) suggest a Tithonian age. In particular, Skwarko (1970) believed that the fossils collected from the Jowlaenga Formation at Mount Clarkson by Brunnschweiler in fact came from the Melligo Sandstone (termed "Melligo Quartzite" by him). Our field studies indicate that there is no Melligo Sandstone (as defined) exposed at Mount Clarkson and it seems that Skwarko has only recognized its presence because he found Aptian fossils there. To us this suggests that the Jowlaenga Formation may be as young as Aptian.

Some of the confusion may have been based on the fact that the boundary between the Jowlaenga Formation and the Melligo Sandstone was previously identified as a disconformity (Brunnschweiler, 1957) and that, therefore, a time break between the two units was explicable. However, the present survey has shown that the boundary is inter-fingering (Section 8) so that a time break is not necessary. We believe that the boundaries between the Jarlemai Siltstone, Jowlaenga Formation, and the Melligo Sandstone are essentially conformable and do not represent major time breaks. With the present dates assigned to the units (see Playford and others, 1975) this is difficult to explain because of the time range involved. Further palaeontological work is probably necessary to resolve this problem.

Unit Jowlaenga Formation	Symbol Jw	Defined by Brunnschweiler (1957); Guppy and others (1958); McWhae and others (1958).

Distribution Only recognized on surface in western DERBY but may be present in parts of western MOUNT ANDERSON as it is recognized (BMR Basin Studies Group, pers. comm.) in bores just west of the Sheet area boundary.

Lithology Consists of interbedded mudstone and fine to medium-grained quartz wacke with quartz arenite near the top. Both large and small-scale cross-bedding are present and lenses of intraformational conglomerate containing fossils also occur. Towards top unit consists of laminated, well-sorted sediment with scour-and-fill structures and bioturbated zones.

Facies variations None observed.

Thickness Generally less than 40 m thick in petroleum-exploration wells west of the area.	Type section locality Mount Jowlaenga (BROOME: Lat. 17°23'S, Long. 122°57'E)

Age and criteria There is some doubt about the age of the unit (see text).

Fossils Bivalves and belemnites which have been described by Teichert (1950), Brunnschweiler (1951, 1954, 1957, 1960). Plant fossils are described by White (in Veevers & Wells, 1961).

Relations Lower boundary with the Jarlemai Siltstone is gradational. Upper boundary has previously been described as disconformable but our evidence shows that it interfingers with the Melligo Sandstone.

Subdivisions None.	Nature of exposure Exposed in scree slopes and as small benches.
	Remarks The unit may be a correlative of upper sandstone part of the Jarlemai Formation that occurs in the eastern Edgar Ranges.

Depositional environment

The lithology of the Jowlaenga Formation is transitional between that of the underlying Jarlemai Formation and that of the overlying Melligo Sandstone. The lower boundary is probably gradational (Rattigan & Elliott, 1954) and there is an increase in sandstone towards the top of the unit. This, together with the presence of marine fossils, indicates that the unit was laid down as the sea that deposited the Jarlemai Formation became shallower. The unit contains small scour-and-fill structures, bioturbated zones, and some large and small-scale cross-bedding; all features of shallow-water sediments deposited in the tidal zone. The presence of interpreted sand-volcano structures at the contact with the overlying Melligo Sandstone (which is interpreted as a beach deposit) is compatible with this interpretation (see under Melligo Sandstone).

MELLIGO SANDSTONE (Table 27)

Depositional environment

The Melligo Sandstone consists of very well-sorted mainly fine-grained quartz wacke commonly cemented by opaline silica. The unit is interpreted as a beach deposit on the basis of its high textural maturity, the presence of parallel lamination, primary current lineation, and the unit's position above the shallow-water marine deposits of the Jowlaenga Formation. The small fossils which occur at the base of the unit are also compatible with the beach environment.

At Dampier Hill there are two cycles of Jowlaenga Formation/Melligo Sandstone deposition (Section 8) and this suggests that the shoreline oscillated as it retreated from the area.

At the contact between the Melligo Sandstone and the Jowlaenga Formation there is an unusual lenticularity. Figure 9 shows the nature of these lenses of Melligo Sandstone which occur at the boundary. The presence of small centrally located protrusions at the tops of some of the lenses and the occurrence of convex-upwards foresets within them suggest that the lenses may represent sand-volcano deposits (R.V. Burne, pers. comm.). Such structures are

Unit Melligo Sandstone	Symbol Km	Defined by Brunnschweiler (1957); McWhae and others (1958).

Distribution Occurs in a strike ridge and line of mesas in western DERBY. Tentatively identified exposures occur in Fraser River area. The unit also occurs on Valentine Island in King Sound (Brunnschweiler, 1957).

Lithology At Dampier Hill, the unit consists of fine to medium-grained quartz wacke which is very well sorted. The grains are spherical to well rounded and the unit is laminated. The laminations are mainly planar and current lineation is common. Brunnschweiler (1957) stated that the unit also contains coarse-grained sandstone and minor conglomerate. The unit is characteristically white but contains abundant liesegang bands. The matrix is commonly opaline silica. See Section 8.

Facies variations None recognized.

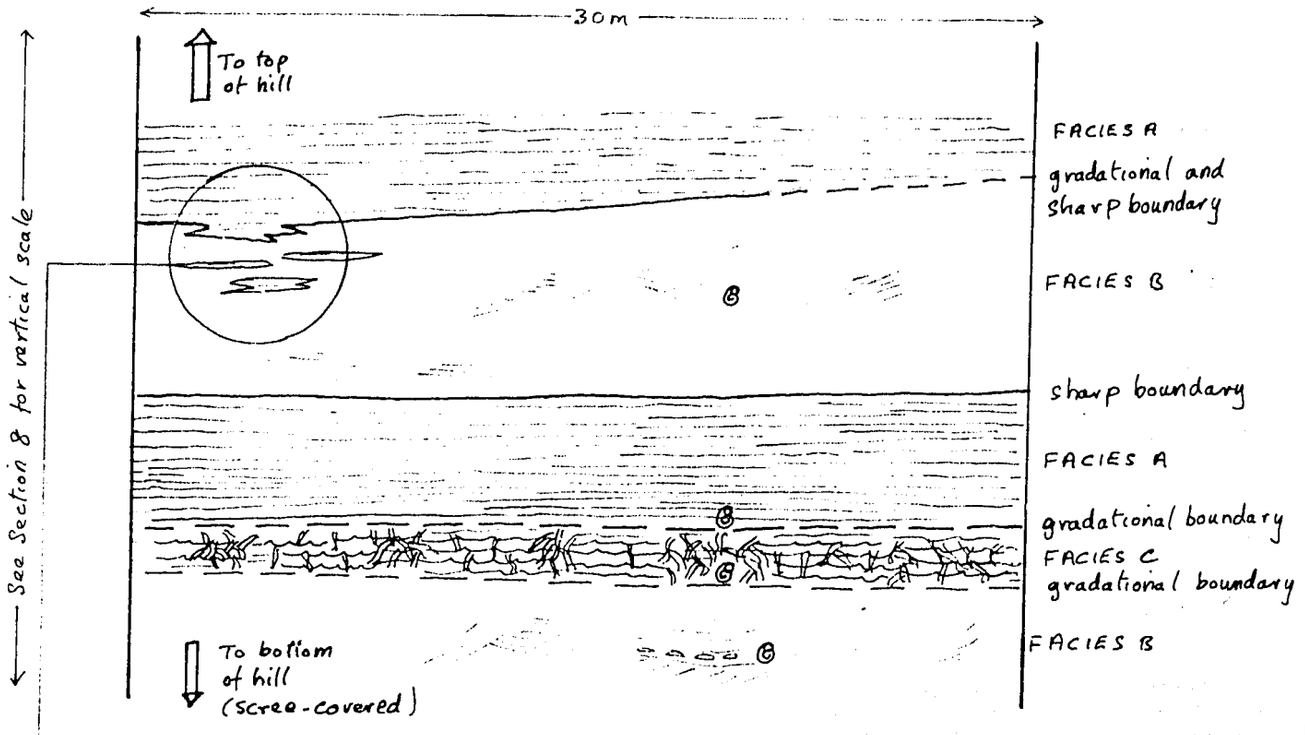
Thickness Brunnschweiler (1957) believed the unit reached a thickness of 21 m but Rattigan & Elliott (1954) show a maximum of 43 m.	Type section locality None defined.

Age and criteria Dated as Aptian on palaeontological evidence (Brunnschweiler, 1957 and Skwarko, 1970). The unit contains Fissilunula clarkei, a key Aptian fossil.

Fossils Bivalves and belemnites described by Brunnschweiler (1957) and Skwarko (1970).

Relations The base of the unit appears to be erosional (Brunnschweiler, 1957) but at Dampier Hill it is interfingering. The top is either covered by Cainozoic deposits or eroded.

Subdivisions None.	Nature of exposure Well exposed in quarries at Dampier Hill and adjacent to Great Northern Highway.
	Remarks Known locally as 'Kimberley Colourstone' due to the purple and red liesegang banding. Used as building stone.



Facies A (Melligo Sandstone); White very fine-grained quartz arenite with siliceous cement. Planar laminated with current lineation on bedding planes.

Facies B (Jowlaenga Formation); Brown fine-grained quartz arenite with no cement. Contains locally abundant clay-pellet conglomerate which follows foresets of large-scale trough cross-bedding. Lamination is faint.

Facies C (Transitional); Mainly light brown or white quartz arenite with minor amounts of matrix. Contains abundant ripple cross-lamination and wavy bedding which is mainly destroyed by burrows (0·5 - 1cm thick). This facies does not appear to occur along upper boundary of second cycle.

Diagrams showing nature of lenses of facies A which occur in facies B.

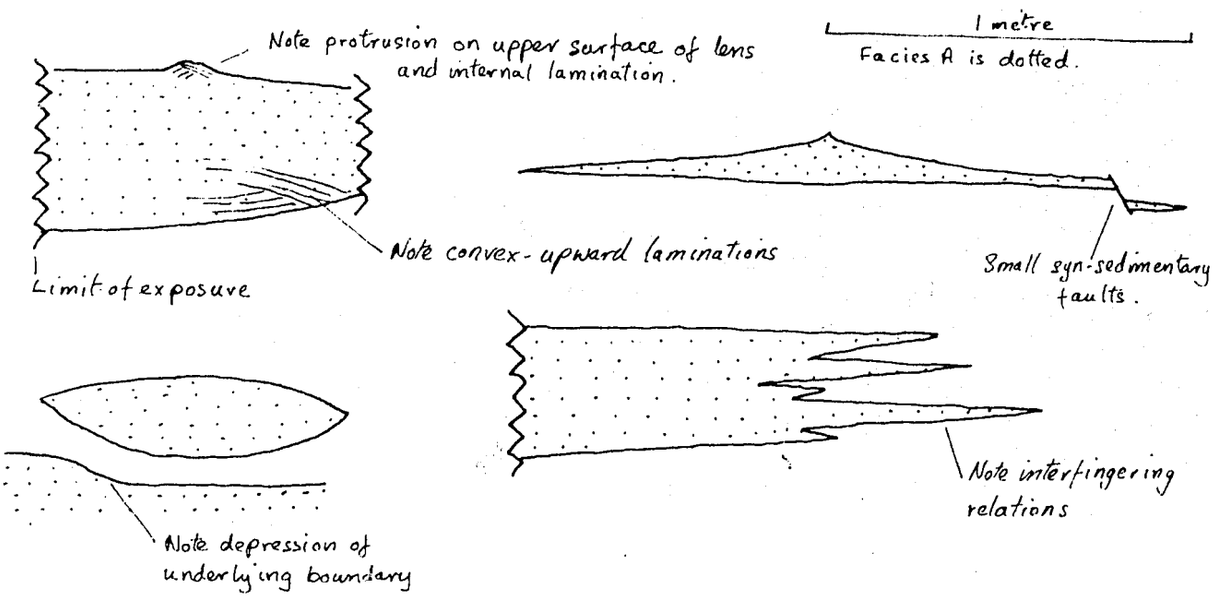


Fig. 9 Relations between Jowlaenga Formation and Melligo Sandstone at Dampier Hill.

common in the near-shore environment (Coneybeare & Crook, 1968) andy they form by dewatering of underlying saturated sediment as it becomes overloaded.

In conclusion, the Melligo Sandstone represents the beach deposits of the Jurassic marine regression which in the western DERBY area is interpreted as a linear shoreline regression.

FITZROY LAMPROITE

The Fitzroy Lamproite (Casey, 1958; Thomas, 1958b; Veevers, 1958) only occurs at one locality in this area: Rice Hill, its type section (Lat. 17°57'S, Long. 124°19'E; Playford and others, 1975). At this locality the unit forms either a flow or a sill according a Prider (1960) and consists of alkaline leucite lamproite.

The unit has been dated as Jurassic by the Rb-Sr method (Prider, 1960; Kaplan and others, 1967) but Tertiary dates have been obtained by the K-Ar method (Kaplan and others, 1967; Wellman, 1973). Kaplan and others favoured the Rb-Sr Jurassic age and attributed the Tertiary re-setting of the K-Ar date to later movement along the margins of the lamproite bodies. On the other hand, Wellman stated that there was no evidence of post-emplacement Tertiary tectonism and consequently preferred the younger age. Since, contrary to Wellman's statement, there is evidence of minor Tertiary movement involving tilting and faulting in the area (Brunnschweiler, 1957; Wright 1964) we believe that the age of the lamproites is still in doubt.

STRUCTURAL PATTERNS IN THE EDGAR RANGES-MATCHES SPRINGS AREA

Smith & Williams (1955) carried out detailed mapping in the eastern Edgar Ranges and in Matches Springs, and showed that the area is characterized by apparently random folding and associated faulting of the Jurassic Alexander Formation, Jarlemai Siltstone, and Mowla Sandstone. Their mapping showed that displacements on the faults are generally small (less than 30 m) and that the faults dip towards the centre of synclines. The fold structures mapped by Smith & Williams were considered by them to be drape folds caused largely by differential compaction of beds over an irregular pre-Jurassic topography. The

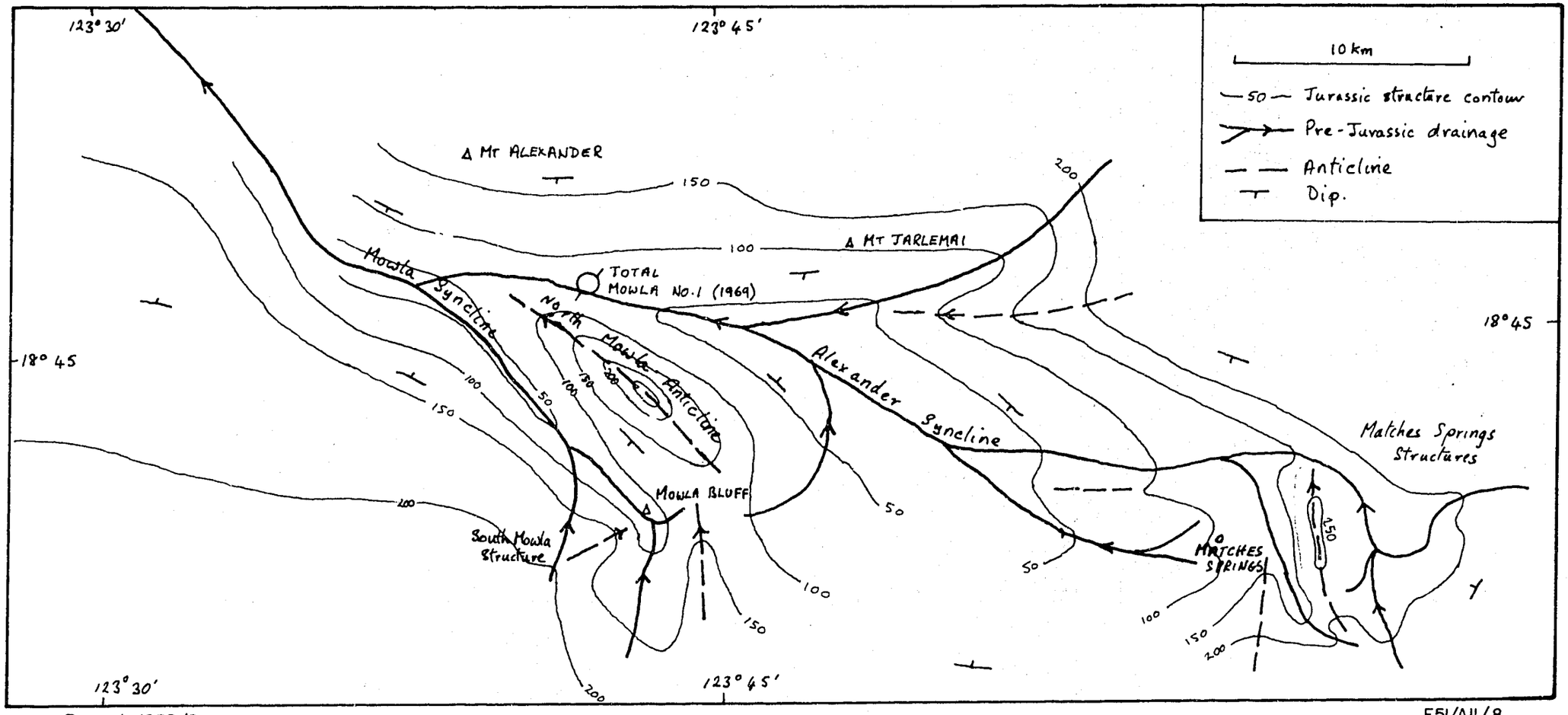
random orientation of all the Mesozoic fold axes appears to form a dendritic pattern (Fig. 10) and they interpreted the small-scale strike faults as probably associated with the compaction of the draped sediments. Subsequently, Total Mowla No 1 (Total, 1969) was drilled in 1969 close to the axis of Smith and Williams' Alexander Syncline. Total (1969) showed that the well spudded directly into Permian rocks. However, recent micropalaeontological work by J. Backhouse and E.M. Kemp (written communications) indicates that Jurassic rocks are present in the top 274 m of the well (Fig. 21, Appendix II). The base of the Wallal Sandstone is deeper in this well than elsewhere in the area, indicating a syncline, but the Wallal Sandstone and Alexander Formation are interpreted to be no thicker than in other wells or outcrop in the area; thus Smith & Williams' interpretation is not supported by the results of this well.

The dendritic pattern mapped by Smith & Williams (Fig. 10) suggests that the pre-Wallal Sandstone drainage flowed northwestwards, and if their theory is correct, it implies that this part of the Broome Platform was a positive feature in pre-Jurassic times.'

POST-EARLY CRETACEOUS TECTONISM

The Late Jurassic and Early Cretaceous rocks in the area presently occur topographically above the main level of the land underlain by the Fitzroy Trough. In particular, the Edgar Ranges occur some 100 m above that level. Wright (1964) believes this topographical difference was caused by Miocene tilting about a coastal hinge line and this agrees with Brunnschweiler's (1957) theory that the Dampier Peninsula was upwarped and the King Sound area downwarped. This doming of the Dampier Peninsula (forming the Fraser River Structure, DERBY) is inferred by Brunnschweiler to have been responsible for diverting the Fitzroy River from its original course towards Roebuck Bay (to the west of the area) towards its present course where it flows into King Sound.

Jurassic rocks adjacent to the Fenton Fault also show evidence of being faulted. However, as Williams & McKellar (1958) point out, the amount of throw on these faults is probably very small. The sense of movement is normal and the faulting was probably related to the uplift of the Edgar Ranges area on the Broome Platform.



Record 1978/8

E51/A11/8

Fig. 10 Pre-Jurassic drainage pattern in Edgar Ranges / Matches Springs area. An interpretation of the origin of the Edgar Range Folds. Adapted from Smith & Williams (1955).

PART II

GEOLOGICAL HISTORY

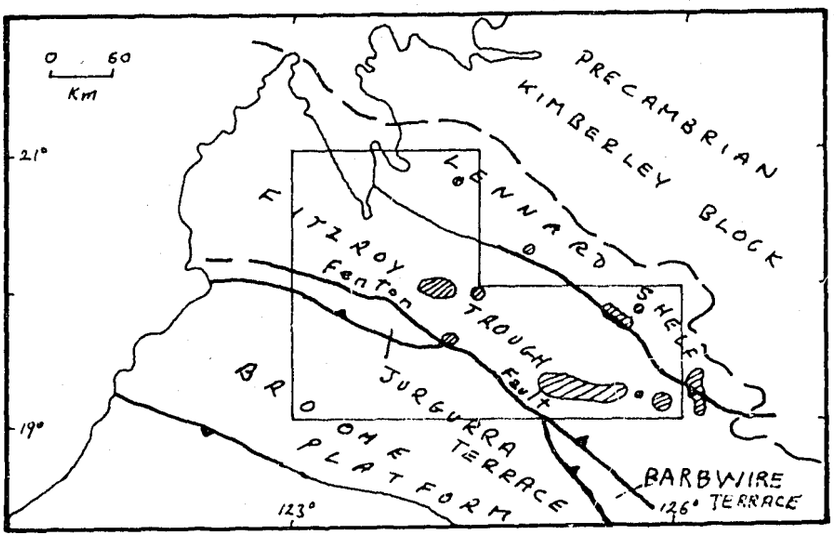
LATE CARBONIFEROUS TO EARLY PERMIAN

After deposition of the Early Carboniferous rocks, the area underwent an extensive period of uplift and erosion before sediment of the Grant Group was deposited in the Late Carboniferous. The lower part of the Betty Formation (Carboniferous part) is mainly confined to the Fitzroy Trough and so it is probable that this was an area of faster subsidence than the rest of the Canning Basin, as it was throughout most of the Palaeozoic. It is not certain whether the Betty Formation is a continental or marine deposit but it contains tentatively identified glacial erratics suggesting the presence of ice. Outside the area the unit contains some marine fossils so possibly it was laid down in a sea with floating ice. This phase of deposition continued into the Early Permian (Sakmarian) when the inferred sea spread over the whole area. It is thought that the next unit, the Winifred Formation, may indicate a relative rise in the water level as it consists of finer-grained sediments.

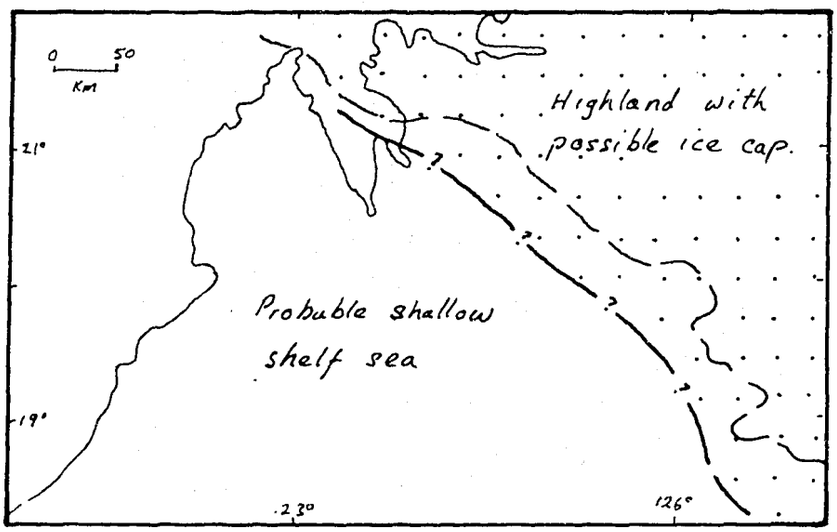
Deposition of the Carolyn Formation is thought to have occurred in a shallow sea, probably still under the influence of a cold climate (Fig. 11B). This sea is then believed to have retreated from the area south of the Fenton Fault. Exposures of Carolyn Formation in the Mount Arthur area represent near-shore conditions at that time (Fig. 11C). The presence of varves at the base of the Wye Worry Member to the east of the area led Crowe & Towner (1976c) to postulate deposition in a quiet-standing body of relatively fresh water which contained floating ice (Fig. 11C). This water body may have been a restricted arm of the sea that deposited the Wye Worry Member in the study area because later the same body of water became connected to the sea as indicated by the lack of varves and the presence of marine fauna (Crowe & Towner, 1976c). The barrier responsible for the marine restriction could have been sand bars that are interpreted to have been present in the Grant Range area during this time (Fig. 11C & D). Sand bar development probably continued in the Grant Range area throughout the rest of Wye Worry Member deposition.

Fig. 11

PALAEOGEOGRAPHIC MAPS FOR CAROLYN FORMATION

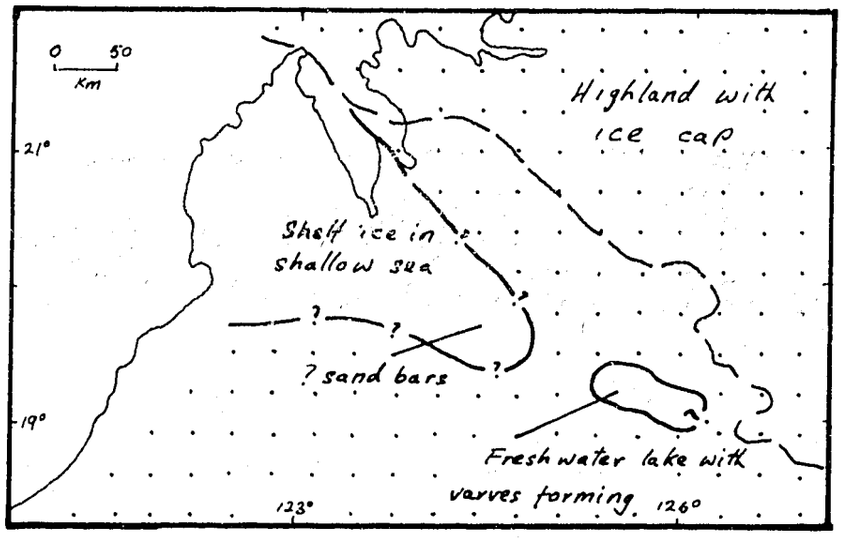


A. Showing area covered by this report together with area covered by Crowe & Towner (1976c). Also shows structural subdivisions and relevant exposures of Carolyn Formation.

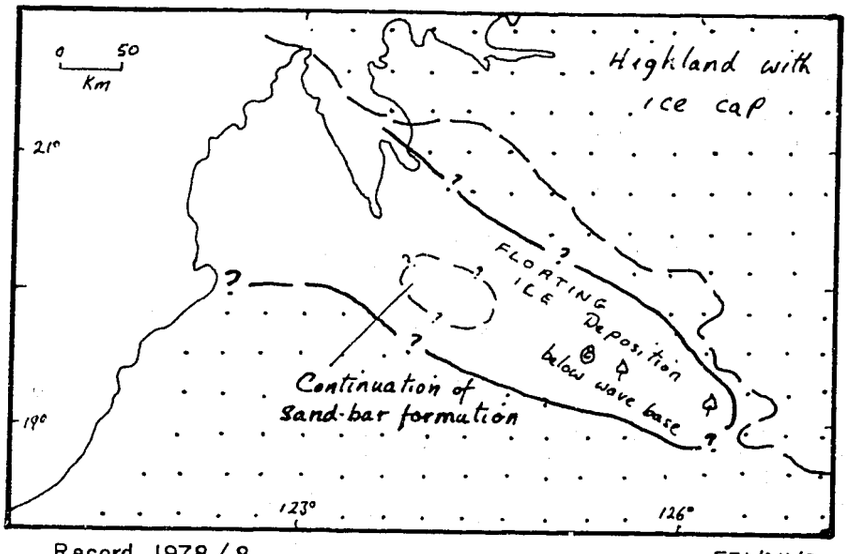


B. CAROLYN FORMATION, PRE-WYE WORRY MEMBER. Basin area was probably covered by a shallow shelf sea depositing clastics. Shoreline facies not identified but distribution of unit suggests it was just basinward of present basin margin

Fig. 11 (cont.)



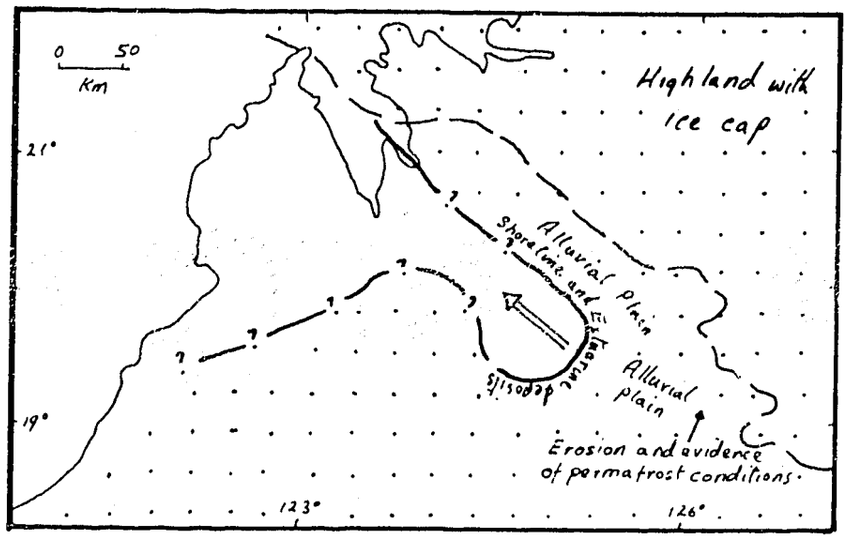
C. LOWER WYE WORRY MEMBER. Probable regression of sea from southern part of basin. Sea withdraws or is cut-off from eastern Fitzroy Trough and freshwater lake with floating ice forms. Cut-off may be due to sand-bar development in Grant Range area.



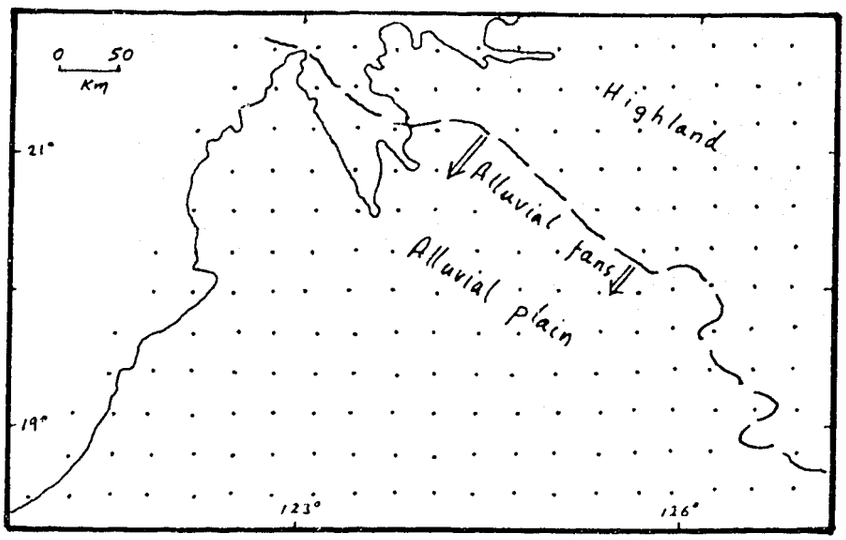
Record 1978/8 E51/A11/9

D. MIDDLE WYE WORRY MEMBER. Rise in relative sea level allows sea to reach at least as far as Mount RAMSAY Sea then becomes shallower marking the end of Wye Worry Member deposition.

Fig. 11 (cont.)



E. LOWER MILLAJIDDEE MEMBER. Permafrost conditions prevail in east while shoreline retreats from Fitzroy Trough.



Record 1978/8 E51/All/9

F. UPPER MILLAJIDDEE MEMBER. Area becomes land. Alluvial fans shed from upstanding Kimberley Block highlands. Fitzroy Trough is an alluvial plain. Extensive slumping of sediments due to dewatering caused by deglaciation and/or to uplift, folding, and faulting that followed deposition of the Carolyn Formation.

The sea then started to retreat from the area leaving the regressive deposits of the Millajiddee Member behind. As the regression continued alluvial plains formed over the area. Crowe & Towner (1976c) describe fossil ice wedges at this level and these indicate that the climate was still cold and that permafrost conditions probably prevailed on the newly formed alluvial plains (Fig. 11E). To the east of the area (and probably also within the area) the upper part of the Millajiddee Member is extensively slumped. This is tentatively interpreted to be due to 'ice tectonics' where the slumping is produced by melting and/or moving ice. However slumping associated with steep-sided scours and intraformational breccias such as occur at Hawkstone Peak are interpreted as due to deposition by mudflows on alluvial fans which were probably shed from the upstanding Kimberley Block (Fig. 11F). The presence of melting ice on the Kimberley Block would explain the rapid sedimentation which produced such alluvial fans.

After deposition of the Grant Group the area was folded and faulted. At least some of the faults are of the reverse type (if not all of them) and it is consequently inferred that this period of tectonism was compressional. The area was then eroded and although no sediments of this erosion cycle were found in the area, some were discovered by Crowe & Towner (1976c) to the east.

EARLY TO LATE PERMIAN

The area was probably eroded to a fairly flat plain before the next marine transgression occurred in the Early Permian and deposits of the Nura Nura Member of the Poole Sandstone were laid down. This sea probably covered all of the area (except perhaps the extreme northwest) and its diverse fauna indicates that the climate was relatively warm in comparison to the cold climate of Grant Group deposition. This sea is interpreted to have become progressively shallower as an extensive barrier-bar system migrated westwards across the area (Fig. 12).

During this time a westward-flowing river system was debouching via a delta into the sea to the east of the area (Fig. 12; Crowe & Towner, 1976b). Between this delta and the barrier bar system a lagoon is believed to have existed. The lagoon is interpreted to have gradually covered the whole of the area (at least within the Fitzroy Trough) and the Tuckfield

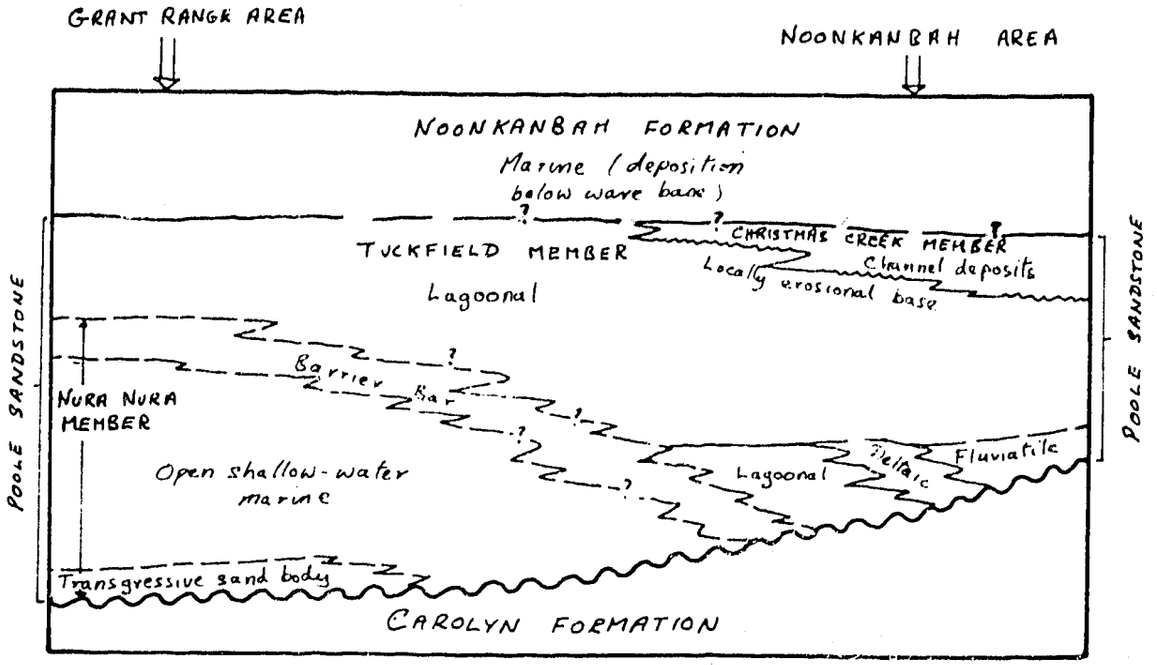


Fig. 12 Diagrammatic relations of facies within the Poole Sandstone between Grant Range/mount ANDERSON) and NOONKANBAH (see also Crowe & Towner, 1976c). Boundaries as in Fig. 13.

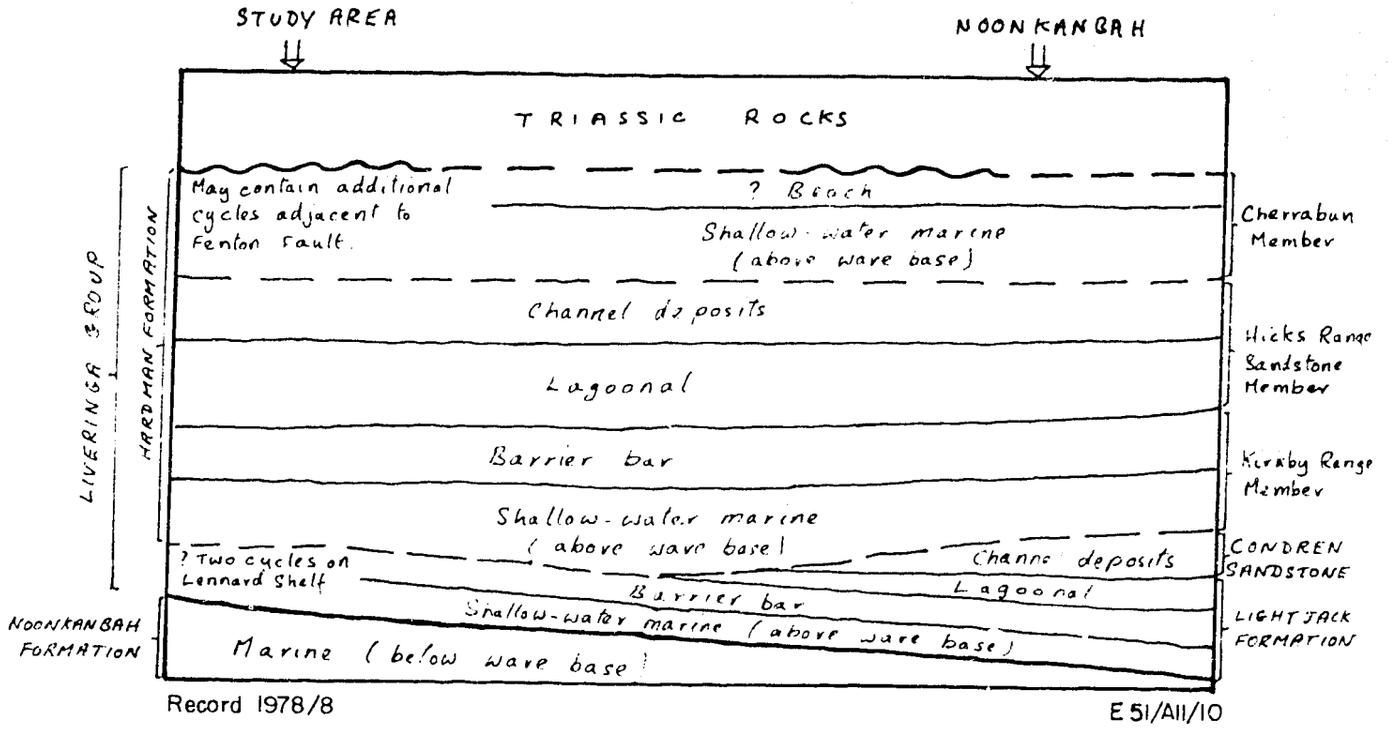


Fig. 13 Diagrammatic relations of facies within the Liveringa Group between the study area and NOONKANBAH (see also Crowe & Towner, 1976c).

Boundaries:- ——— conformable, – – – disconformable, ~~~ angular unconformity.

Member was laid down in it. Channels within this interpreted lagoon may have been tidal in origin. However the absence of a marine fauna in the unit suggests that there was no open connection with the sea that deposited most of the Nura Nura Member. As deposition of the Tuckfield Member continued, differential subsidence of the Fitzroy Trough was taking place. The homogeneity of the Tuckfield Member facies shows that subsidence was roughly keeping pace with deposition. However, the fact that the Tuckfield Member is thicker in anticlinal areas (Crowe & Towner, 1976c) indicates that these areas were subsiding at a slightly faster rate than surrounding areas.

After deposition of the Poole Sandstone, open marine conditions returned to the area. This may have been due to a rise in relative sea level or it could have been due to sediment starvation of the complex. The former alternative is preferred because the boundary between the Poole Sandstone and the Noonkanbah Formation is abrupt (it may be disconformable) and appears to represent a sudden change to deposition below wave base. Moderate-depth marine deposition continued throughout the Artinskian and into the Kungurian as the Noonkanbah Formation was laid down. However, the presence of some shallow-water indicators in the formation on the Jurgurra Terrace suggests that this area may have been positive with respect to the Fitzroy Trough. The exposures of the formation on the Jurgurra Terrace also contain substantial coarse-grained material, which poses a problem because there is no known nearby source for this material. It is possible, therefore that parts of the Broome Platform may have formed islands at this time, as was probably the case during the Mesozoic.

During the Kungurian, barrier sand bars spread across the area as the sea retreated. The middle part of the Lightjack Formation is believed to have been deposited as such sand bars (Fig. 13) and it marks the beginning of a paralic phase of deposition which occurred in the Late Permian. The area may have been subjected to subaerial deposition after the Lightjack Formation was laid down but if so, then the deposits (Condren Sandstone) were removed before the next marine incursion (represented by the Kirkby Range Member) took place. After this latter incursion, the sea again regressed from the area (Hicks Range Sandstone Member) before a final transgression and regression occurred (Cherrabun Member). Figure 13 shows the relation of these three depositional regressive cycles and it can be seen that in the study area additional

cycles may be present. It is difficult to believe that this cyclic deposition (represented by the Liveringa Group) was brought about entirely by changes in relative sea level caused by tectonism. No angular relations are known in the sequence and it is therefore more likely that the cycles were caused by other means. Crowe & Towner (1976c) believed that the deltaic model described by Scruton (1960) offers a better explanation.

Scruton (1960), in describing the Mississippi delta deposits, explained how a delta lobe builds into the sea and deposits a typical regressive sequence until that lobe is abandoned owing to lateral migration of the debouching river. When this happens a new delta lobe is built elsewhere and with continuing subsidence of the basin (due in part to the increased load of sediment) the first lobe may be buried and preserved. Should the river change its course again a further lobe may be built out over the first and in this way a vertical sequence of regressive cycles can be built up. As Crowe & Towner (1976c) point out, this is the simplest explanation of the complex facies within the Liveringa Group and it is consequently thought that the group represents the deposits of a large imbricate delta that built out into, and gradually filled in, the Late Permian sea in the area.

No deposits of the Liveringa Group are known south of the Fenton Fault in the area and although some parts of the group may have been deposited and subsequently eroded, it is more probable that the Broome Platform and the Barbwire and Jurgurra Terraces were positive features during the Late Permian and that the sea had largely regressed from them by that time.

After the final regression of the sea from the area in the Late Permian, there was probably minor movement along the faults which bound the Fitzroy Trough. This movement is inferred to have been the cause of minor folding which occurred in these areas before the Triassic cycle of deposition began.

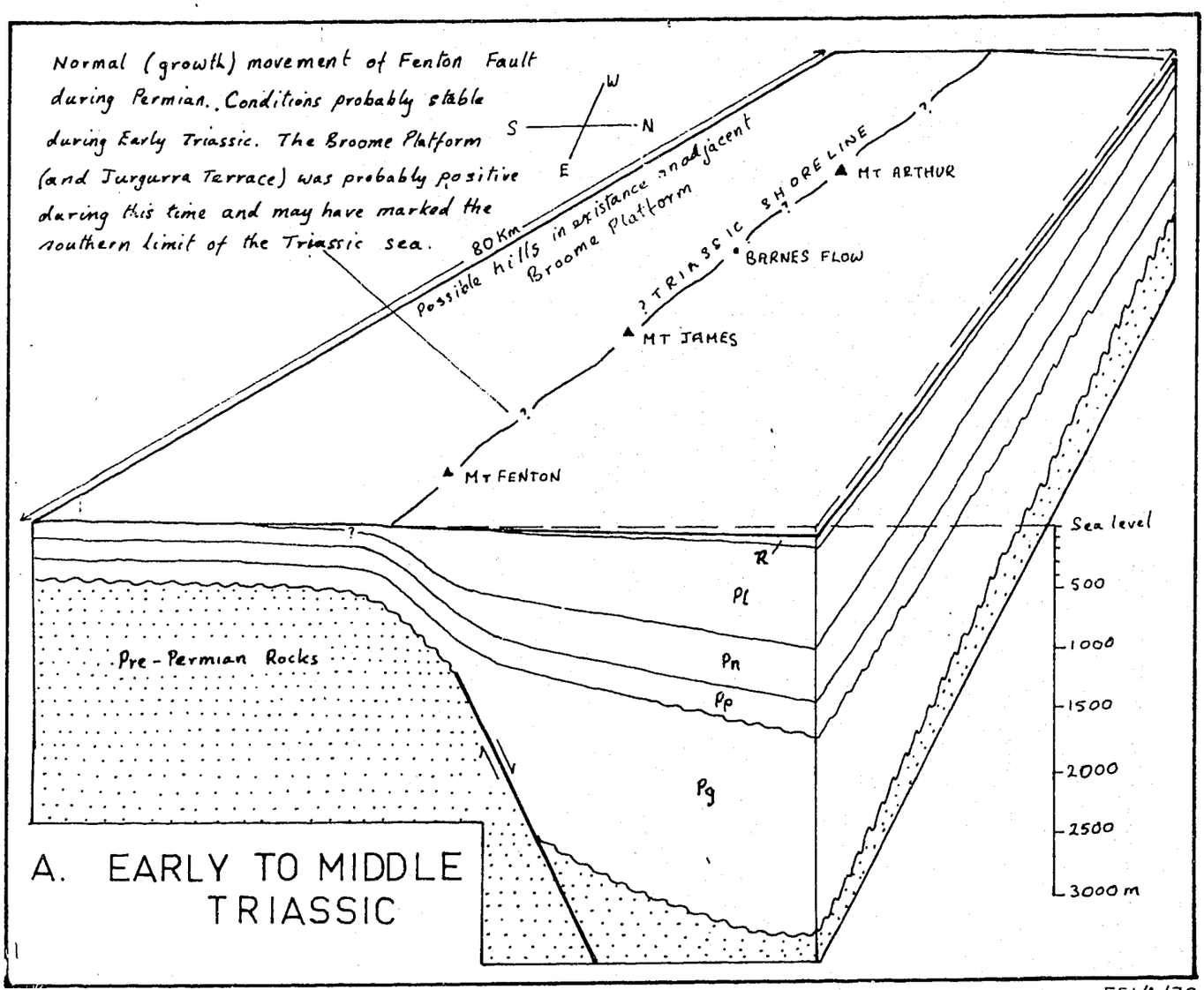
TRIASSIC

Not much is known about the earliest Triassic deposition in the area. Farther to the southeast, it is thought that deposition started in a continental environment (Yeates and others, 1975b), but the deposits of the Millyit Sandstone in the study area may represent the start of the transgression which occurred in the Early Triassic. This transgression deposited muds of the Blina Shale and it is thought that deposition occurred mainly in very shallow water. The evidence suggests that the area experienced intermittent subaerial exposure and we believe that the Blina Shale represents deposition in a mudflat. It is also thought that the sea that deposited this sequence may not have been directly connected to the oceans. The distribution of the Blina Shale shows that the sea covered the Fitzroy Trough and Lennard Shelf but that it may not have extended south of the Fenton Fault. Evidence from the overlying Erskine Sandstone suggests that the Broome Platform may have been upstanding at this time (see also Fig. 14).'

The Erskine Sandstone is interpreted to have been deposited by a delta and it marks the retreat of the Triassic sea from the area. Current directions in the Erskine Sandstone indicate that the channels probably flowed towards the north and this suggests that the source area may have been the area south of the Fenton Fault. The indication of pre-Jurassic valleys in the Edgar Ranges/Matches Springs area (see under 'Structural patterns in the Edgar Ranges/Matches Springs area') suggests that hills existed in this area. The interpreted drainage pattern (Fig. 10) also shows a flow off the Broome Platform, so that the combined evidence for the Broome Platform being a Triassic positive feature is fairly strong.

The Erskine Sandstone is the last record of Triassic sedimentation in the area, but in WAPET Fraser River No. 1 dolerite-gabbro intrusions were intersected in Carboniferous rocks (WAPET, 1956b) and these are believed to be Triassic (Playford and others, 1975). The source or style of the intrusions is not known.

Fig. 14 Schematic block diagrams showing relations between structure and sedimentation during Triassic (A) and Jurassic (B). Adapted and updated from Williams & McKellar (1958).

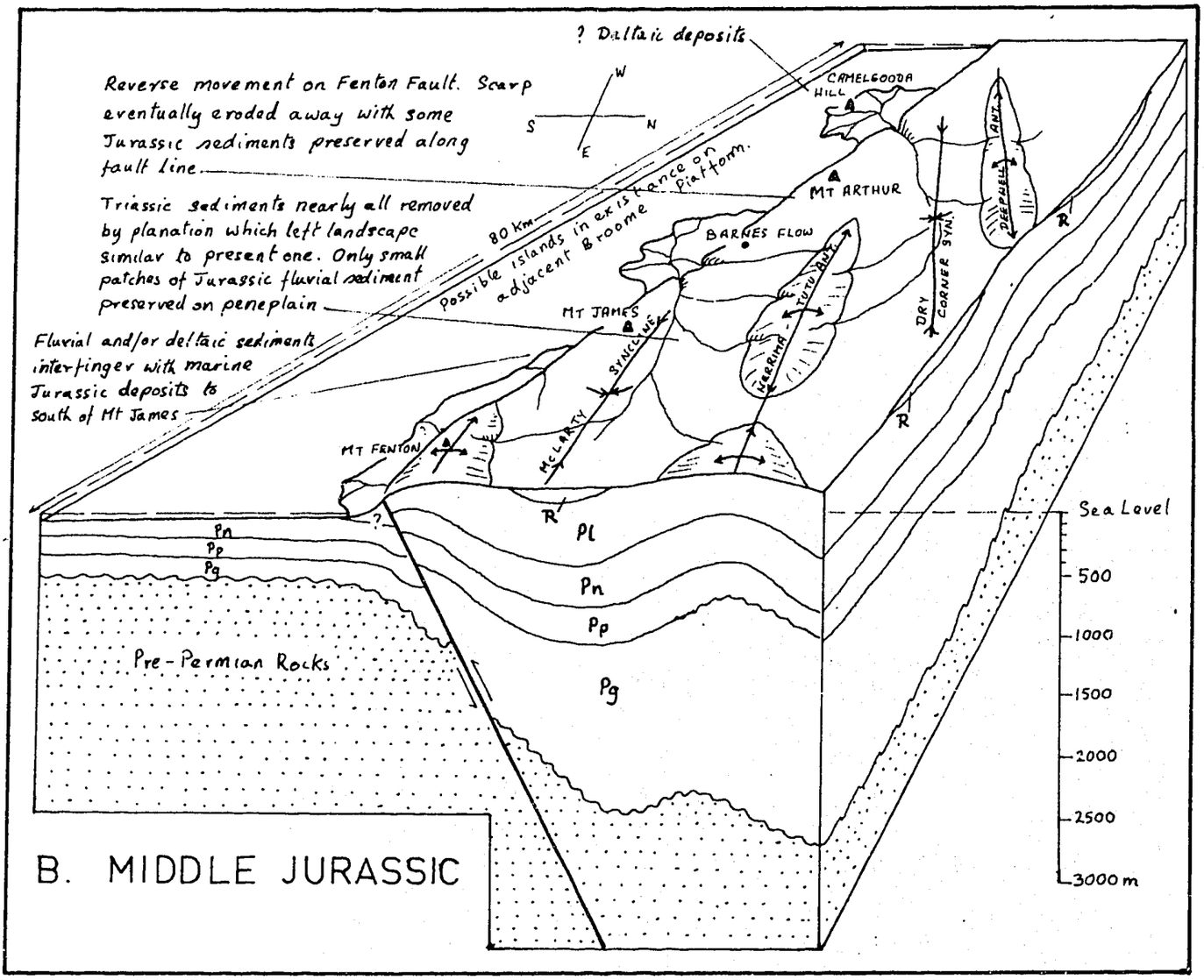


Record 1978/8

E51/A/36

Symbols used; Pg - Grant Group; Pp - Poole Sandstone; Pn - Noonkanbah Formation; Pl - Liveringa Group; R - Triassic formations.

Fig. 14 (cont.)


? Deltaic deposits
Reverse movement on Fenton Fault. Scarp eventually eroded away with some Jurassic sediments preserved along fault line.
W
S
N
E
CAMELGOODA HILL
Triassic sediments nearly all removed by planation which left landscape similar to present one. Only small patches of Jurassic fluvial sediment preserved on peneplain
80 Km
Possible islands in existence on adjacent Broome Platform.
MT ARTHUR
BARNES FLOW
DEEP HELL ANT.
DRY CORNER SYN.
MT JAMES
SYNCLINE
Fluvial and/or deltaic sediments interfinger with marine Jurassic deposits to south of Mt James
MT FENTON
MCLARTY
R
Pl
Pn
Pp
Pg
Pre-Permian Rocks
Sea Level
500
1000
1500
2000
2500
3000 m
B. MIDDLE JURASSIC

JURASSIC TO CRETACEOUS

After deposition in the Early and Middle Triassic, the area is thought to have remained stable until the Early or Middle Jurassic when a phase of tectonism began. This tectonism was caused by compressional movement of the northern Kimberley Block against the southern Canning Basin (Fig. 6). The result of the right-lateral wrench movement together with complementary lateral movement (Rattigan, 1967; Smith, 1968) in the area was that the previously normal movement of the Fenton Fault was reversed, and the sediments in the Fitzroy Trough were folded into large anticlines and synclines. The tensional stresses caused by the folding formed a large number of mainly north-trending normal faults, particularly in the axial areas of the folds. The sediments in areas adjacent to the Fitzroy Trough were only slightly tilted. Intrusion of the Fitzroy Lamproite may have occurred during the Jurassic and it is inferred to have been related to the Jurassic phase of tectonism.

The result of this tectonism was that the areas north of the Fenton Fault in eastern MOUNT ANDERSON and the eastern half of DERBY were uplifted relative to the remaining areas. The Fenton Fault, in eastern MOUNT ANDERSON, is thought to have formed a south-facing scarp or slope which acted as a barrier to the transgressing Jurassic sea (Fig. 14B). Farther westwards, in western MOUNT ANDERSON, there appears to have been little reverse movement on the fault and the Jurassic sea transgressed it.

Only two local facies of the oldest Jurassic Formation crop out. They indicate that deposition probably started in a continental environment with rivers flowing westwards (Mudjalla Sandstone 'Member') and possibly southwards (Barbwire Sandstone) from the uplifted structures in the Fitzroy Trough. On the plain that is thought to have existed, south of the Fenton Fault, sand dunes formed (Jurgurra Sandstone 'Member') and these may be of the coastal type as there are reports of rare marine fossils in the unit (Brunnschweiler, 1954).

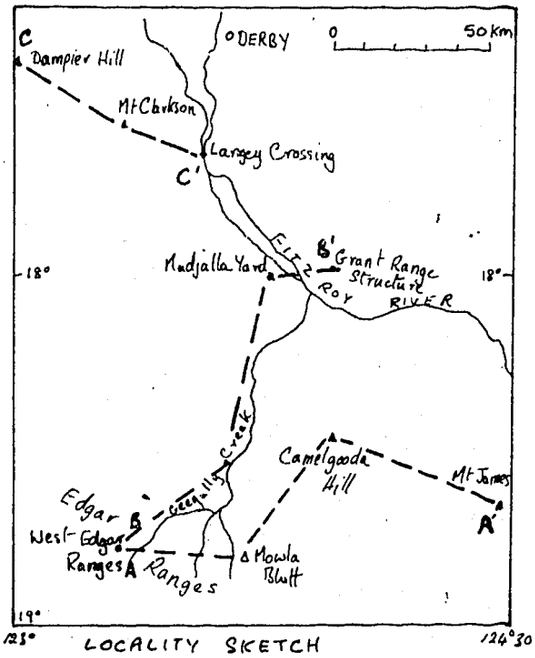
The Jurassic sea then transgressed these deposits and laid down tidal deposits in an open shallow-water marine environment (Alexander Formation). As the transgression continued the water depth is thought to have increased and suspension deposits of the Jarlemai Siltstone were laid down. At the same time, the channels that were depositing the Barbwire Sandstone along the Fenton Fault are inferred to have debouched into the sea and formed possible deltas (Camelgooda Hill sequence; Fig. 15). Farther south, on the Broome Platform, there is evidence to suggest that the Jurassic sea was lapping onto old valleys in the Edgar Ranges/Matches Springs area.

While the sea was depositing sediment in the southern and western parts of the area, the remaining parts of the Fitzroy Trough and Lennard Shelf were experiencing continental conditions. The Meda Formation which is interpreted to be fluviatile is thought to have been laid down on this landsurface although its exact age and correlations are unknown.

Deposition in the Jurassic sea may have been slow. This is suggested by the apparent compression of palynological zones in the Jarlemai Siltstone and it would explain the general absence of bedding structures, thought to be due to intense organic reworking. Towards the end of deposition of the Jarlemai Siltstone, the water is thought to have become shallower in southeastern MOUNT ANDERSON. This is inferred to have marked the beginning of the regression which probably occurred in the southern part of the area in the Late Jurassic. However, it appears that the same regression did not occur until later in the northern part of the area.

As the sea regressed from the southern part, deltas are thought to have built out into it, at least in the eastern Edgar Ranges area. These deltaic deposits may have been continuous with deposits that were laid down earlier adjacent to the Fenton Fault (Fig. 15) but erosion has since separated the sequences.

In the northwestern part of the area the start of the Jurassic regression is represented by the Jowlaenga Formation which is interpreted as a tidal deposit. The final phase of this regression is marked by the occurrence of the beach facies of the Melligo Sandstone

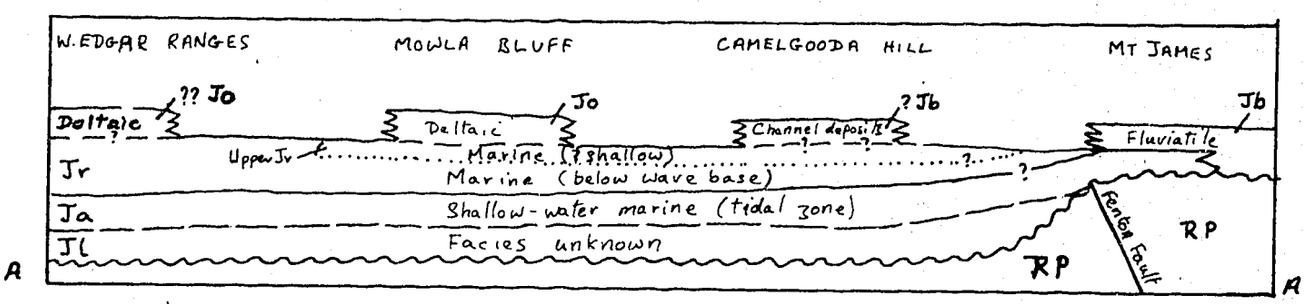


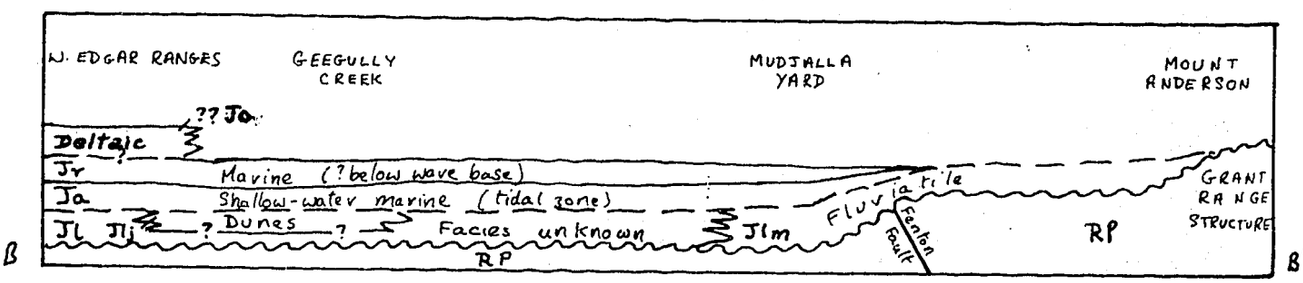
Symbols: RP - Folded Permo-Triassic rocks; Jl - Wallal Sandstone: Jlj - Jurgurra Sandstone 'Membar': Jlm - Madjalla Sandstone 'Membar': Ja - Alexander Formation: Jv - Jarlemai Siltstone: Jb - Barbwire Sandstone: Jo - Mowla Sandstone: Jj - Jowlaenga Formation: Km - Melligo Sandstone.

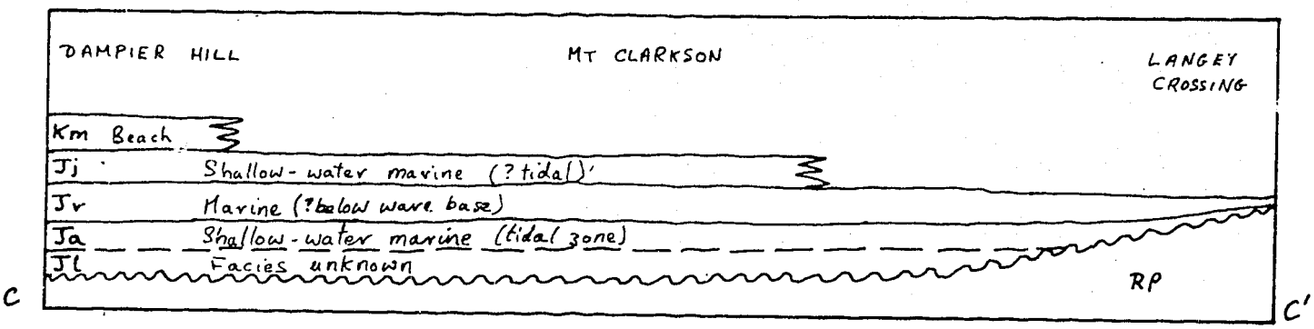
angular unconformity

discontformity

conformable boundary







Record 1978/8

Fig. 15 Interpreted facies correlations of the Jurassic sequence.

E51/A/37

at the top of the sequence along the western margin of the area (Fig. 15). The interfingering relation between the Jowlaenga Formation and the Melligo Sandstone at Dampier Hill implies that the shoreline oscillated as it moved westwards.

The Late Cretaceous history of the area is unknown as there are no deposits of this age preserved. It can be assumed, however, that the area experienced a continental environment and it may be that the present major drainage lines started developing in the Late Cretaceous (see van de Graaff and others, 1977). Minor post-Mesozoic tectonism (Early Tertiary) is then thought to have been responsible for modifying the drainage patterns and producing the landscape that is largely present today.

ACKNOWLEDGEMENTS

We gratefully acknowledge the permission to publish information from the Paradise Boreholes by Australian Inland Exploration. We also thank the many station managers and people throughout the area who gave valuable guidance on the positions and conditions of the tracks and bores or who gave assistance in other ways.

BIBLIOGRAPHY

AQUITAINE (Australian Aquitaine Petroleum Pty Ltd), 1969 - Wilson Cliffs No. 1, well completion report. Bureau Mineral Resources Australia file 68/2011 (unpublished).

AFO (ASSOCIATED FRENEY OILFIELDS N.L.), 1955 - Nerrima No. 1, well completion report. (Unpublished company report).

AFO (ASSOCIATED FRENEY OILFIELDS N.L.), 1956 - Myroodah No. 1, well completion report. (Unpublished company report).

AFO (ASSOCIATED FRENEY OILFIELDS N.L.), 1957 - The Sisters No. 1, well completion report. (Unpublished company report).

BALME, B.E., 1961 - Palynological examination of samples from WAPET Samphire Marsh No. 1. Bureau of Mineral Resources Australia Petroleum Search Subsidy Acts Publication 5, 22-6

BALME, B.E., 1962 - Palynological Examination of samples from WAPET Meda No. 1. Bureau of Mineral Resources Australia, Petroleum Search Subsidy Acts Publication 7, Appendix A, p 23-4.

BALME, B.E., 1963 - Plant fossils from the Lower Triassic of Western Australia. Palaeontology, 6, 12-40.

BALME, B.E., 1964 - The palynological record of Australian pre-Tertiary floras. In CRANWELL, L. (Ed.) - ANCIENT PACIFIC FLORAS: Honolulu, University of Hawaii Press, 49-80.

BALME, B.E., 1967 - Palynological examination of samples from WAPET Blackstone No. 1. In WAPET (1967b).

BALME, B.E., 1969 - The Triassic System in Western Australia. The APEA Journal, 9 (2), 67-78.

BALME, B.E., & HELBY, R., 1973 - Floral modification at the Permian-Triassic boundary in Australia. In LOGAN & HILLS (Eds.), 1973, 433-44.

BLATCHFORD, T., 1927 - The Geology of portions of the Kimberley Division, with special reference to the Fitzroy Basin and the possibilities of the occurrence of mineral oil. Geological Survey of Western Australia, Bulletin 23.

BRUNNSCHWEILER, R.O., 1951 - Notes on the geology of Dampier Land, northwestern Australia. Australian Journal of Science, 14, 6-8.

BRUNNSCHWEILER, R.O., 1954 - Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. Journal of the Geological Society of Australia, 1, 35-54.

BRUNNSCHWEILER, R.O., 1957 - The geology of the Dampier Peninsula, Western Australia. Bureau of Mineral Resources Australia, Report 13.

BRUNNSCHWEILER, R.O., 1960 - Marine fossils from the Upper Jurassic and Lower Cretaceous of Dampier Peninsula, Western Australia. Bureau of Mineral Resources Australia, Bulletin 59.

BURNE, R.V., & CROWE, R.W.A., 1977 - Jurassic eolianites in the Jurgurra Sandstone at Geegully Creek, Mount Anderson Sheet area, W.A. BMR Journal of Australian Geology and Geophysics, 12(4), 314-17.

CASEY, J.N., 1958 - Mount Anderson - 4-Mile Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-11.

COLEMAN, P.J., 1957 - Permian Productacea of Western Australia. Bureau of Mineral Resources Australia, Bulletin 40.

CONEYBEARE, C.E.B., & CROOK, K.A.W., 1968 - Manual of sedimentary structures. Bureau of Mineral Resources Australia, Bulletin 102.

COSGRIFF, J.W., 1965 - A new genus of Temnospondyli from the Triassic of Western Australia. Journal of the Royal Society of Western Australia, 48, 65-90.

COSGRIFF, J.W., 1969 - Blinasaurus, a brachyopod genus from Western Australia and New South Wales. Journal of the Royal Society of Western Australia, 52, 65-88.

COSGRIFF, J.W., 1974 - Lower Triassic Temnospondyli of Tasmania. Geological Society of America, Special Paper 149, 1-134.

CROCKFORD, J., 1957 - Permian Bryozoa from the Fitzroy Basin, Western Australia. Bureau of Mineral Resources Australia, Bulletin 34.

CROWE, R.W.A., & TOWNER, R.R., 1976a - Permian stratigraphic nomenclature, Noonkanbah 1:250 000 Sheet, Western Australia. Geological Survey of Western Australia, Annual Report 1975.

CROWE, R.W.A., & TOWNER, R.R., 1976b - Environmental interpretation of the Permian Nura Nura Member of the Poole Sandstone, Noonkanbah Sheet area, Canning Basin: a gradation between fluviatile and shallow-water marine facies. Geological Survey of Western Australia, Annual Report 1975.

CROWE, R.W.A., & TOWNER, R.R., 1976c - Permian depositional history of the Noonkanbah 1:250 000 Sheet area, W.A. Bureau of Mineral Resources Australia, Record 1976/24 (unpublished).

CROWE, R.W.A., & TOWNER, R.R., in prep. - Noonkanbah, W.A. - 1: 250 000 Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-12.

CROWE, R.W.A, & TOWNER, R.R., in press - Definitions of some new and revised rock units in the Canning Basin. Geological Survey of Western Australia, Annual Report 1977.

DICKINS, J.M., 1963 - Permian pelecypods and gastropods from Western Australia. Bureau of Mineral Resources Australia, Bulletin 63.

DICKINS, J.M., TOWNER, R.R., & CROWE, R.W.A., in press - A Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia. In Yuri A. Orlov Memorial Volume: Palaeontological Society of India.

DOLBY, J.H., & BALME, B.E., 1976 - Triassic palynology of the Carnarvon Basin of Western Australia. Review of Palaeobotany and Palynology, 22(1976), 105-108.

EDWARDS, A.B., 1953 - An oolitic iron formation from northwestern Western Australia. Commonwealth Scientific and Industrial Research Organization (Melbourne), Mineragraphic Investigation Report 540. (unpublished).

EVANS, P.R., 1966 - Contribution to the palynology of northern Queensland and Papua. Bureau of Mineral Resources Australia, Record 1966/198 (unpublished).

FINDLAY, W.A., 1942 - Geological report Northwestern Fitzroy Basin, Kimberley District, W.A. West Australian Petroleum Pty Ltd, Company Report (unpublished).

GALLOWAY, M.C., & HOWELL, D.J., 1975 - Relinquishment report of TR 5851H to 5896H, 5878H to 5880H, Fitzroy Trough, Western Australia. Company Report, Esso Exploration and Production Aust. Inc. and Dampier Mining Co. (unpublished).

GIBSON, D.L., & CROWE, R.W.A., in prep. - Mount Anderson, W.A. - 1:250 000 Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-11.

GLENISTER, B.F., & FURNISH, W.M., 1961 - The Permian ammonoids of Australia. Journal of Palaeontology, 35, 673-736.

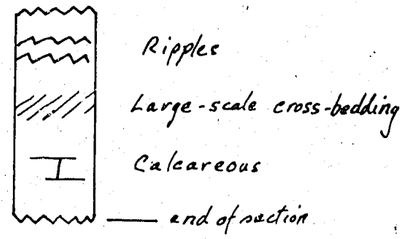
AUSTRALIAN INLAND EXPLORATION PARADISE BOREHOLES
COMPOSITE LOG OF LIVERINGA GROUP

ENCLOSURE No. 1

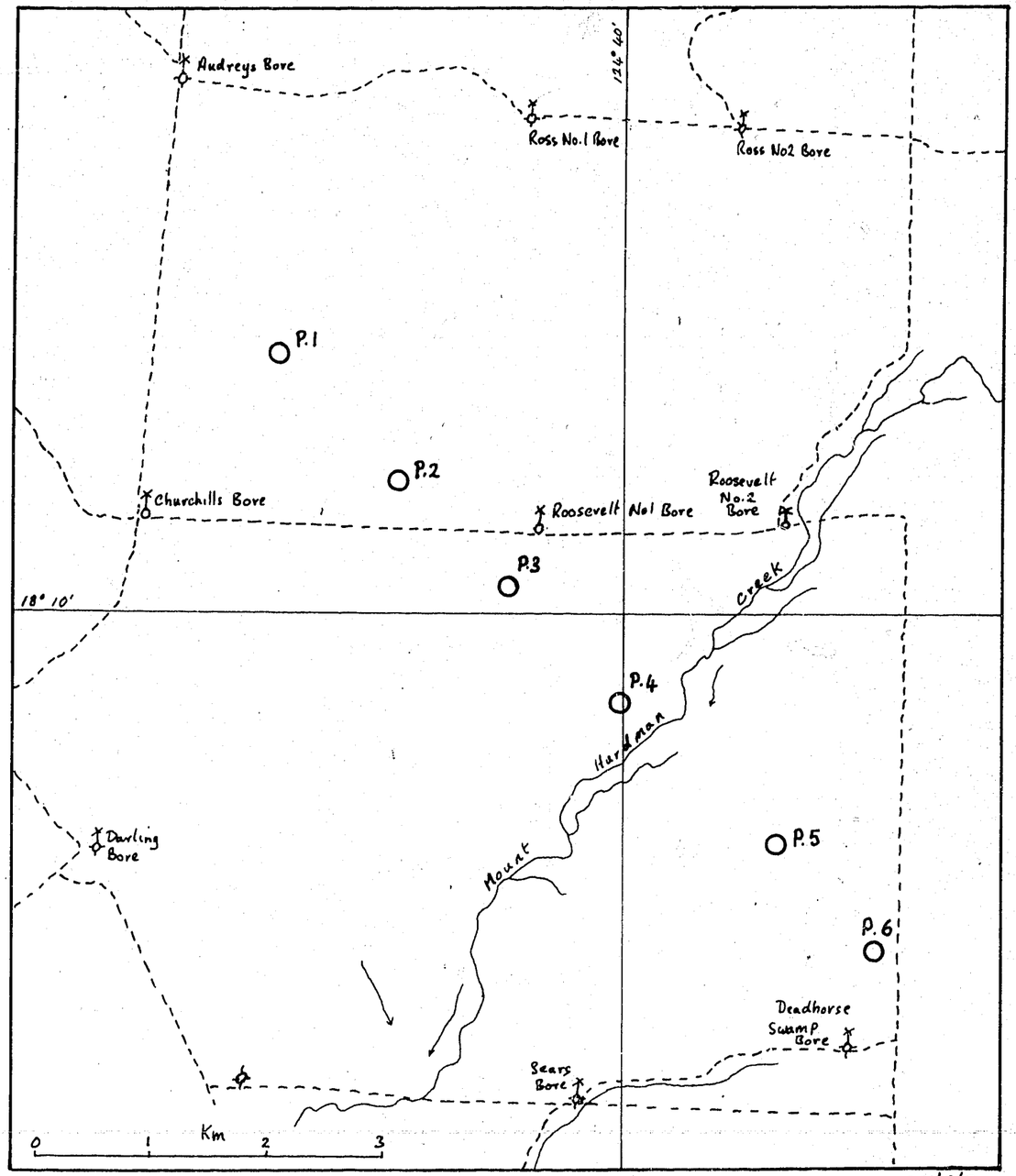
RECORD 1978/8

REFERENCE

- Sandstone
- Mudstone
- Conglomevate
- Coal



- Mudcracks
- Burrows
- Bioturbated
- Graded bedding
- M Micaceous
- Fossil roots
- Fossil leaves
- Marine macrofossils
- USA Palynology sampling point with palynological zone



LOCATION SKETCH SHOWING POSITIONS OF A.I.E. PARADISE BORES

ES1/A/30

ACKNOWLEDGEMENTS

Bores drilled by; Australian Inland Exploration in 1971 (continuous coreholes)

Lithological logs by; Esso in 1974 (Galloway & Howell, 1975).

Electric logs by; Australian Inland Exploration and Esso.

Palynology by; R. Paten and P. Price of Mines Administration Pty Ltd (pers. comm.) and R. Helby for Esso (in Galloway & Howell, 1975).

Identifications and correlations by; Galloway & Howell (1975) and present authors

GORTER, J.D., in prep. - Permian. In Wales, D.W. (Editor) - Canning Basin Atlas. Bureau of Mineral Resources Australia.

GUPPY, D.J., CUTHBERT, J.O., & LINDNER, A.W., 1950 - Geology of the Nerrima Dome, Kimberley Division, Western Australia. Bureau of Mineral Resources Australia, Report 4.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1952 - The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. 19th International Geological Congress, Algeirs, 1950, Symposium Series de Gondwana, 107-114.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1958 - Geology of the Fitzroy Basin, Western Australia. Bureau of Mineral Resources Australia, Bulletin 36.

HELBY, R.J., 1973 - Review of the Late Permian and Triassic palynology of New South Wales. The Geological Society of Australia, Special Publication 4, 141-155.

HENDERSON, S.D., CONDON, M.A., & BASTIAN, L.V., 1963 - Stratigraphic drilling, Canning Basin, Western Australia. Bureau of Mineral Resources Australia, Report 60.

INGRAM, R.L., 1954 - Terminology for the thickness of stratification and parting units in sedimentary rocks. Bulletin of the Geological Society of America, 65, 937-38.

JOHNSTONE, M.H., 1961 - Samphire Marsh No. 1, well completion report. Bureau of Mineral Resources Australia. Petroleum Search Subsidy Acts Publication 5.

KAPLAN, G., FAURE, D., ELLOY, R., & HEILAMMER, R., 1967 - Contribution a l'etude de l'origine des lamproites. Centre Recherches Pau-SNPA, 1, 153-59.

KRAUS, P.S., 1941 - Geologic and stratigraphic reconnaissance, north-west portion Caltex Concession 7-H, Kimberley Division, Western Australia. Caltex (Australia) Oil Development Pty Ltd, Company Report (unpublished).

LENNARD OIL, 1970 - Napier No. 2, well completion report. Bureau of Mineral Resources Australia, file 69/2031 (unpublished).

LENNARD OIL, 1971 - Napier No. 5, well completion report. Bureau of Mineral Resources, Australia, file 70/750 (unpublished)

LOGAN, A., & HILLS, L.V., (Editors), 1973 - The Permian and Triassic Systems and their mutual boundary. Canadian Society of Petroleum Geologists, Memoir 2, 433-44.

McKENZIE, K.G., 1961 - Vertebrate localities in the Triassic Blina Shale of the Canning Basin, Western Australia. Journal of the Royal Society of Western Australia, 44, 69-76.

McWHAE, J.R.H., PLAYFORD, P.E., LINDNER, A.W., GLENISTER, B.F., & BALME, B.E., 1958 - The stratigraphy of Western Australia. Journal of the Geological Society of Australia, 4(2), 1-161.

PASSMORE, V.L., in prep. - Jurassic-Cretaceous. In Wales, D.W. (Editor) - Canning Basin Atlas. Bureau of Mineral Resources Australia.

PLAYFORD, P.E., 1957 - Report on the Derby Town, Myalls, and Broome water bores. West Australian Petroleum Pty Ltd, Company Report (unpublished).

PLAYFORD,,P.E., COPE, R.N., LOW, G.H., COCKBAIN, A.E., & LOWRY, D.C., 1975 - GEOLOGY OF WESTERN AUSTRALIA. Geological Survey of Western Australia, Memoir 2.

PORRENGA, D.H., 1967 - Glauconite and chamosite as depth indicators in the marine environment. Marine Geology, 5, 495-501.

POTTER, P.E., & PETTIJOHN, F.J., 1963 - PALAEOCURRENTS AND BASIN ANALYSIS. Berlin, Springer-Verlag.

PRIDER, R.T., 1960 - The leucite lamproites of the Fitzroy Basin, Western Australia. Journal of the Geological Society of Australia, 6, 71-118.

QUINTON, R.S., 1974 - Report on geological investigations within Temporary Reserves 5679H and 5693H, Canning Basin, Western Australia. Unpublished report for Conzinc Riotinto of Australia Pty Ltd.

RATTIGAN, J.H., & ELLIOTT, R.M.L., 1954 - Canning Basin, geological survey of the Fraser River area. West Australian Petroleum Pty Ltd, Company Report (unpublished).

RATTIGAN, J.H., 1967 - Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia. Proceedings of the Australasian Institute of Mining and Metallurgy. 223, 17-22.

REEVES, F., 1951 - Australian oil possibilities. Bulletin of the American Association of Petroleum Geologists, 35, 2479-2525.

REINECK, H.E., & SINGH, I.B., 1973 - DEPOSITIONAL SEDIMENTARY ENVIRONMENTS, WITH REFERENCE TO TERRIGENOUS CLASTICS. Heidelberg, Springer-Verlag.

REINECK, H.E., & WUNDERLICH, F., 1968 - Classification and origin of flaser and lenticular bedding. Sedimentology, 11, 99-104.

RUSSELL, R.T., 1966a - Report on exploration: temporary reserves for phosphate nos. 3563H and 3579H. Period: 15th April 1966 to 15th July 1966. Mines Exploration Pty Ltd, Company Report 1966/17 (unpublished).

RUSSELL, R.T., 1966b - Report on exploration temporary reserve for phosphate no. 3817H, Derby, W.A. Mines Exploration Pty Ltd, Company Report 1966/22 (unpublished).

SCRUTON, P.C., 1960 - Delta building and the deltaic sequence. In SHEPHARD, F.P., PHLEGER, F.B., & ANDEL, T.H. van (Eds.) - RECENT SEDIMENTS, NORTHWEST GULF OF MEXICO. American Association of Petroleum Geologists, Tulsa Oklahoma, 82-102.

SELLEY, R.C., 1970 - ANCIENT SEDIMENTARY ENVIRONMENTS. London, Chapman & Hall.

SKWARKO, S.K., 1970 - Aptian (Lower Cretaceous) 'Apiotrigonia' from the Melligo Quartzite, Dampier Peninsula, Western Australia. Bureau of Mineral Resources Australia, Bulletin 108, 227-35.

SMITH, J.G., 1968 - Tectonics of the Fitzroy Wrench Trough, Western Australia. American Journal of Science, 266, 766-76.

SMITH, D.N., & WILLIAMS, F.B., 1955 - The geology of Edgar Ranges-Matches Springs area. West Australian Petroleum Pty Ltd, Company Report (unpublished).

SMITH, D.N., & WILLIAMS, F.B., 1956 - The geology of the northwest coast of Dampier Land, West Australian Petroleum Pty Ltd, Company Report (unpublished).

STEVENS, G.R., 1965 - The Jurassic and Cretaceous belemnites of New Zealand and a review of the Jurassic and Cretaceous belemnites of the Indo-Pacific region. New Zealand Geological Survey, Palaeontology Bulletin 36.

TEICHERT, C., 1950 - Some recent additions to stratigraphy of Western Australia. American Association Petroleum Geologists, Bulletin 34(9), 1787-1794.

THOMAS, G.A., 1954 - Report on the Permian brachiopods from the Fitzroy Basin, Western Australia. Bureau of Mineral Resources Australia, Record 1954/9 (unpublished).

THOMAS, G.A., 1958a - Permian Orthotetacea from Western Australia. Bureau of Mineral Resources Australia, Bulletin 39.

THOMAS, G.A., 1958b - Noonkanbah, W.A. - 4-mile Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-12.

THOMAS, G.A., & DICKINS, J.M., 1954 - Correlation and age of the Permian Formations of Western Australia. Australian Journal of Science, 16, 219-33.

TOTAL (TOTAL EXPLORATION AUSTRALIA), 1968 - Edgar Range No. 1, well completion report. Bureau of Mineral Resources Australia, File 68/2041 (unpublished.

TOTAL (TOTAL EXPLORATION AUSTRALIA), 1969 - Mowla No. 1, well completion report. Bureau of Mineral Resources Australia, File 69/2039 (unpublished).

TOTAL (TOTAL EXPLORATION AUSTRALIA), 1970 - Matches Springs No. 1, well completion report. Bureau of Mineral Resources Australia, File 69/2023 (unpublished).

TOWNER, R.R., & GIBSON, D.L., in prep. - Derby, W.A. - 1:250 000 Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-7.

TOWNER, R.R., CROWE, R.W.A., & YEATES, A.N., 1976 - Notes on the geology of the South Canning Basin. Bureau of Mineral Resources Australia, Record 1976/95 (unpublished).

VAN DE GRAAFF, W.J.E., CROWE, R.W.A., BUNTING, J.A., & JACKSON, M.J., 1977 - Relict Early Cainozoic drainages in arid Western Australia. Zeitschrift fur Geomorphologie, 21(4), 379-400.

VEEVERS, J.J., 1958 - Lennard River, W.A. - 4-mile Geological Series. Bureau of Mineral Resources Australia, Explanatory Notes SE/51-8.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bureau of Mineral Resources Australia Bulletin 60.

VISHER, G.S., 1965 - Use of vertical profile in environmental reconstruction. Bulletin of the American Association of Petroleum Geologists, 49(1), 41-61.

WADE, A., 1938 - The geological succession in the West Kimberley district of Western Australia. Australian and New Zealand Association of the Advancement of Science, Report 23, 93-96.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1956a - Grant Range No. 1, well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1956b - Fraser River No. 1, well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1957 - Dampier Downs No. 1, well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1962a - Meda No. 1, well completion report. Bureau of Mineral Resources Australia, Petroleum Search Subsidy Acts Publication 7.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1962b - Frome Rocks No. 1 and No. 2, well completion report. Bureau of Mineral Resources Australia, Petroleum Search Subsidy Acts Publication 8.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1962c - Hawkstone Peak No. 1, well completion report. Bureau of Mineral Resources Australia, File 62/1093 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1963 - Langoora No. 1, well completion report. Bureau of Mineral Resources Australia, File 62/1094 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966a - Babrongan No. 1, Langoora No. 1, Hawkstone Peak No. 1, well completion report. Bureau of Mineral Resources Australia, Petroleum Search Subsidy Acts Publication 48.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966b - Sahara No. 1, well completion report. Bureau of Mineral Resources Australia, Petroleum Search Subsidy Acts Publication 80.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1967a - May River No. 1, well completion report. Bureau of Mineral Resources Australia, File 67/4252 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1967b - Blackstone No. 1, well completion report. Bureau of Mineral Resources Australia, File 67/4262 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1968a - Doran No. 1, well completion report. Bureau of Mineral Resources Australia, File 68/2033 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1968b - Logue No.1, well completion report. Bureau of Mineral Resources Australia, File 68/2034 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1973 - Hardman No. 1, well completion report. Bureau of Mineral Resources Australia, File 73/259 (unpublished).

WATERFORD, L.M., 1941 - Resume of oil drilling operations conducted in the west Kimberley district of W.A. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WELLMAN, P., 1973 - Early Miocene potassium-argon age for the Fitzroy lamproites of Western Australia. Journal of the Geological Society of Australia, 19, 471-74.

WHITE, M.E., & YEATES, A.N., 1976 - Plant fossils from the north-eastern part of the Canning Basin, Western Australia. Bureau of Mineral Resources Australia, Record 1976/18 (unpublished).

WILLIAMS, F.B., & McKELLAR, M.G., 1958 - Fenton Fault Project. Unpublished WAPET report.

WILLIAMS, H., TURNER, F.J., & GILBERT, C.M., 1958 - PETROGRAPHY - an introduction to the study of rocks in thin sections. San Francisco, Freeman.

WRIGHT, R.L., 1964 - Geomorphology of the West Kimberley area. Scientific Industrial Research Organisation, Melbourne, Land Research Series 9, 103-118.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L., 1975a - New and revised stratigraphic nomenclature northeast Canning Basin, Western Australia. Geological Survey of Western Australia, Annual Report for 1974.

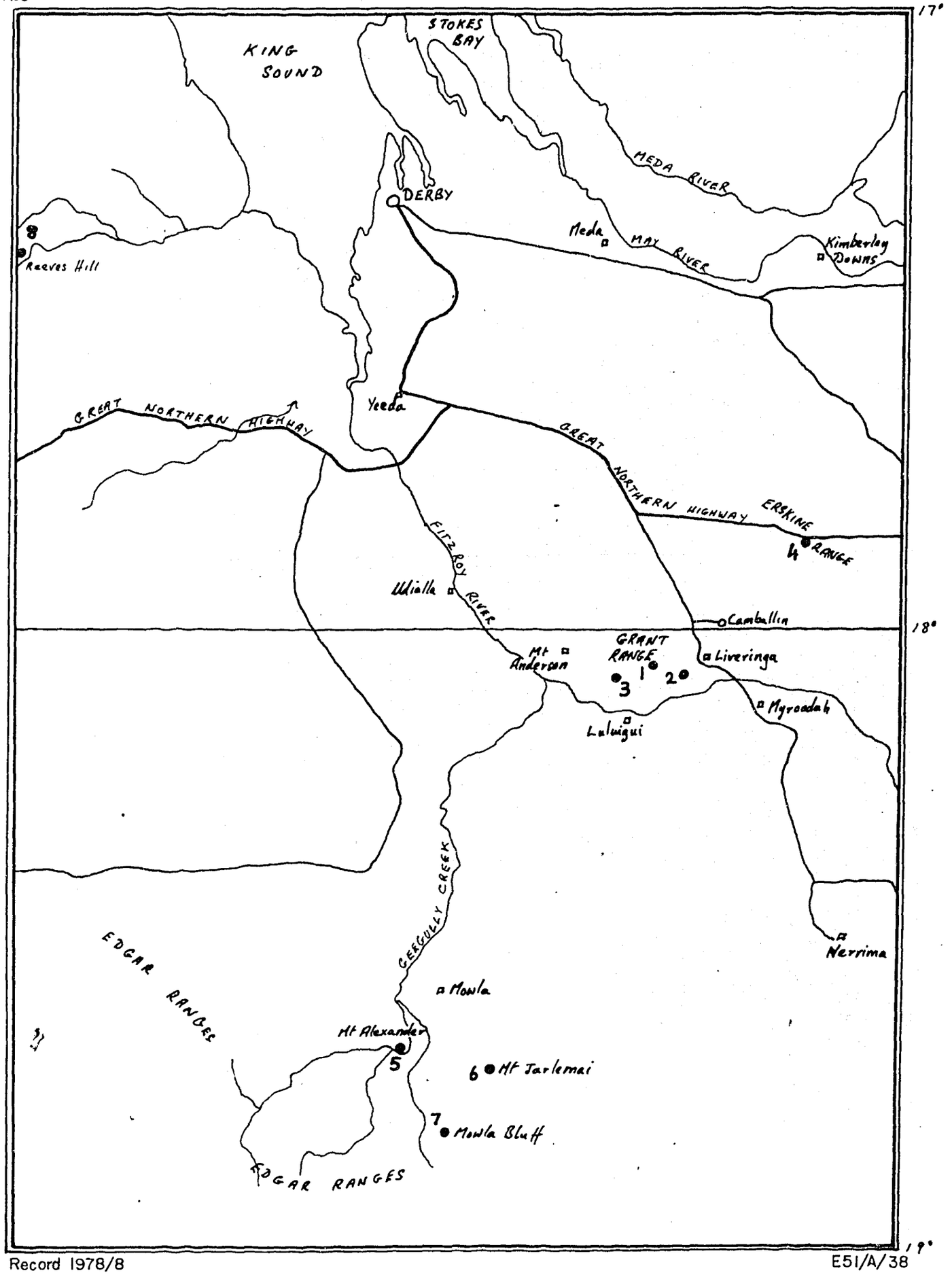
YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L., 1975b - Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia. Bureau of Mineral Resources Australia, Record 1975/77 (unpublished).

APPENDIX 1 - MEASURED SECTIONS

Figure 16 shows the locations of the measured sections. The sections were measured using the 'height-to-eyes' technique for predominantly vertical sections and the tape-and-compass method for mainly horizontal ones. The sections are all shown at the same scale for comparative purposes.

Table 28 - Measured sections

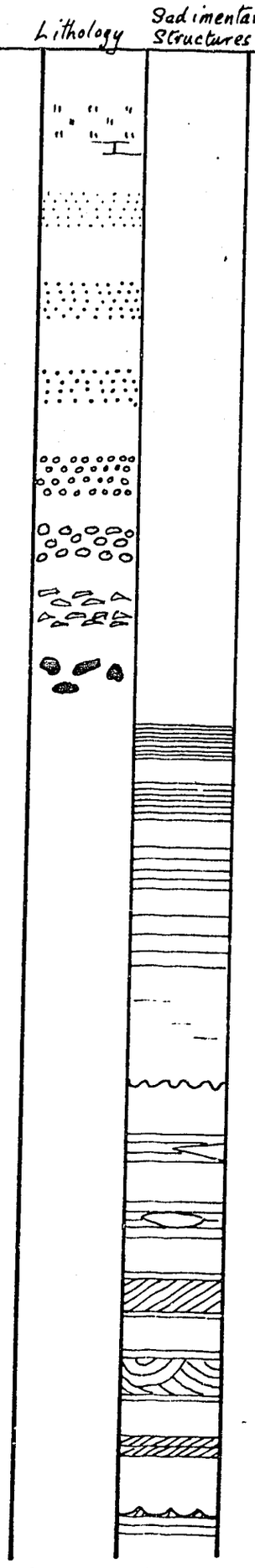
Section number	Name of section	Stratigraphic units
1	Central Grant Range	Carolyn Formation
2	Southeast Grant Range	Poole Sandstone
3	Liveringa Ridge	Noonkanbah, Lightjack, and Hardman Formations
4	Erskine Range	Blina Shale and Erskine Sandstone
5	Mount Alexander	Jurgurra Sandstone and Alexander Formation
6	Mount Jarlemai	Alexander Formation and Jarlemai Siltstone
7	Mowla Bluff	Jarlemai Siltstone and Mowla Sandstone
8	Dampier Hill	Jowlaenga Formation and Meiligo Sandstone



Record 1978/8 E51/A/38

Fig. 16 Sketch map of DERBY and MT ANDERSON showing locations of sections in Appendix 1. Scale; 1:1 000 000

REFERENCE FOR MEASURED SECTIONS



Mudstone – calcareous

Fine-grained sandstone

Medium-grained sandstone

Coarse-grained sandstone

Granule conglomerate

Pebble conglomerate

Clay-pellet conglomerate (intraformational)

Glacial dropstones

Laminated

Thin bedded

Medium bedded

Thick bedded

Poorly bedded or massive

Erosional boundary

Wedge-shaped bed

Lens

Planar cross-bedding } Large scale (greater than 5 cm thick)

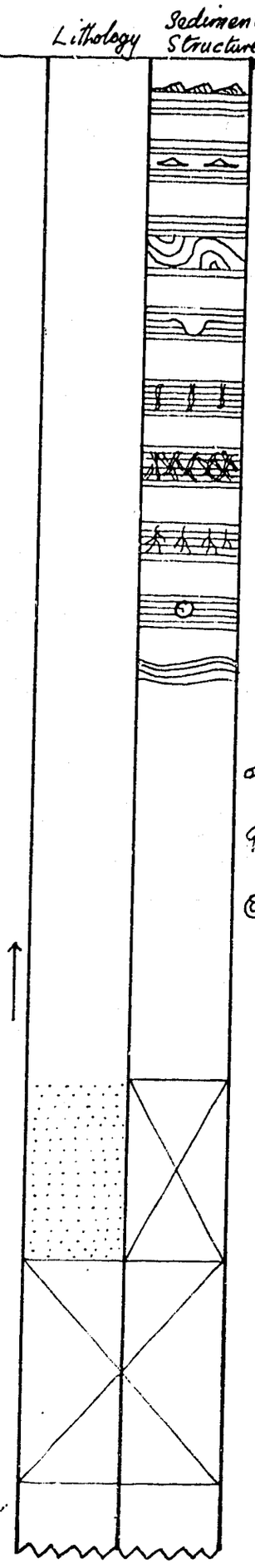
Trough cross-bedding }

Small-scale cross-bedding (less than 5 cm thick)

Symmetrical ripple marks

CONTINUED

REFERENCE FOR MEASURED SECTIONS (CONTINUED)



Asymmetrical ripple marks

Flaser and/or lenticular bedding

Slump

Scour-and-fill structure

Burrows

Bioturbation

Fossil roots

Concretion

Wavy bedding

Fossil wood

Plant fossils

Marine macrofossils

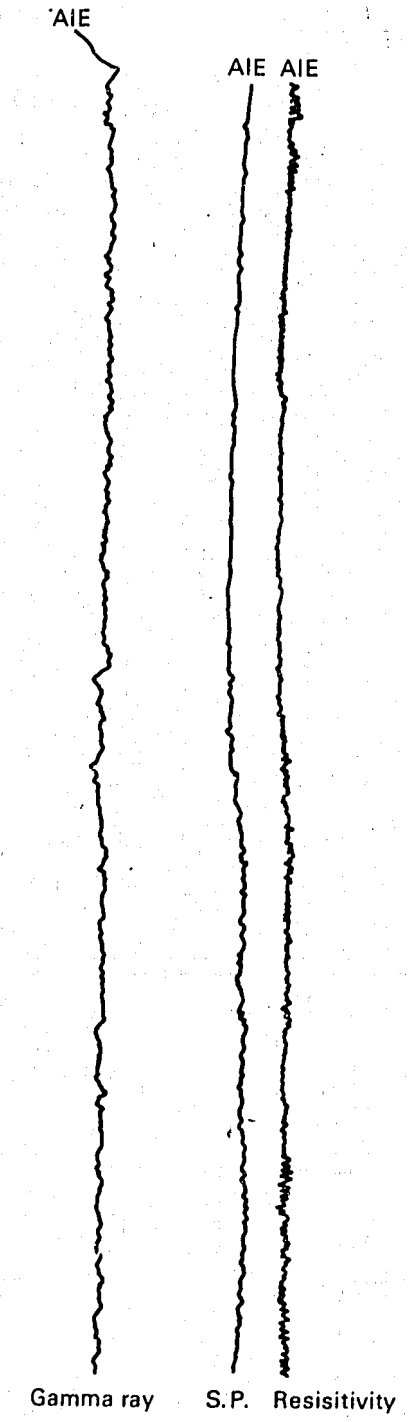
Arrow indicates fining-upwards sequence. Length of arrow indicates thickness of sequence.

Section partly obscured by scree. Bedding not seen.

Section not exposed

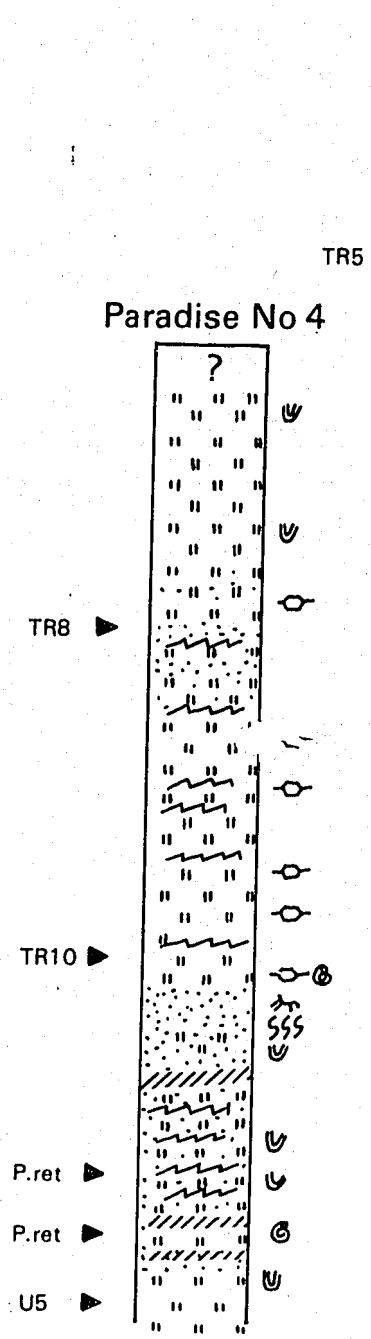
Base of section.

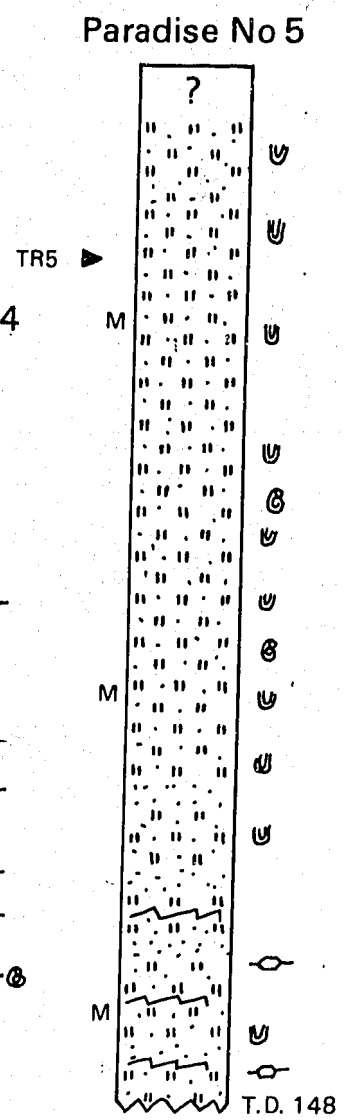
Enclosure No. I (cont.)

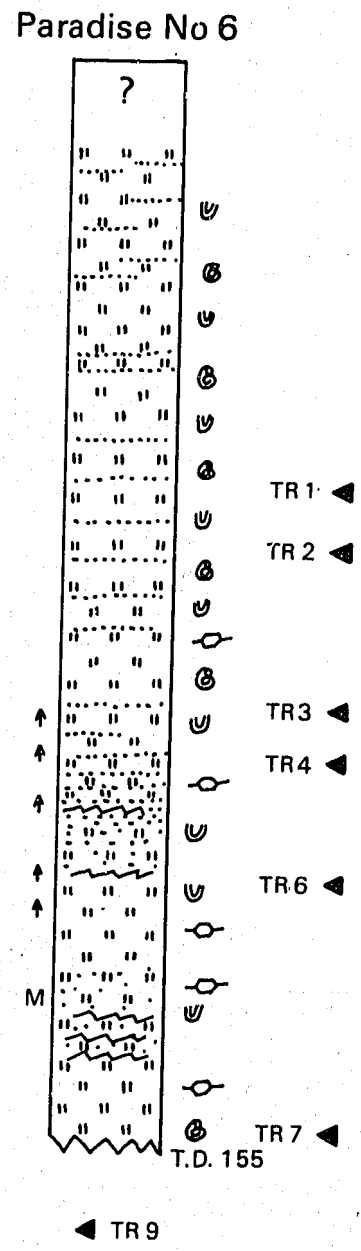


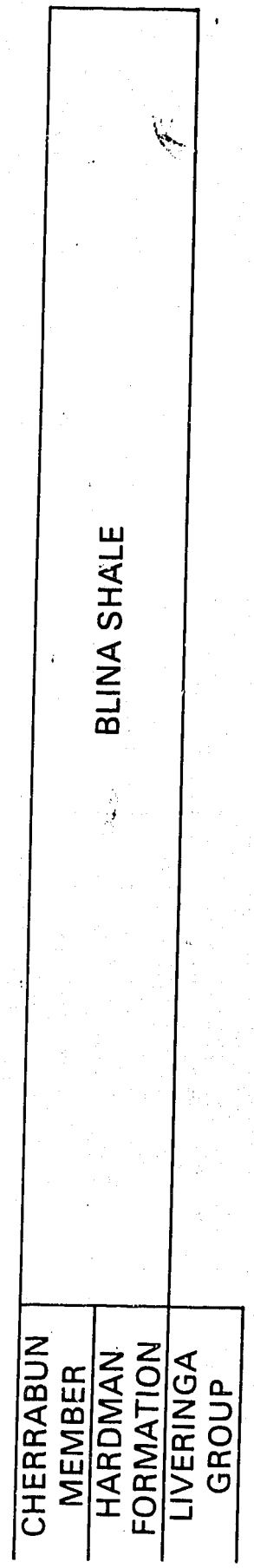


Record 1978/8







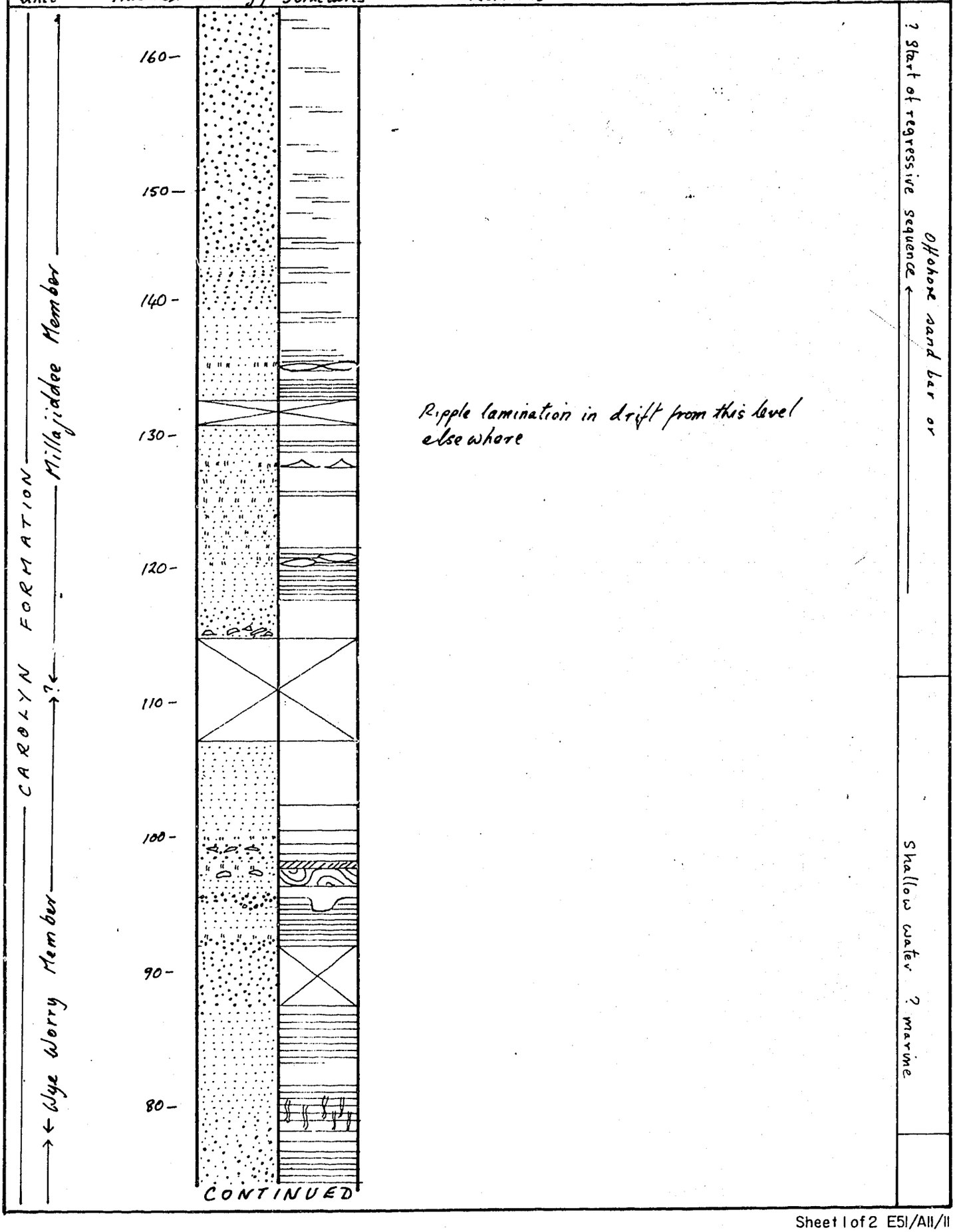


16/E51-12/13
(Part 1 of 4)

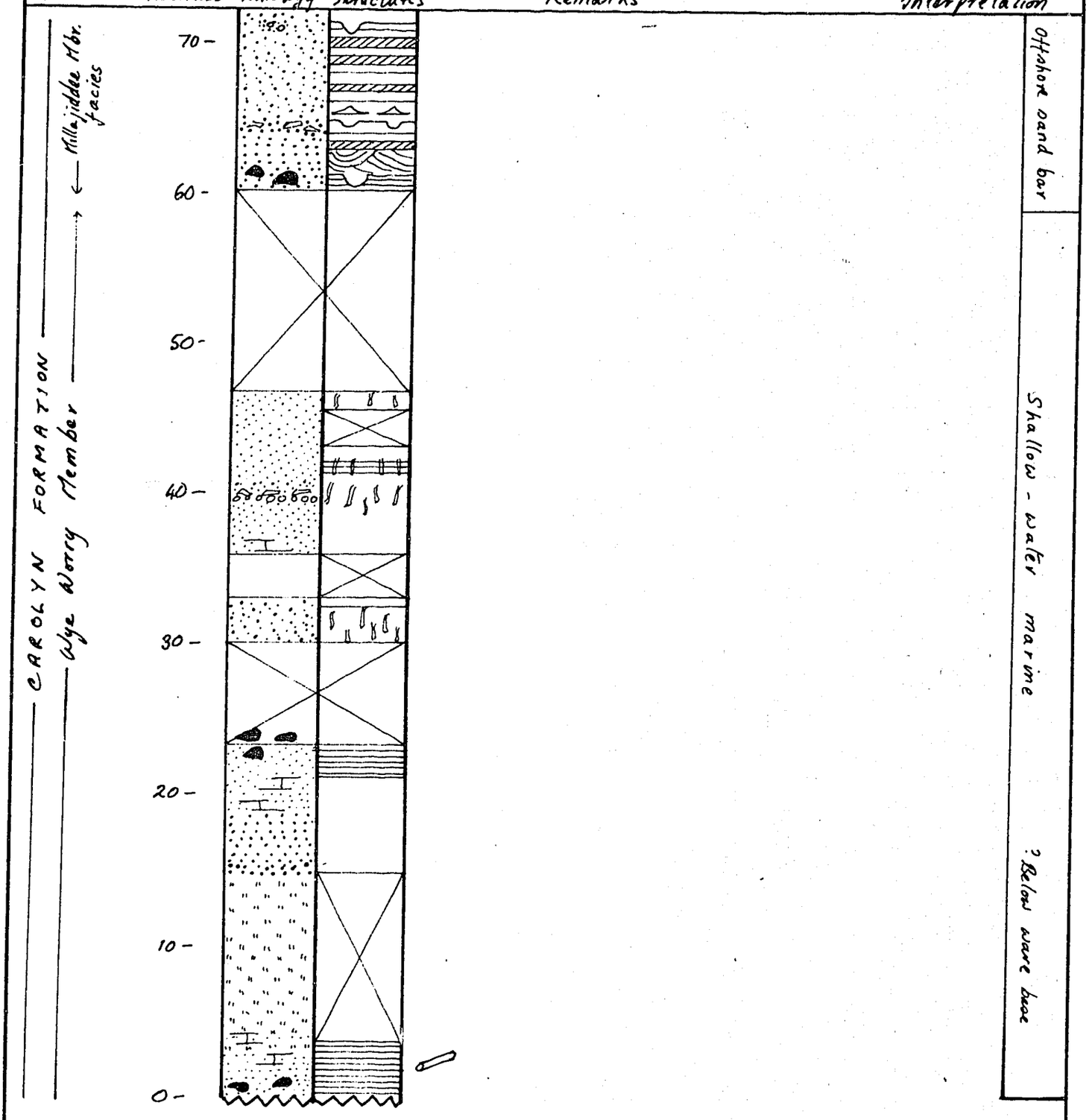
NAME CENTRAL GRANT RANGE SECTION NO. 1

LOCATION LAT. 18° 02' 45" S, LONG. 124° 04' 50" E

Unit	Thickness	Lithology	Sedimentary Structures	Remarks	Environmental Interpretation



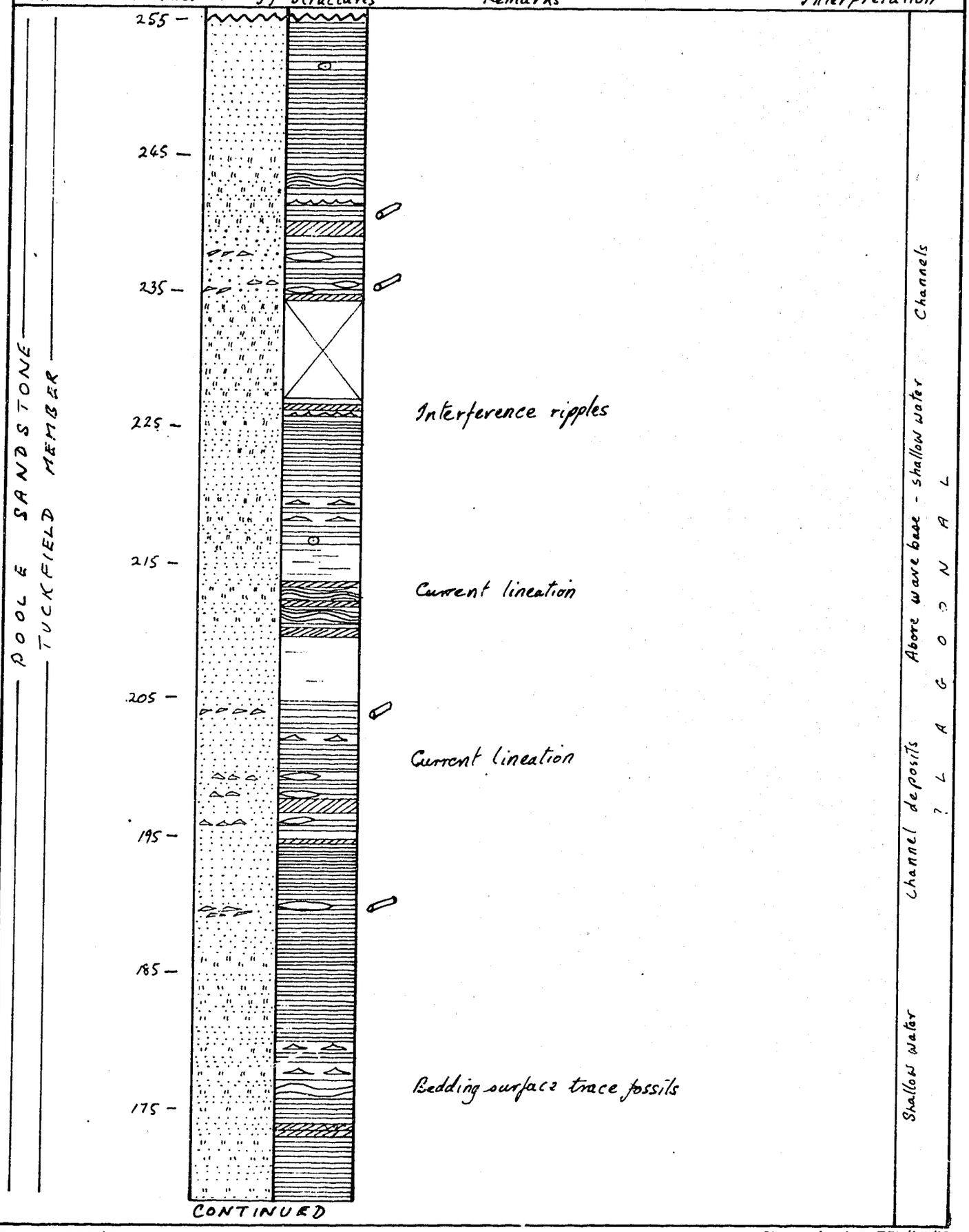
SECTION NO. 1
CONTINUED



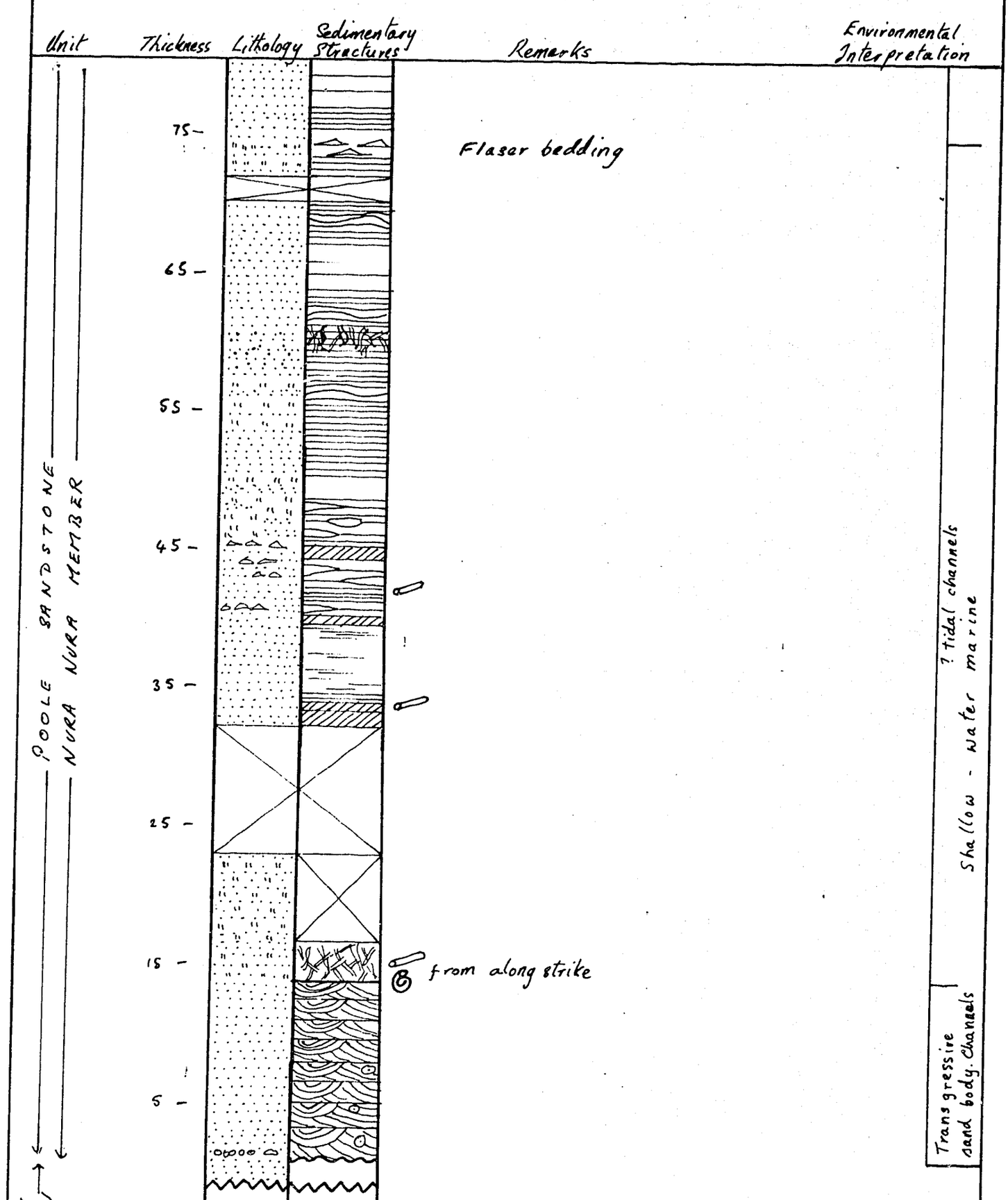
NAME SOUTHEAST GRANT RANGE, POOLE SANDSTONE COMPOSITE

SECTION NO 2

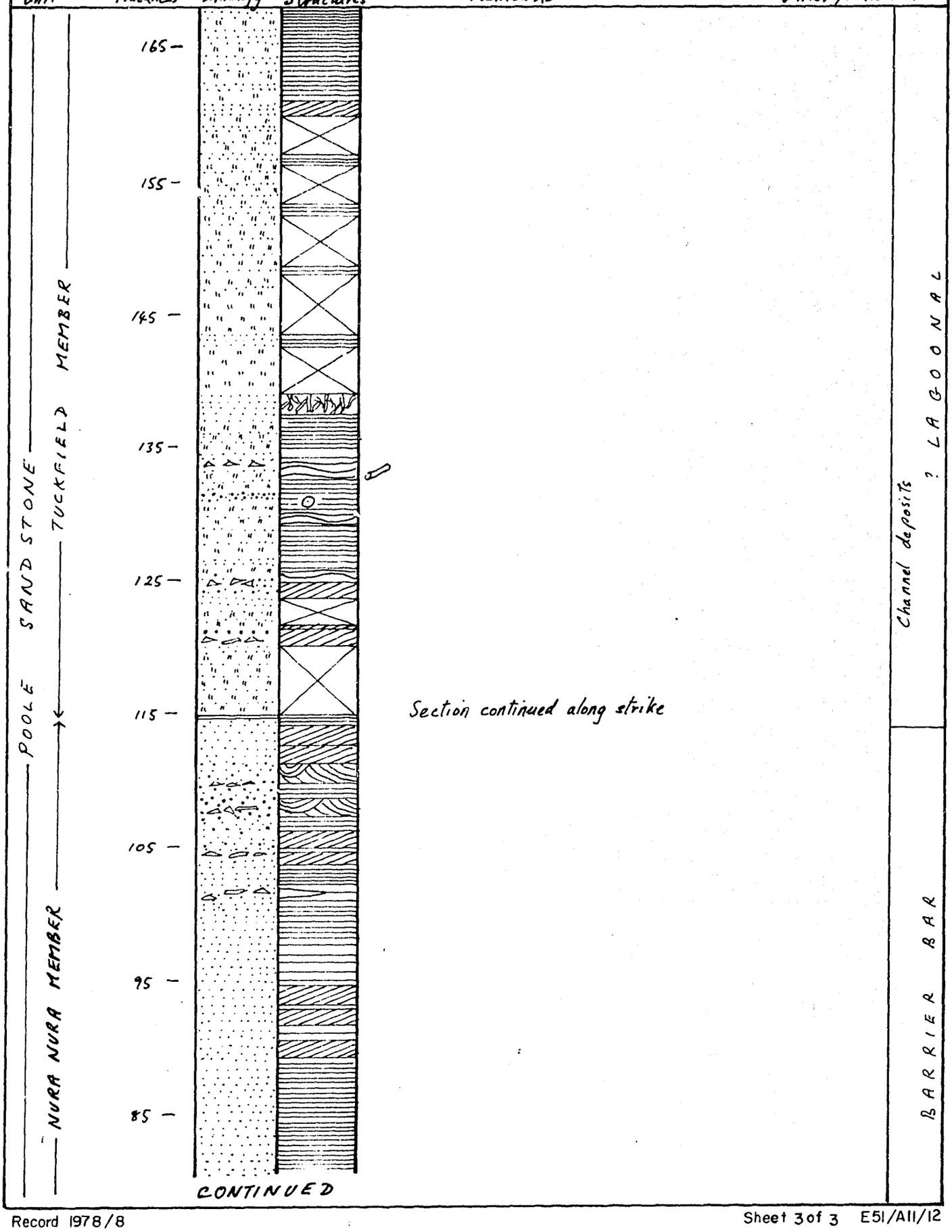
LOCATION LAT. 18°04'30"S, LONG. 124°08'30"E



SECTION NO-2
CONTINUED

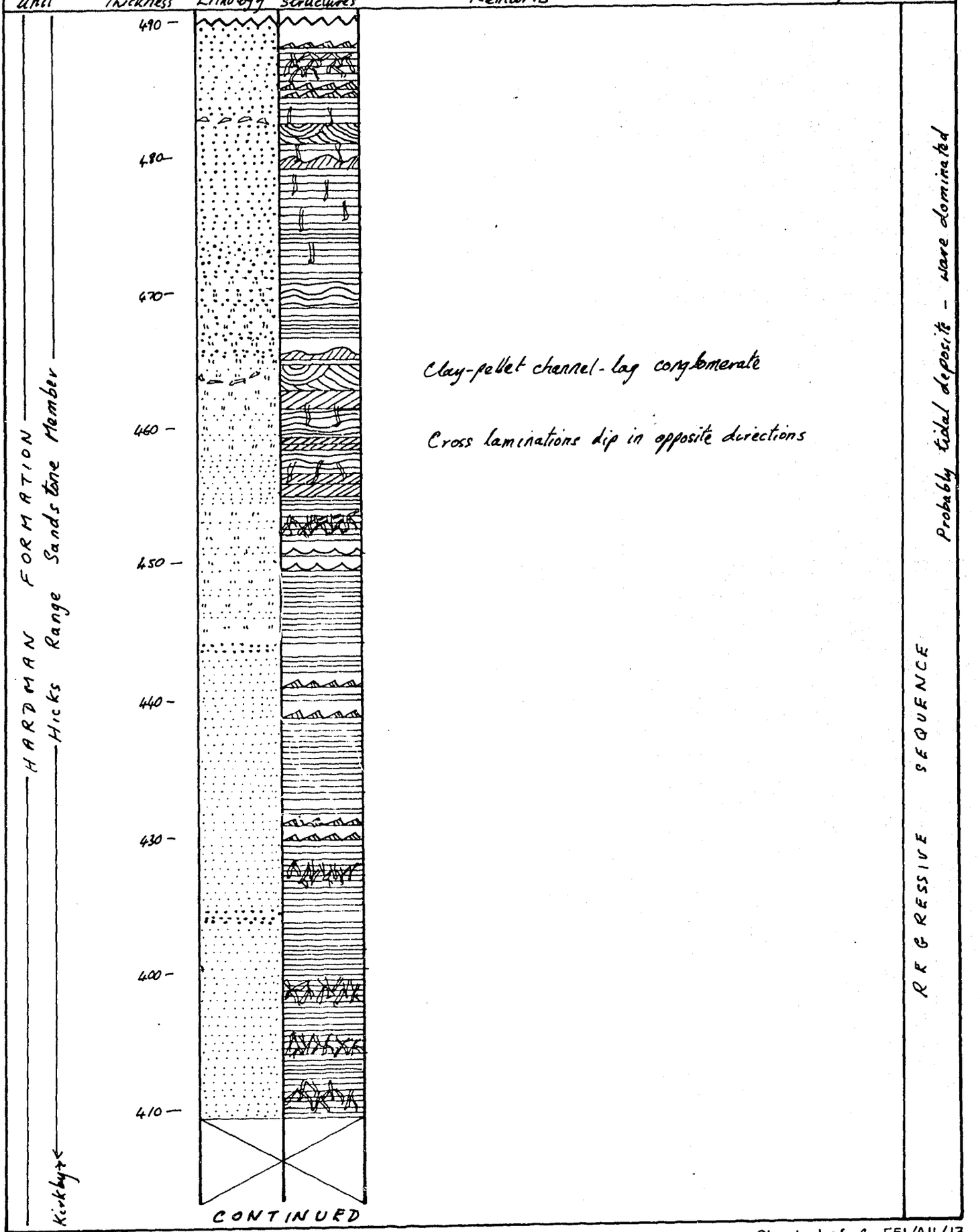


SECTION NO 2
CONTINUED

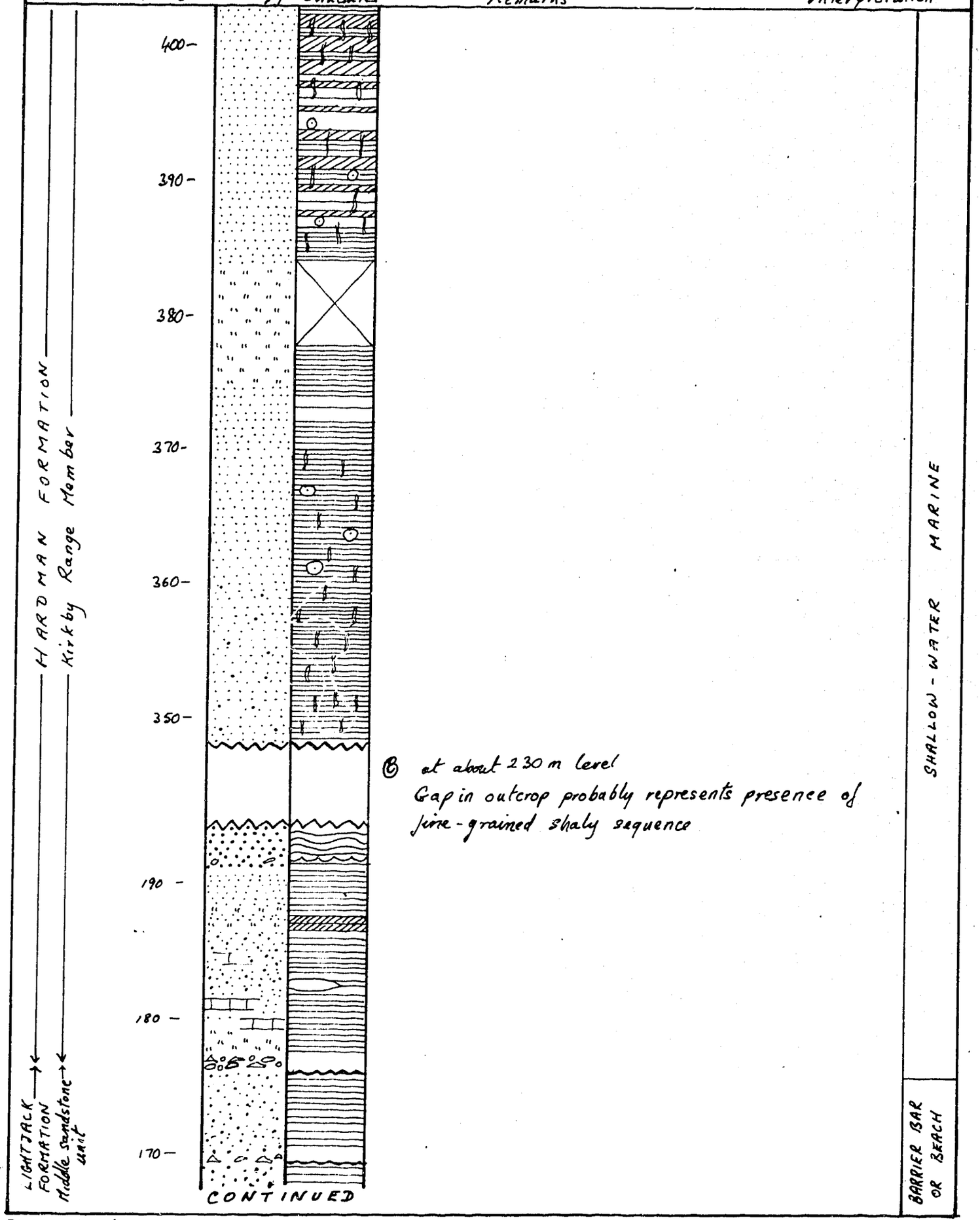


NAME LIVERINGA RIDGE SECTION No 3

LOCATION LAT. 18° 04' 40"S, LONG. 124° 03' 00"E

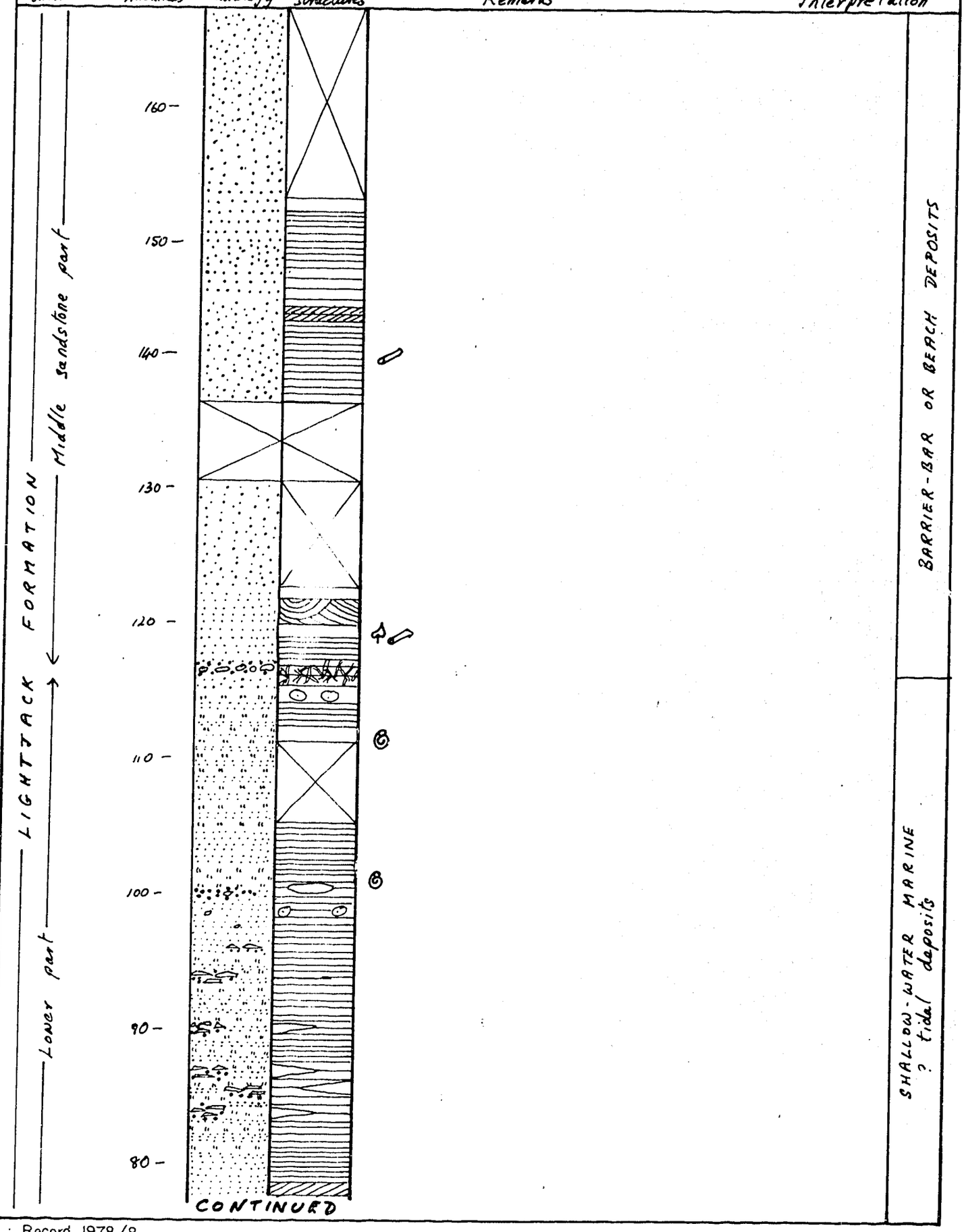


SECTION No 3
CONTINUED

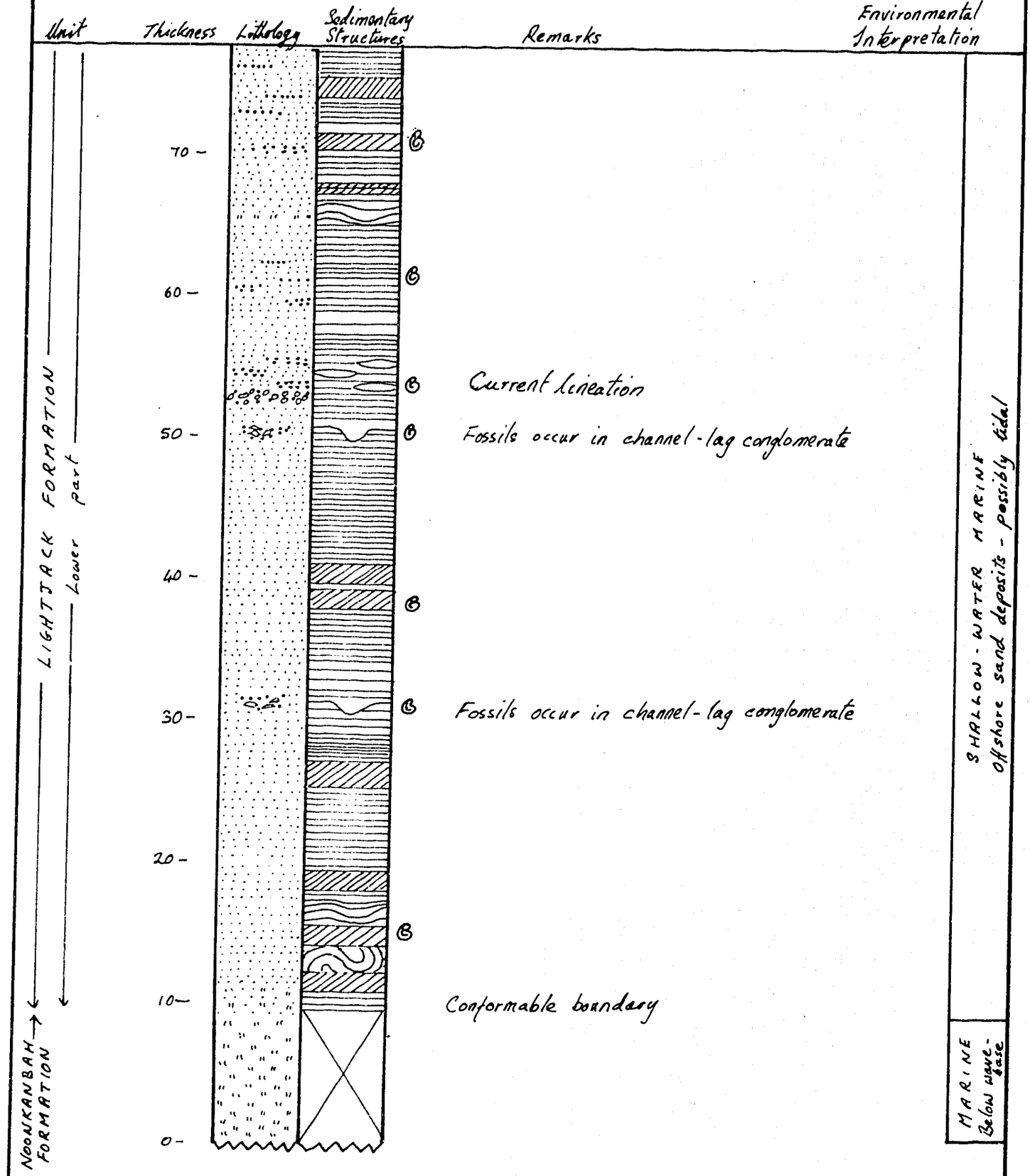


C at about 230 m level
Gap in outcrop probably represents presence of fine-grained shaly sequence

SECTION NO 3
CONTINUED

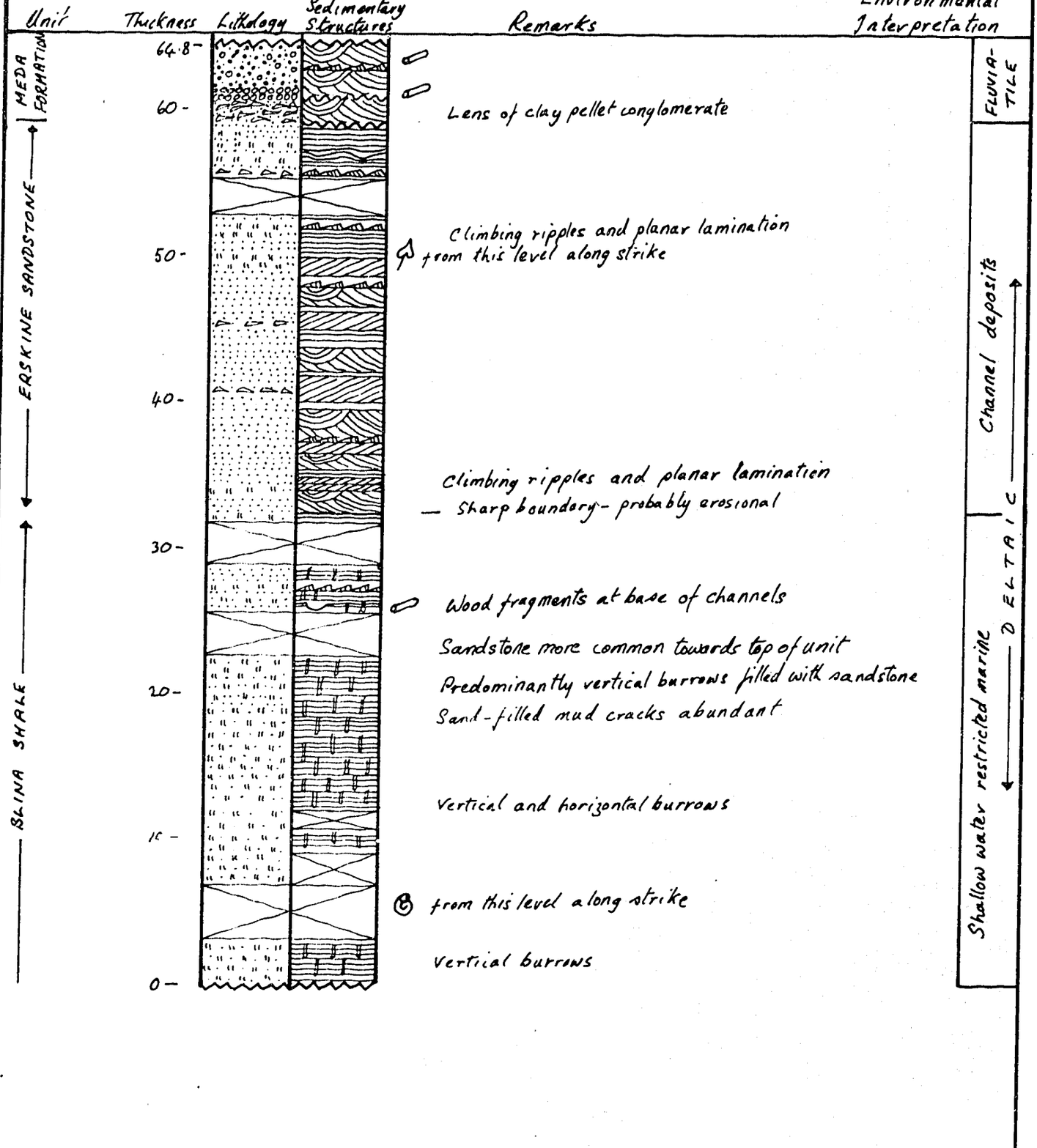


SECTION NO 3
CONTINUED



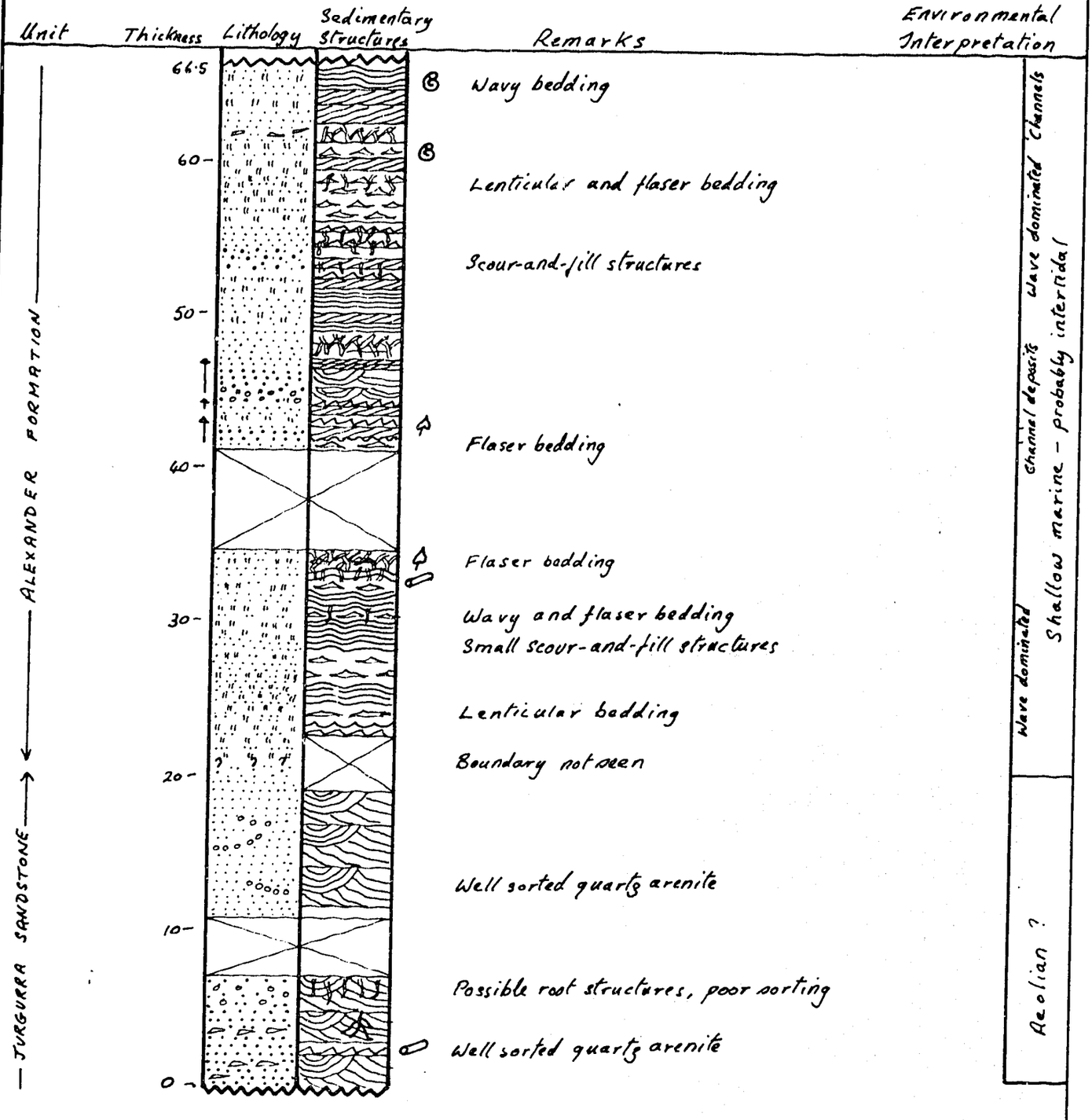
NAME ERSKINE RANGE SECTION NO 4

LOCATION LAT. 17°51'30"S, LONG. 124°21'10"E



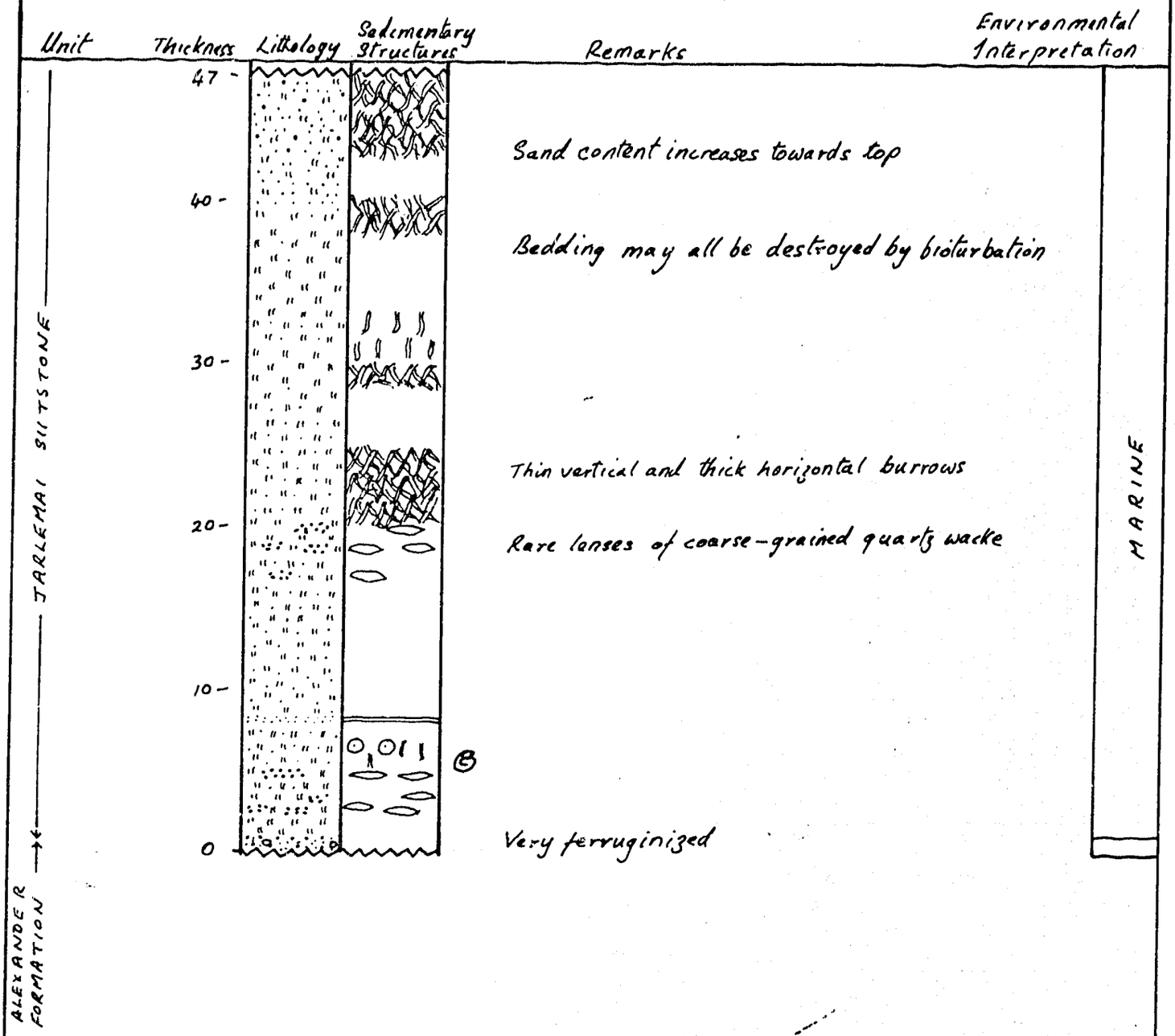
NAME MT ALEXANDER SECTION NO 5

LOCATION LAT. 18° 41' 00"S, LONG. 123° 39' 20"E

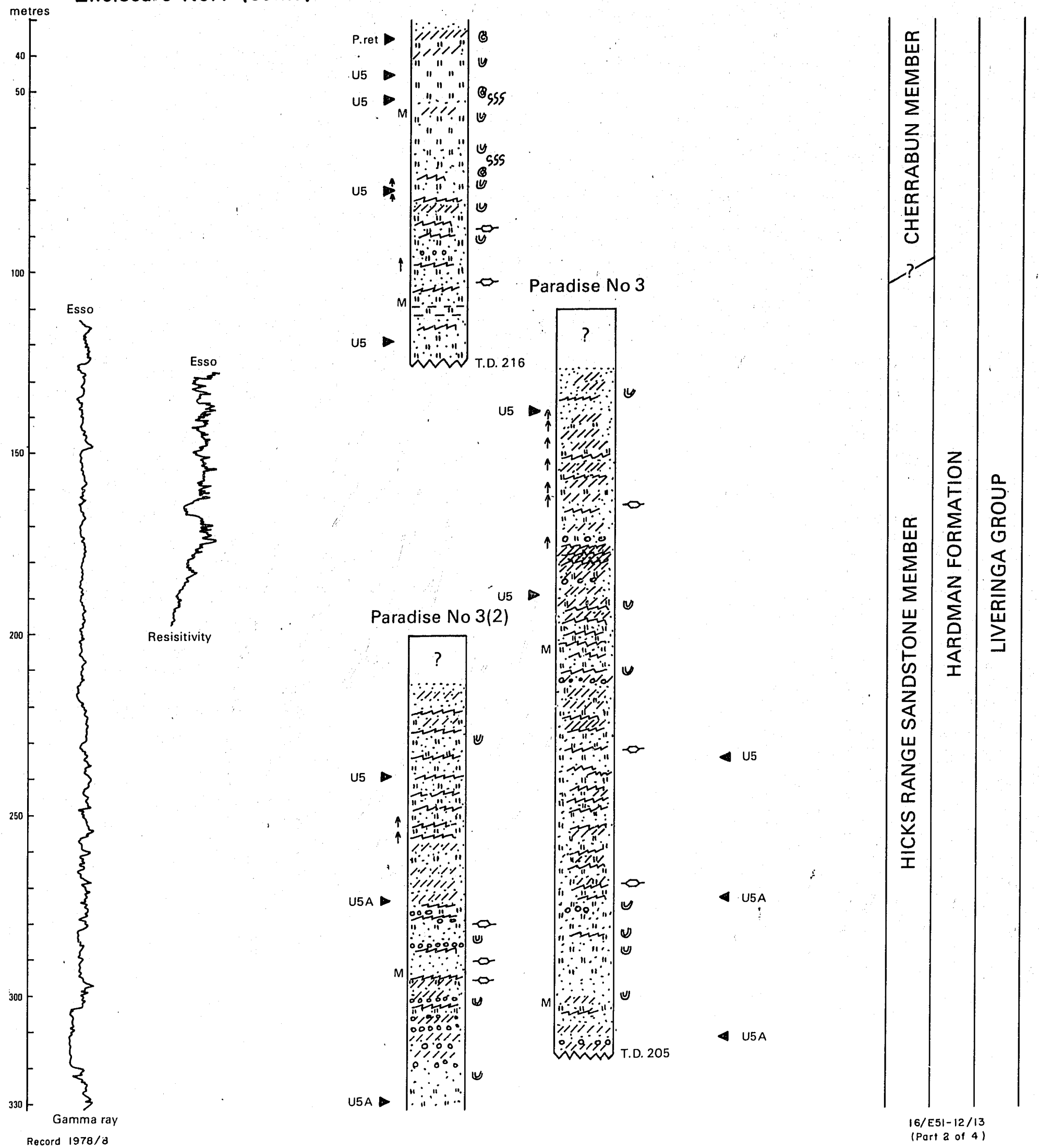


NAME Mt JARLEMAI SECTION NO 6

LOCATION LAT. 18° 42'55"S, LONG. 123° 48'40"E



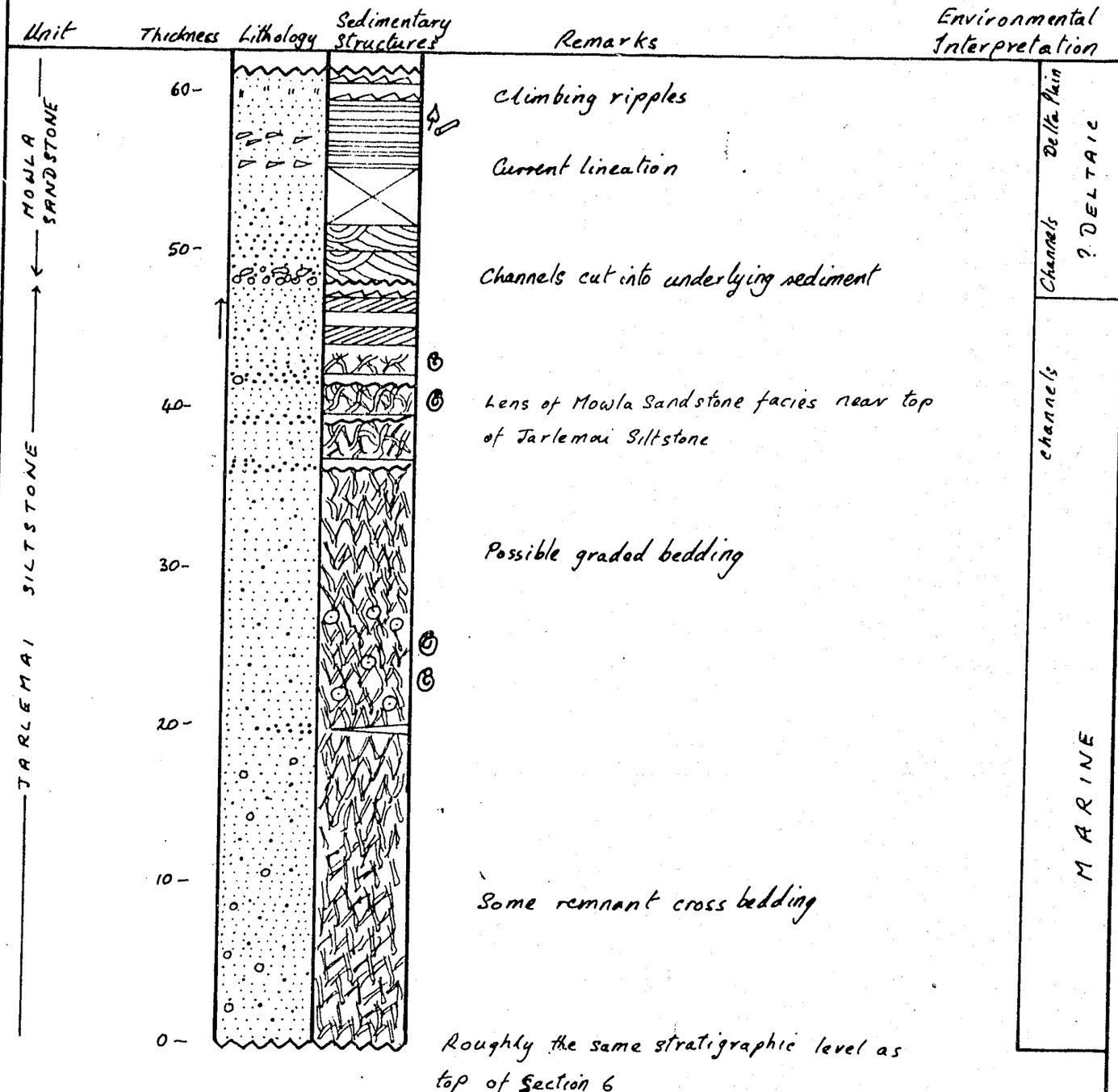
Enclosure No. 1 (cont.)



16/E51-12/13
(Part 2 of 4)

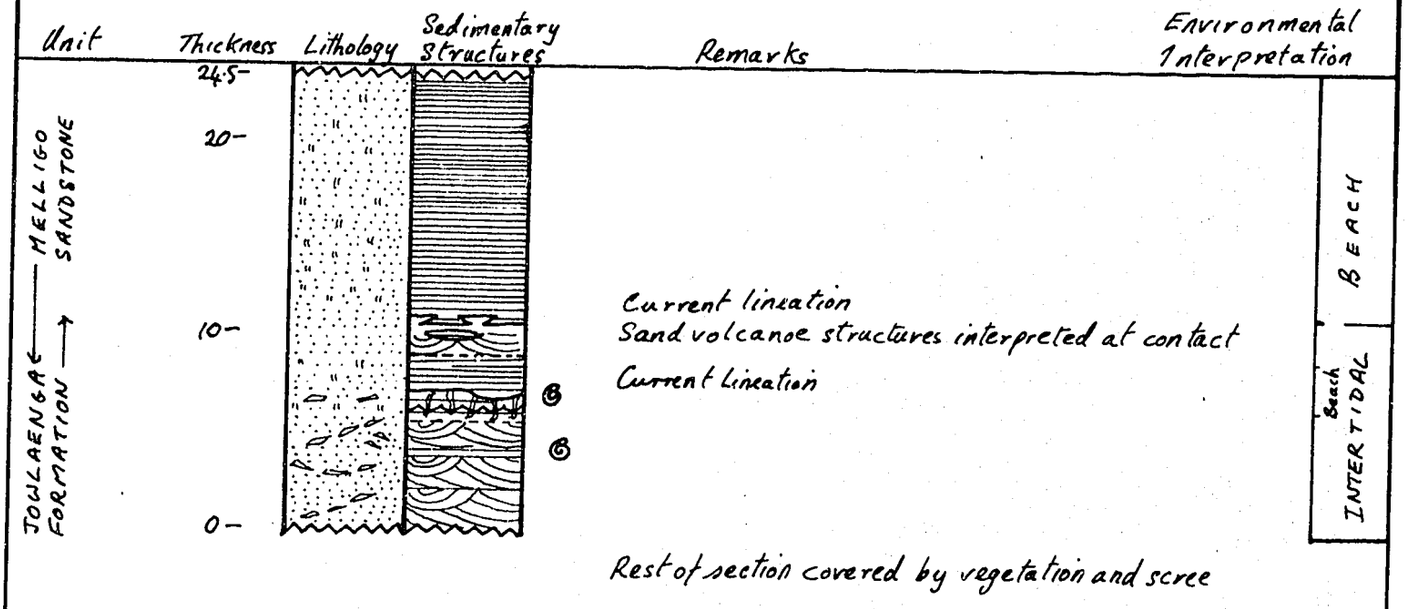
NAME MOWLA BLUFF SECTION NO. 7

LOCATION LAT. 18°49'20"S, LONG. 123°38'50"E



NAME DAMPIER HILL SECTION NO 8

LOCATION LAT. 17°28'30"S, LONG. 123°02'00"E

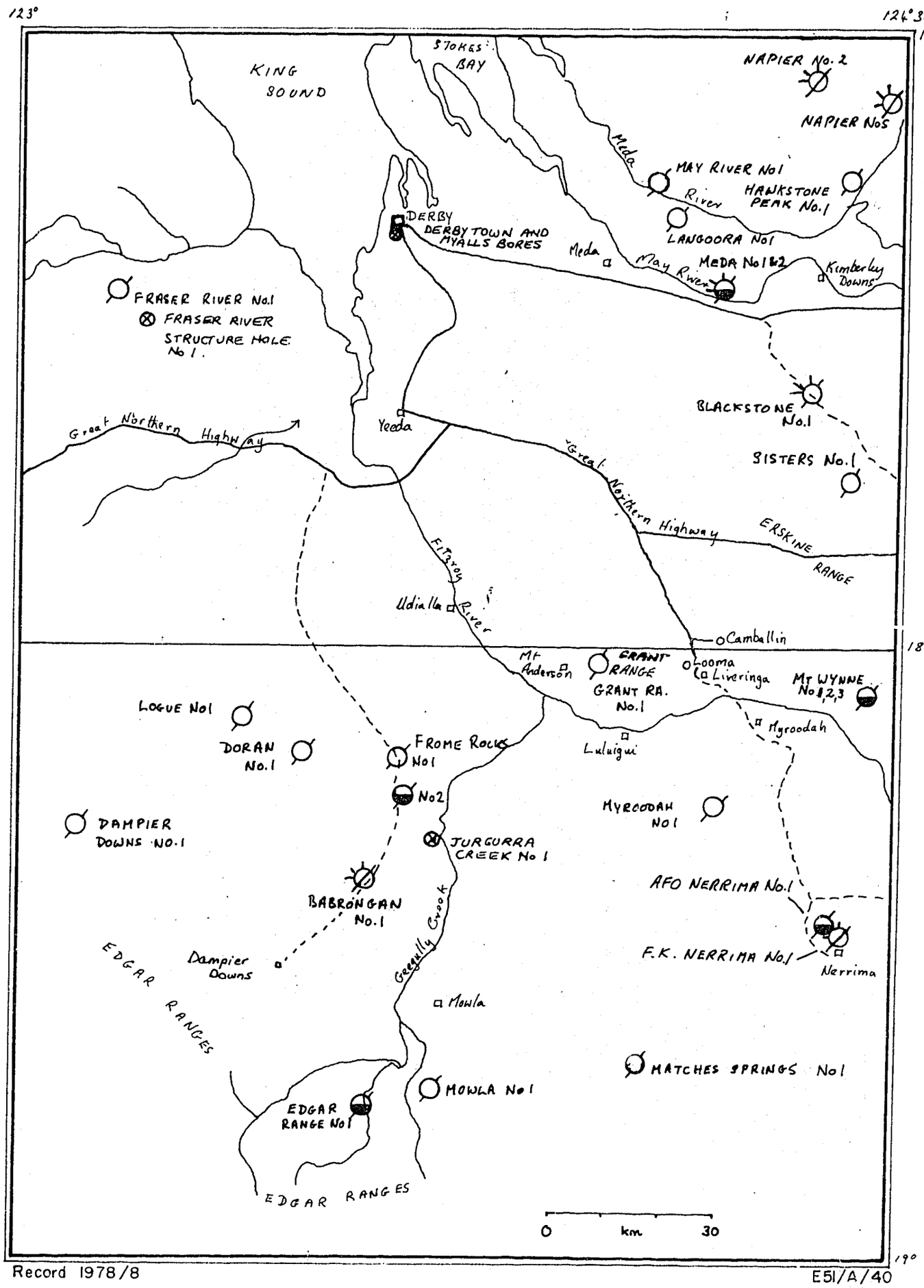


Rest of section covered by vegetation and scree

APPENDIX II - WELL SECTIONS

The positions of the wells are shown in Figure 17.

		Latitudes	Longitude	Principal Reference
1.	Babrongan No.1	18°23'23"S	123°35'37"E	WAPET (1966a)
2.	Blackstone No.1	17°35'14"S	124°21'01"E	WAPET (1967b)
3.	Dampier Downs No.1	18°18'00"S	123°06'00"E	WAPET (1957)
4.	Derby Town Bore	17°19'00"S	123°38'30"E	PLAYFORD (1957)
5.	Doran No. 1	18°10'56"S	123°29'06"E	WAPET (1968a)
6.	Edgar Range No.1	18°45'26"S	123°35'33"E	Total (1968)
7.	Fraser River No.1	17°25'04"S	123°09'39"E	WAPET (1956b)
8.	Frome Rocks No.1	18°11'48"S	123°38'42"E	WAPET (1962b)
9.	Frome Rocks No.2	18°15'15"S	123°39'35"E	WAPET (1962b)
10.	Grant Range No.1	18°01'00"S	124°00'02"S	WAPET (1956a)
11.	Hawkstone Peak No.1	17°14'45"S	124°24'26"E	WAPET (1966a)
12.	Jurgurra Creek No.1	18°19'49"S	123°42'45"E	Henderson and Others (1963)
13.	Langoora No.1	17°18'07"S	124°06'48"E	WAPET (1966a)
14.	Logue No.1	18°07'33"S	123°23'24"E	WAPET (1968b)
15.	Matches Springs No.1	18°41'28"S	124°03'11"E	Total (1970)
16.	May River No.1	17°14'50"S	124°05'01"E	WAPET (1967a)
17.	Meda No.1	17°24°00"	124°11'30"E	WAPET (1962a)
18.	Meda No.2	17°24'36"S	124°11'23"E	
19.	Mount Wynne No.3	18°06'00"S	124°27'00"E	Blatchford (1927)
20.	Mowla No.1	18°43'50"S	123°42'35"E	Total (1969)
21.	Myalls Bore	17°21'00"S	123°40'00"E	Playford (1957)
22.	Myroodah No.1	18°16'15"S	124°11'27"E	AFO (1956)
23.	Napier No.2	17°04'55"S	124°21'20"E	Lennard Oil (1970)
24.	Napier No.5	17°06'30'S	124°28'06"E	Lennard Oil (1971)
25.	Nerrima No.1 (AFO)	18°26'55"S	124°22'17"E	AFO (1955)
26.	Sisters No.1	17°43'31"S	24°25'09"E	AFO (1957)



Record 1978/8

E51/A/40

Fig. 17 Sketch map of DERBY and MT ANDERSON showing location of deep wells

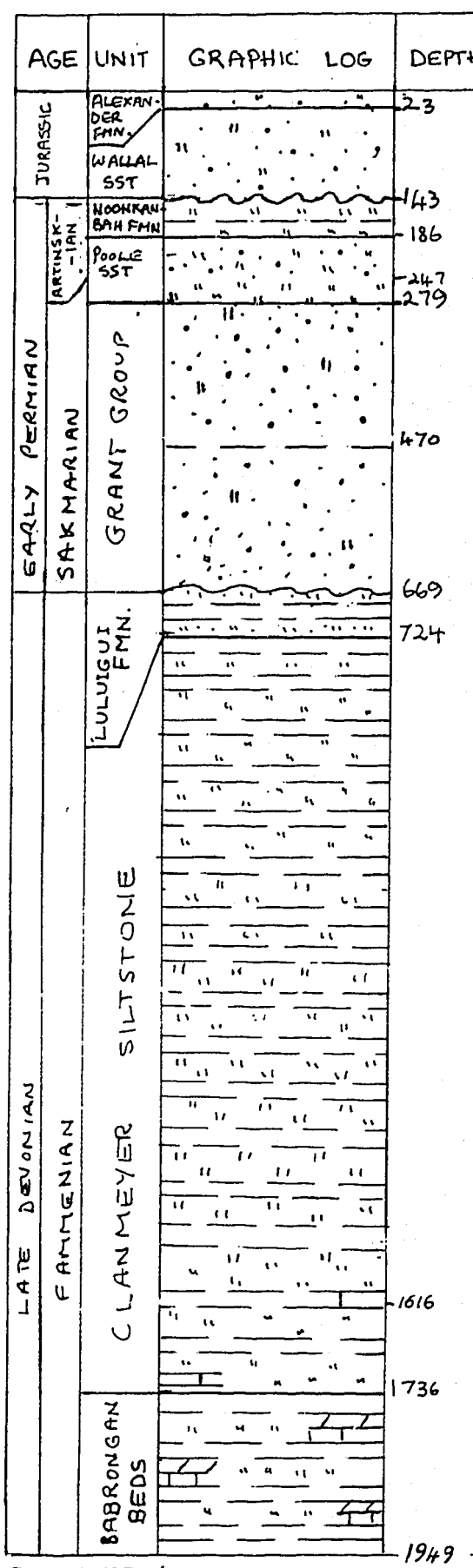
Petroleum exploration wells:

- Dry well, abandoned
- Abandoned well; show of oil
- Abandoned well; Show of oil and gas
- Abandoned well; show of gas

Other deep wells:

Fig 1 WAPET Babrongan No 1

Scale : 10mm = 100m



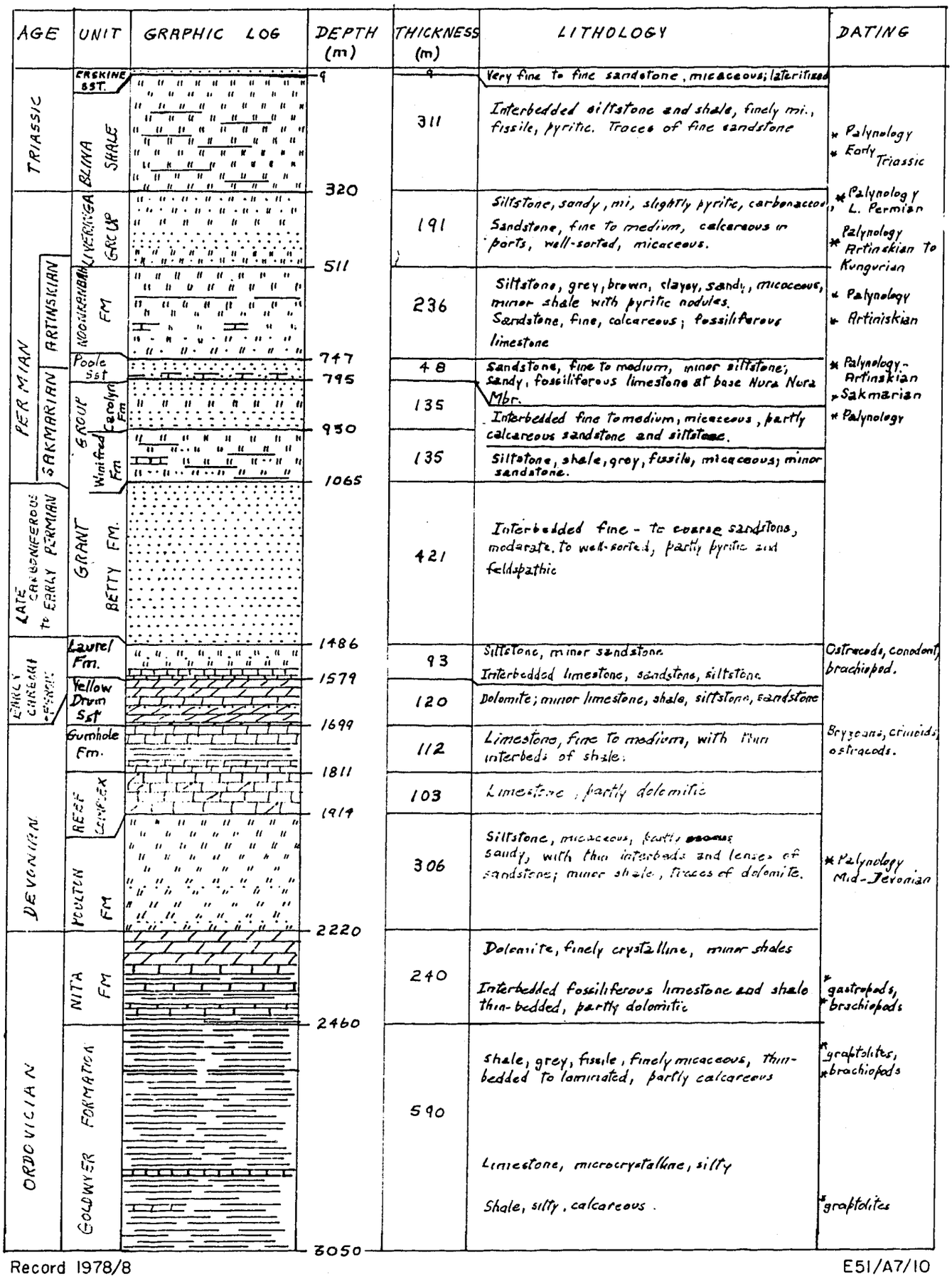
THICKNESS	LITHOLOGY	DATING
14	Interbedded fine-to coarse-grained quartzose sandstone and micaceous siltstone. Base of Alexander Formation picked from gamma ray log.	
120		
43	Interbedded shale and siltstone	
93	Interbedded siltstone and fine to coarse grained quartzose sandstone; siltstone below 247m (Nura Nura Member).	
390	Fine-to coarse-grained quartzose sandstone with thin beds of siltstone. 7m shale bed at 470m is probably Winifred Fmn	
55	Calcareous siltstone with interbedded shale and fine-to medium-grained sandstone	mid - late Fammenian
1012	Calcareous, greyish green siltstone and shale. Some limestone below 1616m.	mid-late Fammenian
213	Shale and siltstone interbedded with dolomite and dolomitic limestone	

Record 1978/8

E51/A11/17

Fig 2 WAPET BLACKSTONE No 1

Scale : 10mm = 150m.



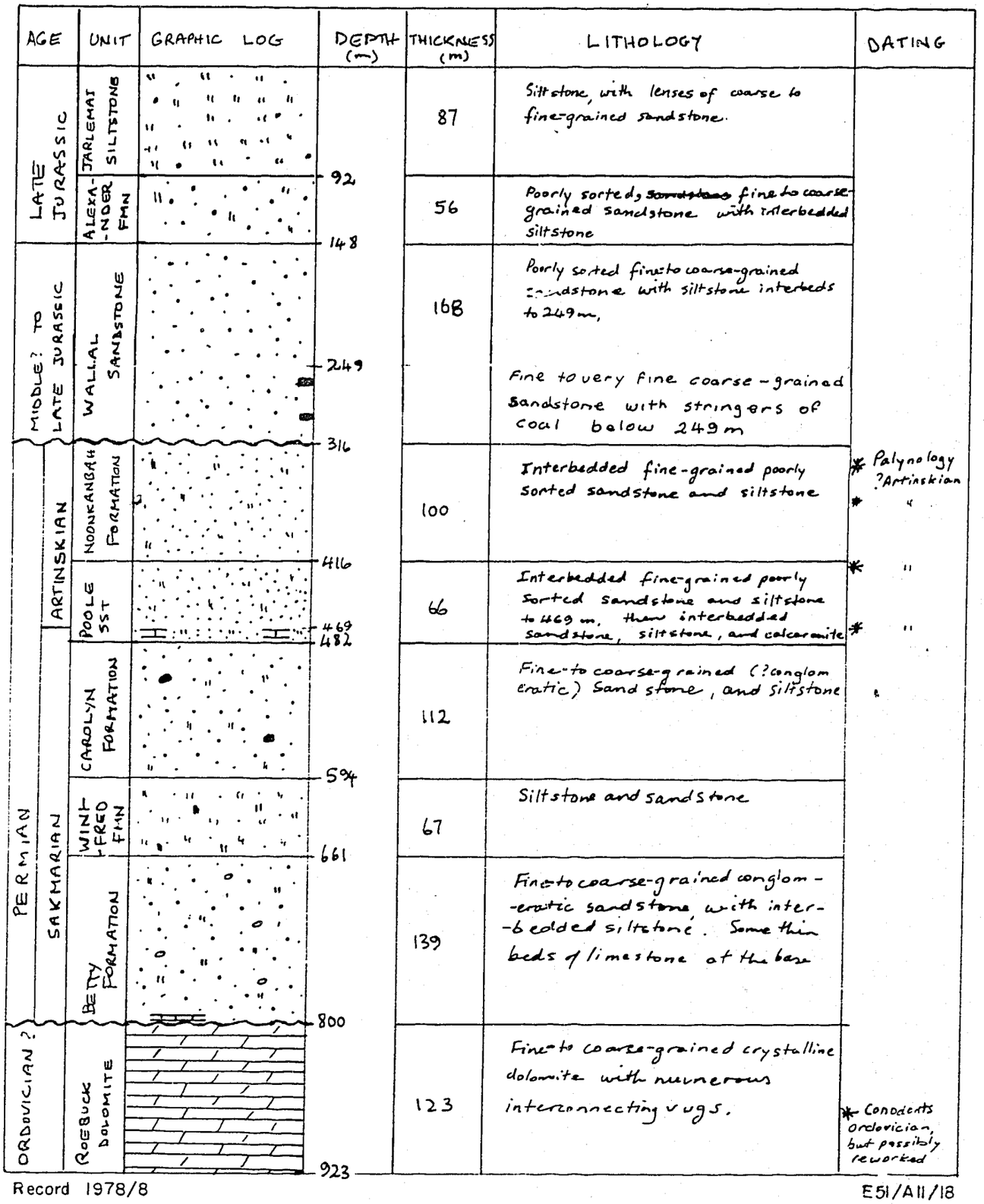
Record 1978/8

E51/A7/10

Interpretation by BMR Basin Study Group, Druce & Radke (in prep.) and the authors.

Fig 3 WAPET DAMPIER DOWNS No 1

Scale: 10mm = 50m



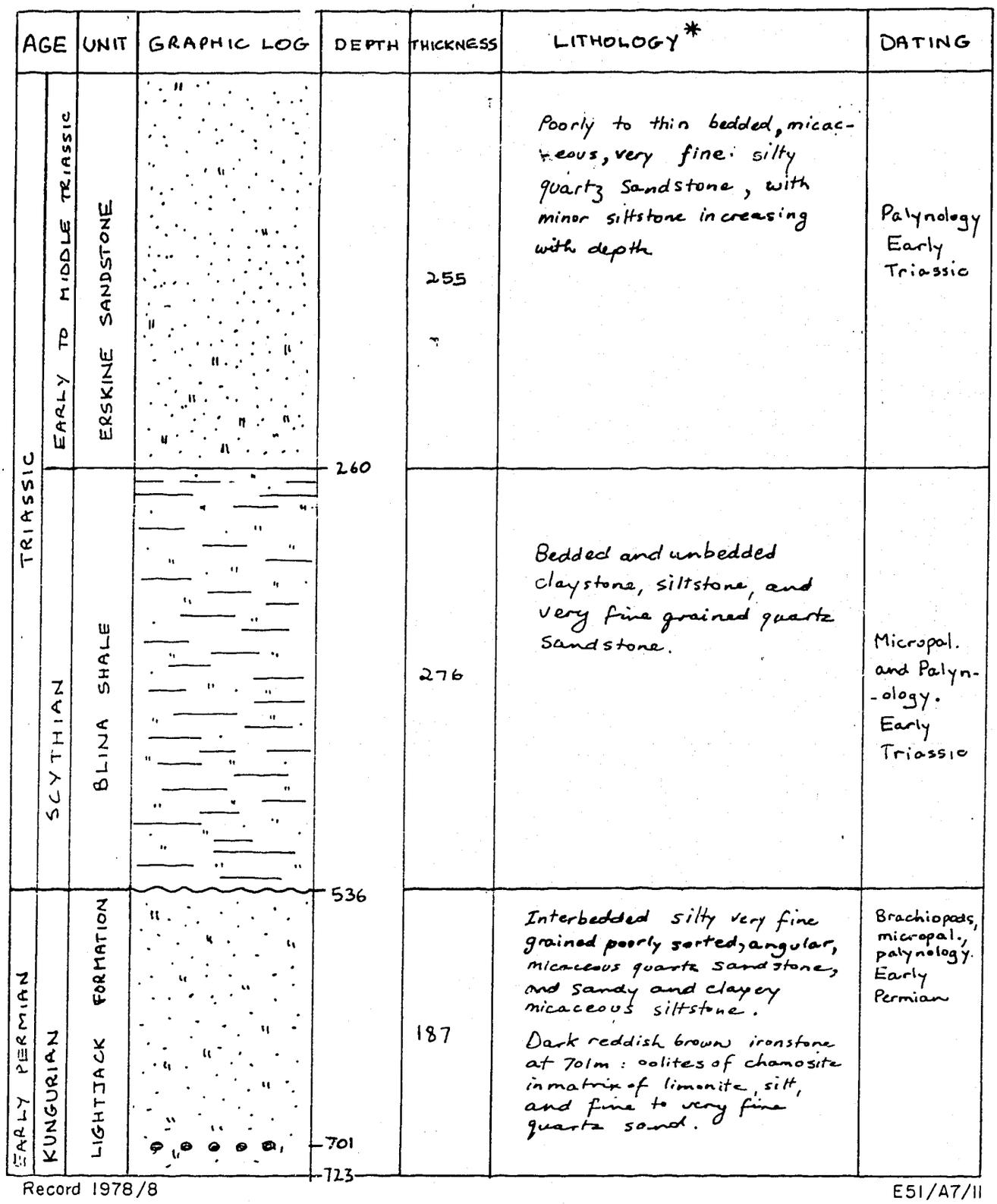
Record 1978/8

E51/A11/18

Interpretation by BMR Basin Studies Group and the authors

Fig 4 DERBY TOWN BORE

Scale:- 10mm = 40m



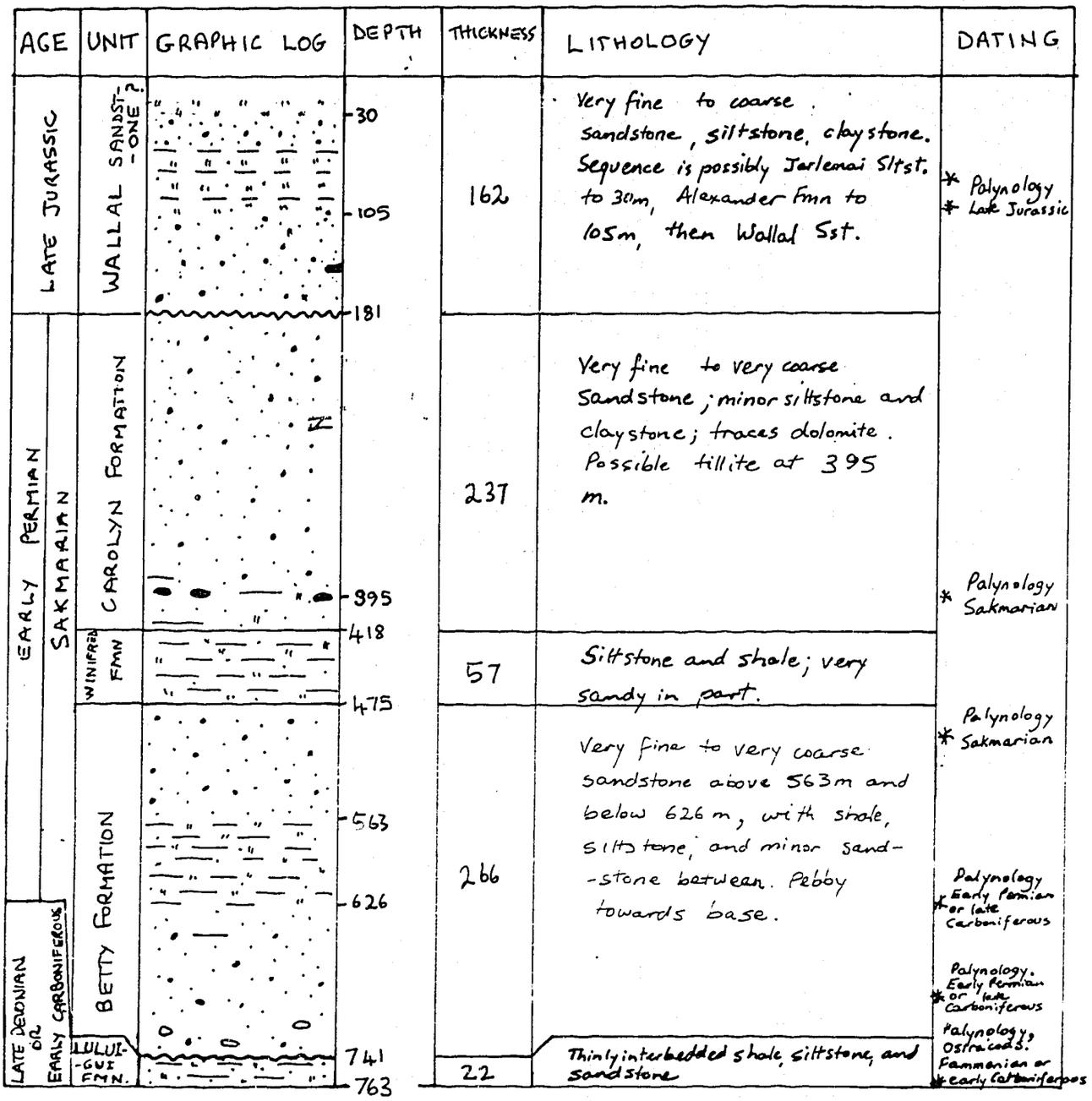
Record 1978/8

E51/A7/11

* Based on driller's log and unlabelled samples. Interpretation by Playford (1957).

Fig 5 WAPET Doran Corehole No 1

Scale : 10mm = 50 m

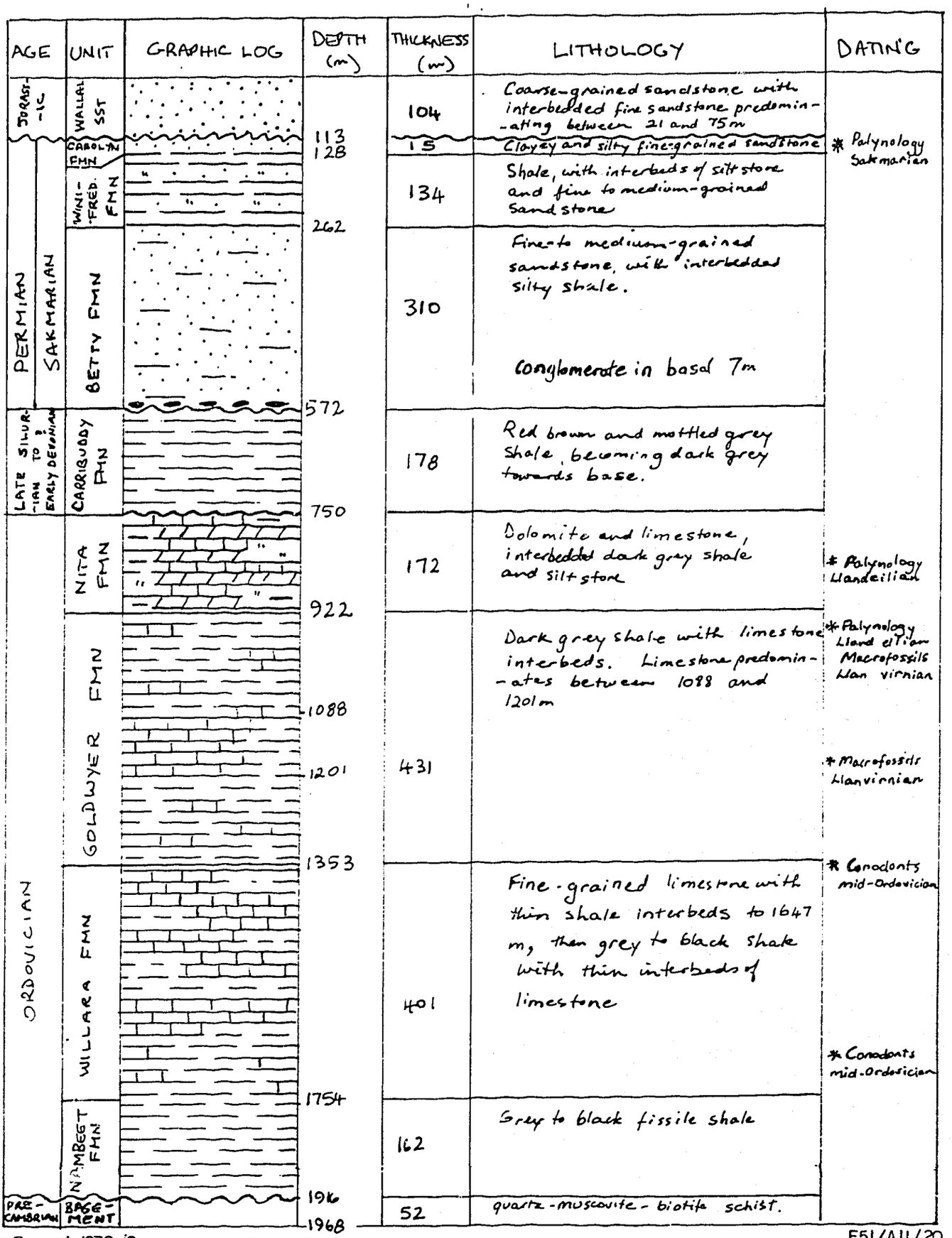


Record 1978/8

E51/A11/19

Fig 6 TOTAL EDGAR RANGE No 1

Scale : 10 mm = 100 m



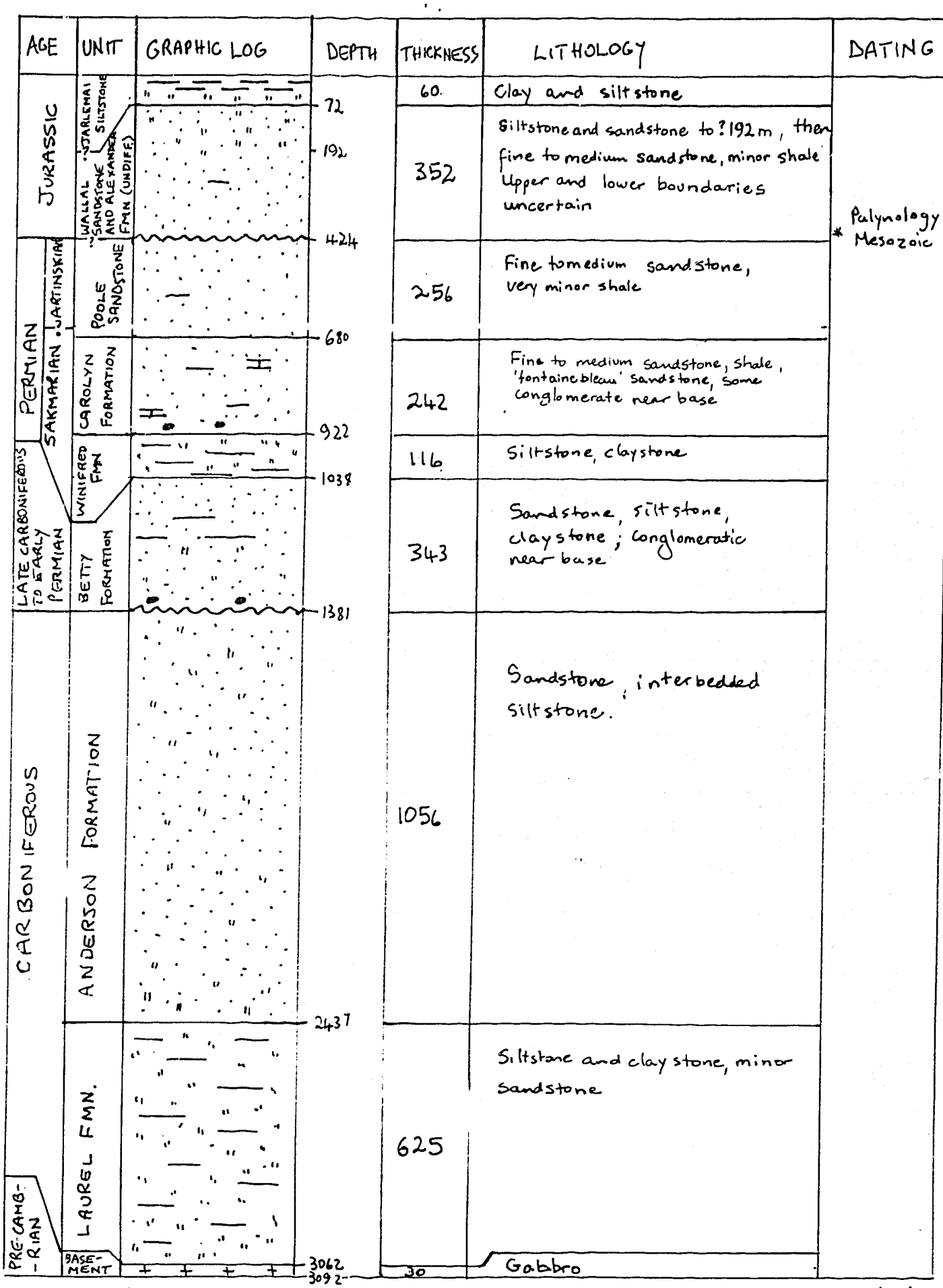
Record 1978/8

E51/A11/20

Interpretation by BMR Basin Studies Group and the authors

Fig 7 WAPET Fraser River No 1

Scale: 10mm = 150m



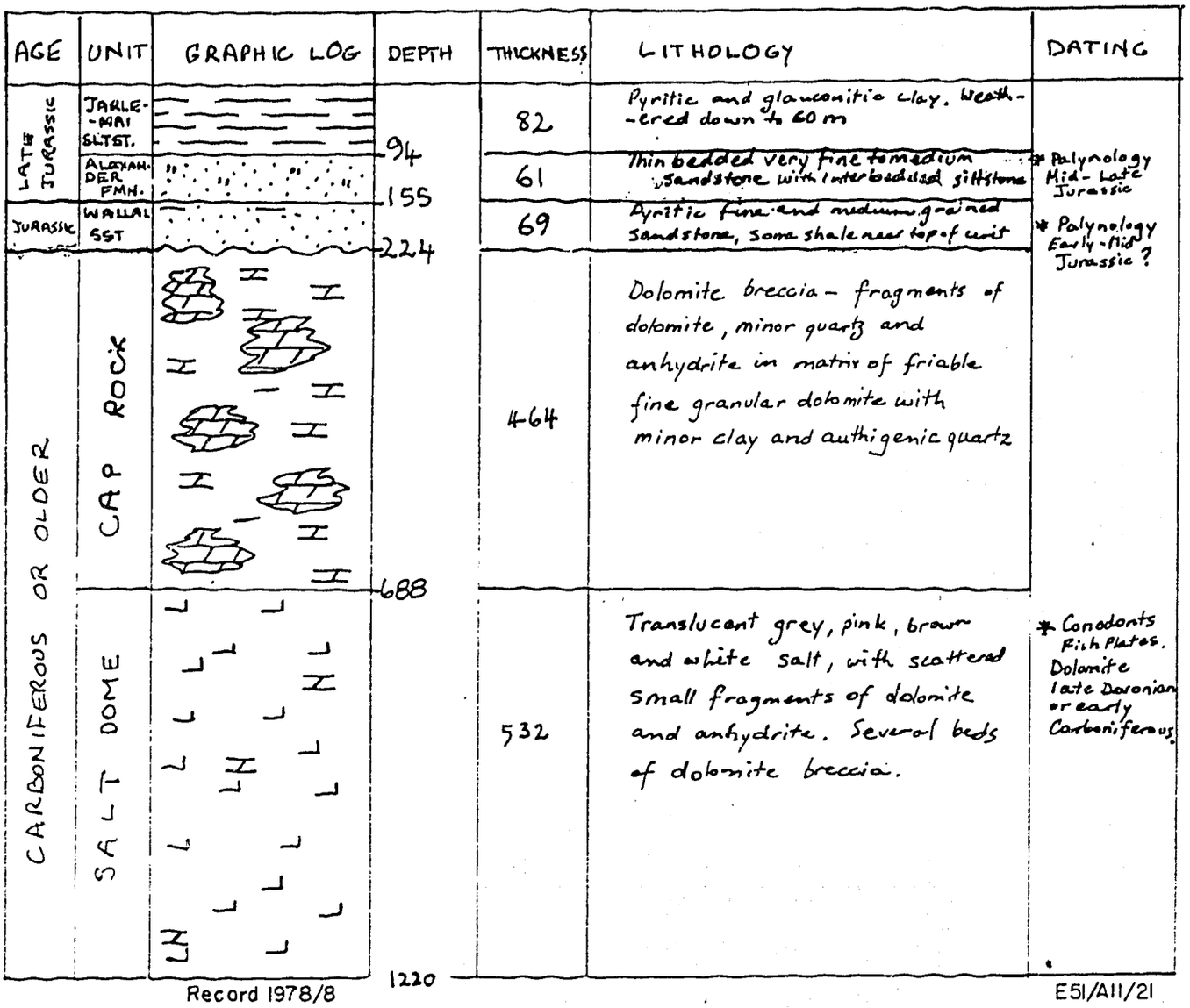
Record 1978/8

E51/A7/12

Interpretation by BMR Basin Studies Group and the authors, from composite well and gamma logs. Dating by Crespin (1955) is now considered inaccurate, and is not shown.

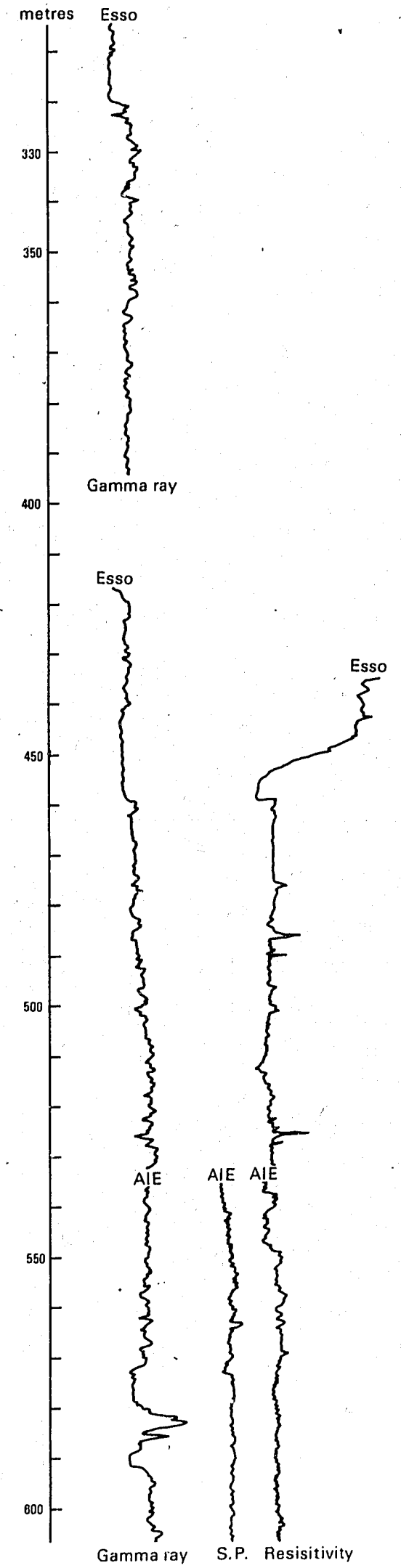
Fig 8 WAPET FROME ROCKS No 1

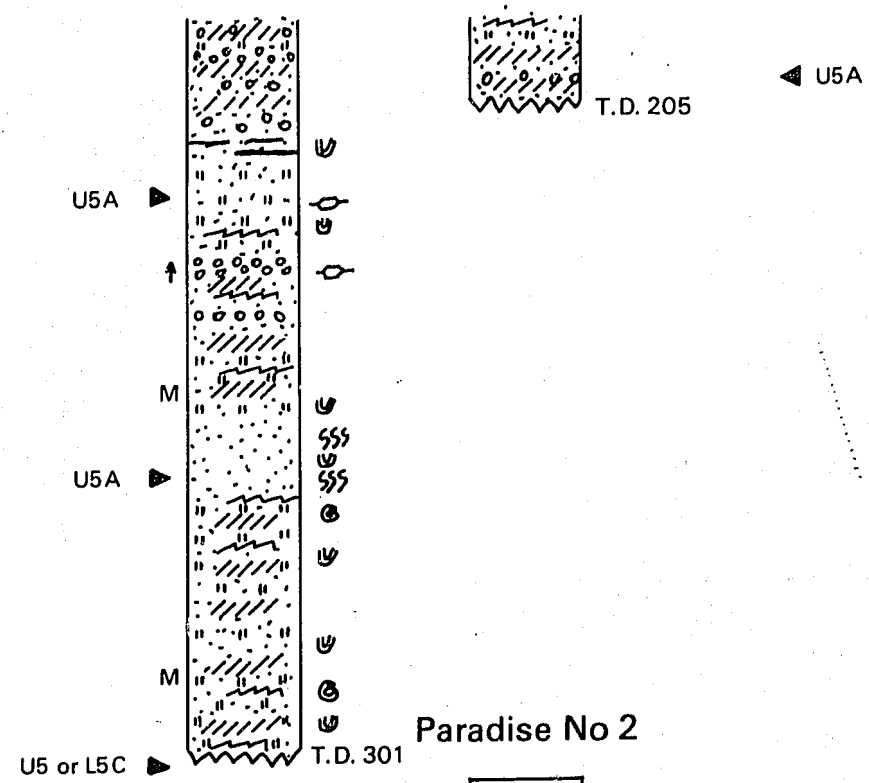
Scale :- 10 mm = 100 m

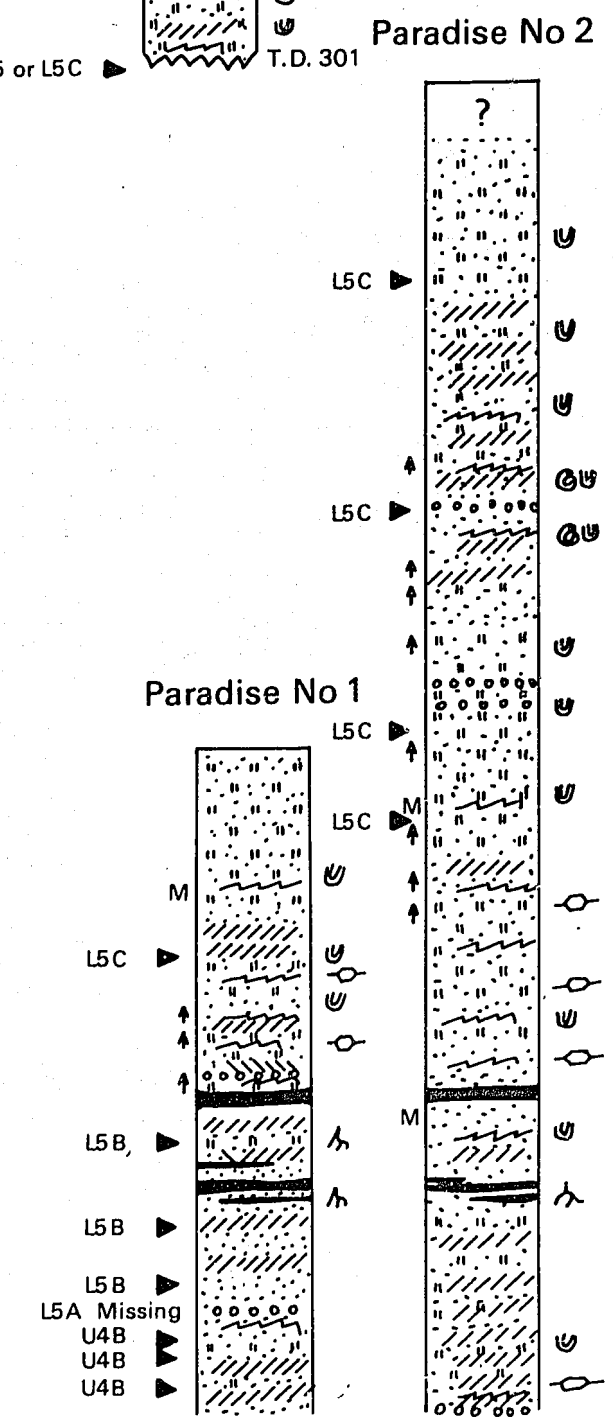


Interpretation by BMR Basin Studies Group and the authors.

Enclosure No. 1 (cont.)







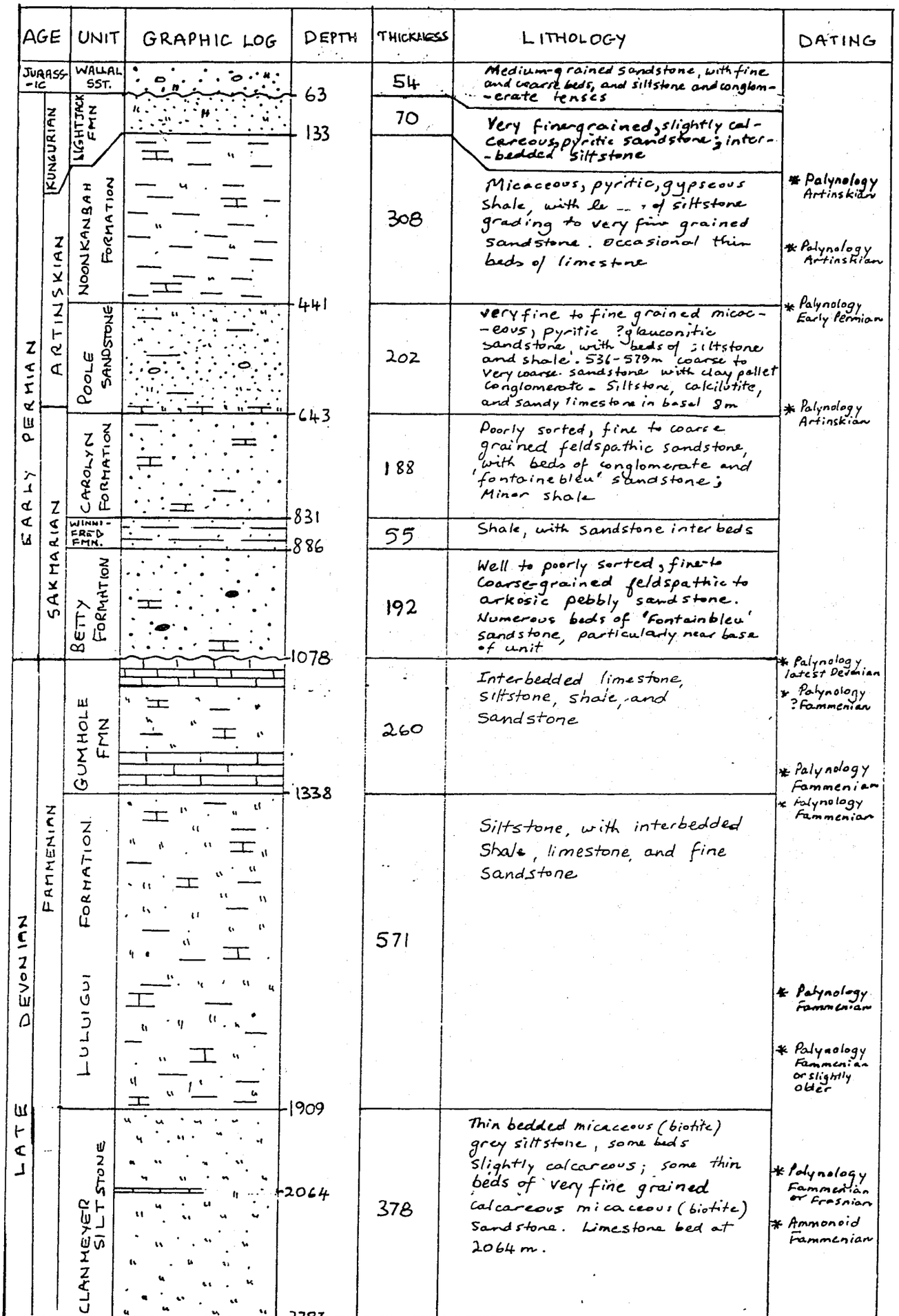
			HICKS RANGE SANDSTONE MEMBER ?
		KIRKBY RANGE MEMBER	
			HARDMAN FORMATION
LIVERINGA GROUP	LIGHTJACK FORMATION	Middle sandstone part	
		Lower part	

Record 1978/8

16/E51-12/13
(Part 3 of 4)

Fig 9 WAPET FROME ROCKS No 2

Scale:- 10mm = 100m

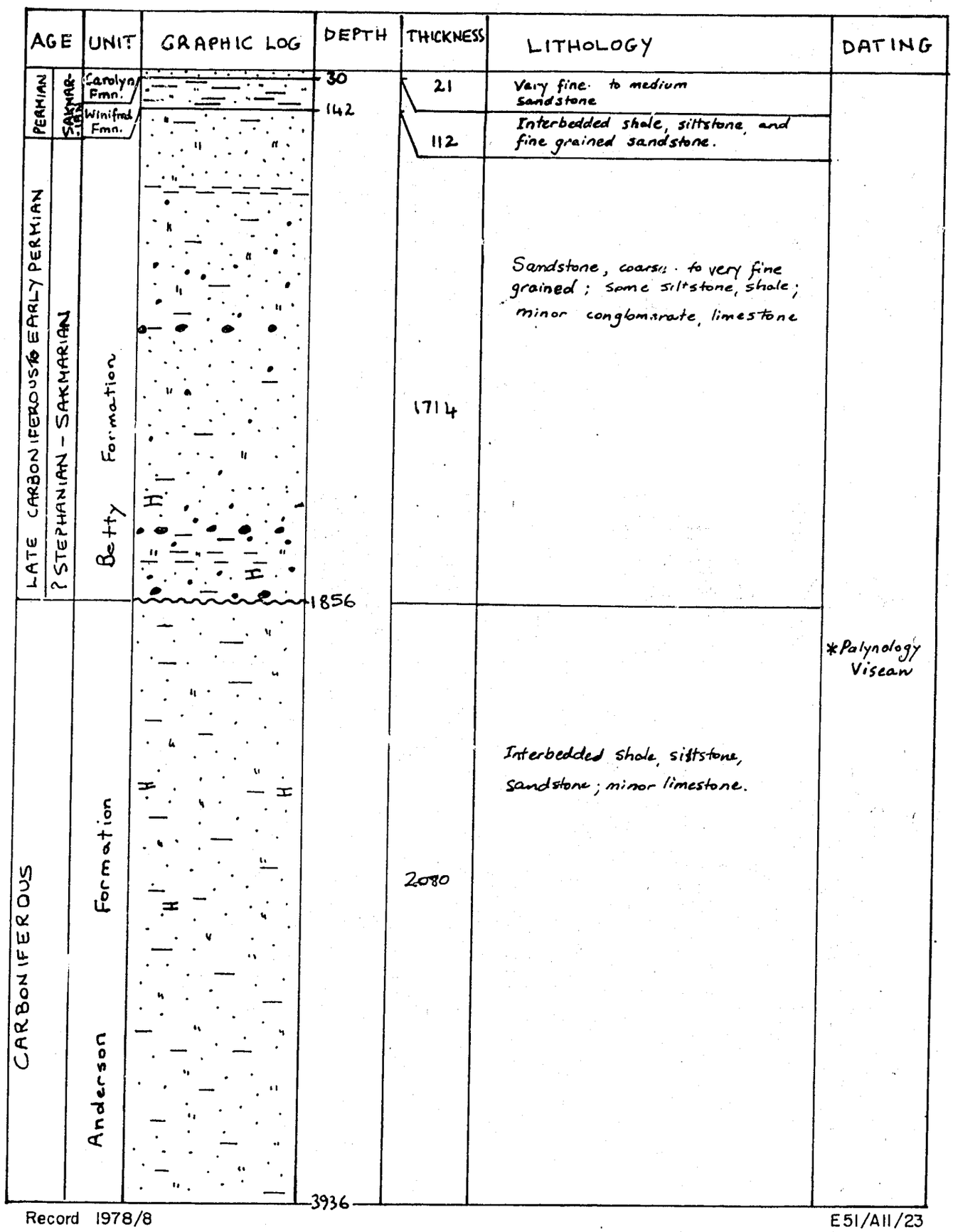


Record 1978/8 E51/A11/22

Interpretation by BMR Basin Studies Group, Druce + Radke (in prep.), and the authors.

Fig 10 WAPET Grant Range No. 1

Scale : 10mm = 200 m



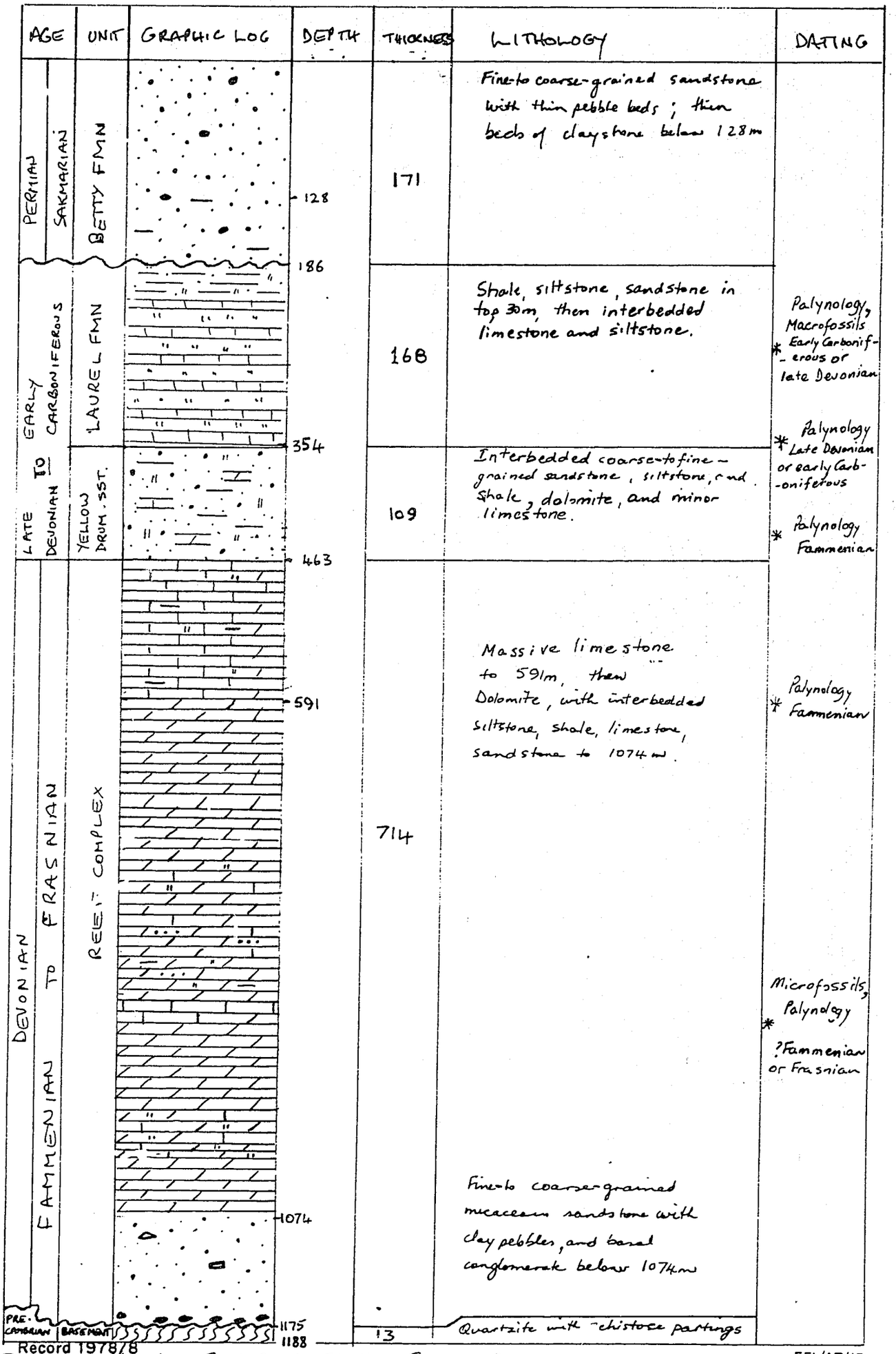
Record 1978/8

E51/A11/23

Interpretation by BMR Basin Studies Group and the authors

Fig 11 WAPET : HAWKSTONE PEAK No 1

Scale : 10mm = 50m



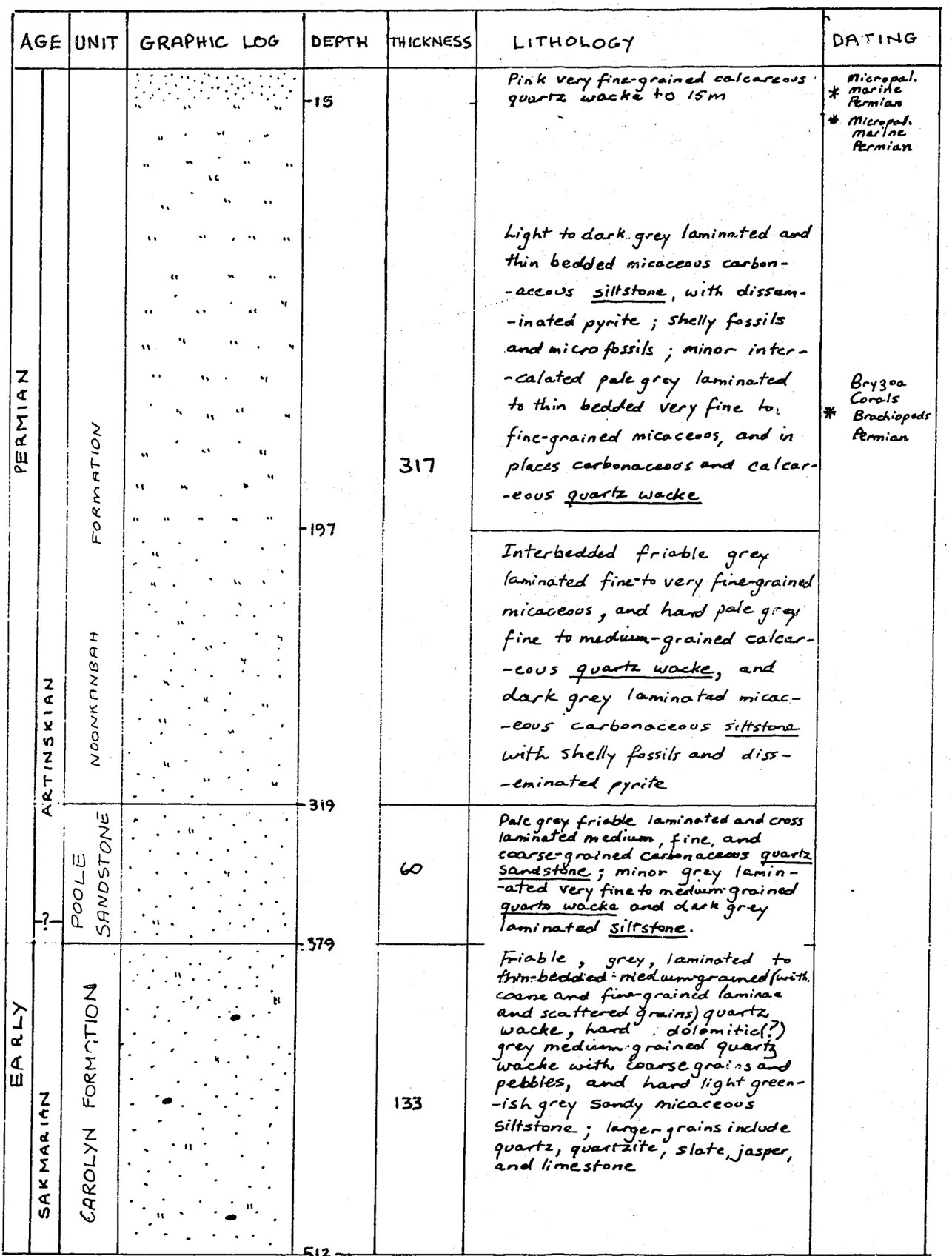
Record 1978/8

Interpretation by BMR Basin Studies Group, Druce + Radke (in prep.), and the authors

E51/A7/13

Fig 12. BMR No 1 Jurgurra Creek

Scale :- 10mm = 25m

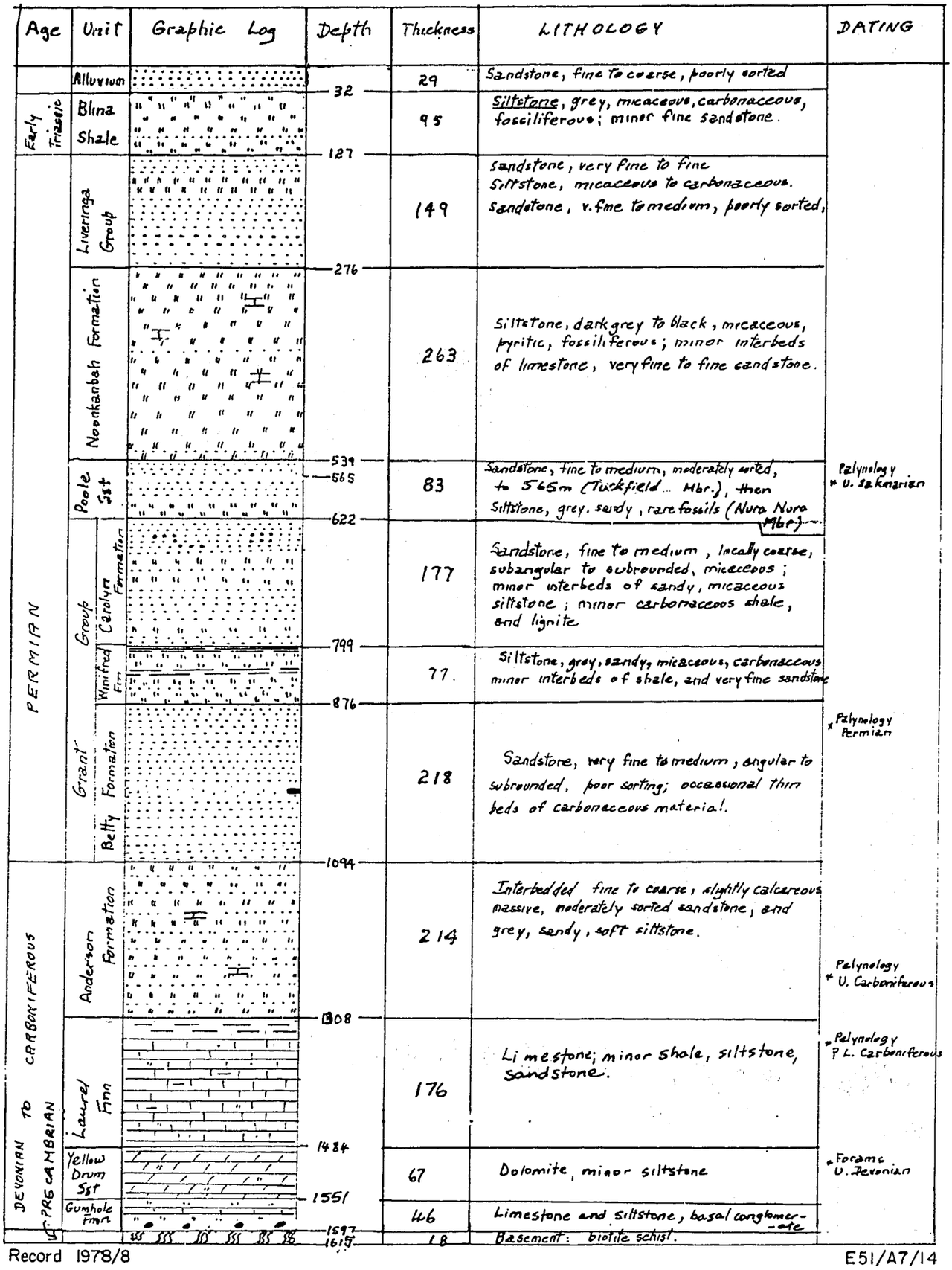


Record 1978/8

E51/A11/24

Fig 13 WAPET LANGOORA 1

Scale:- 10mm = 80m



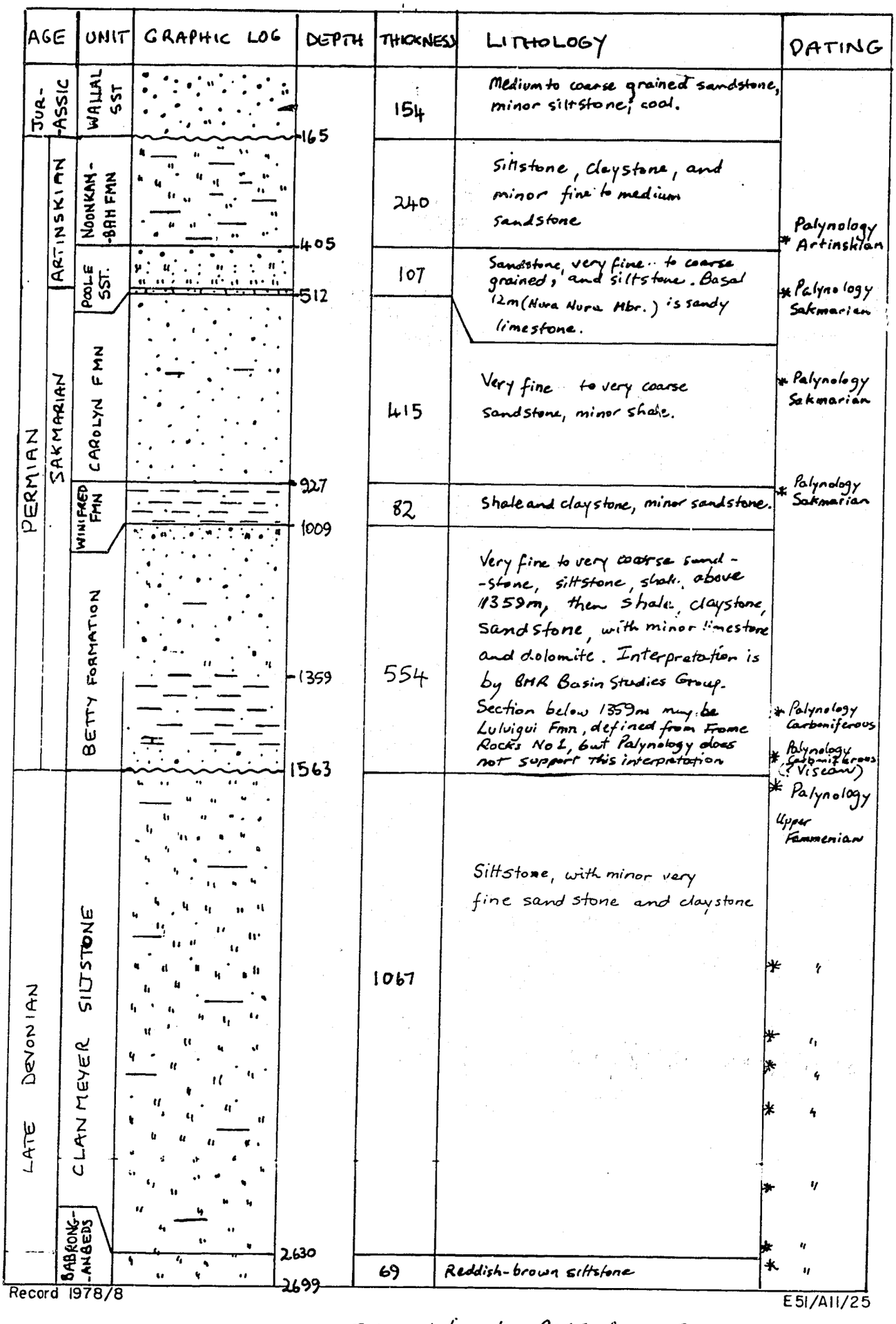
Record 1978/8

E51/A7/14

Interpretation by BMR Basin Studies Group, Druce & Radke (in prep.), and the authors.

Fig 14 WAPET Logue No 1

Scale : 10 mm = 120 m



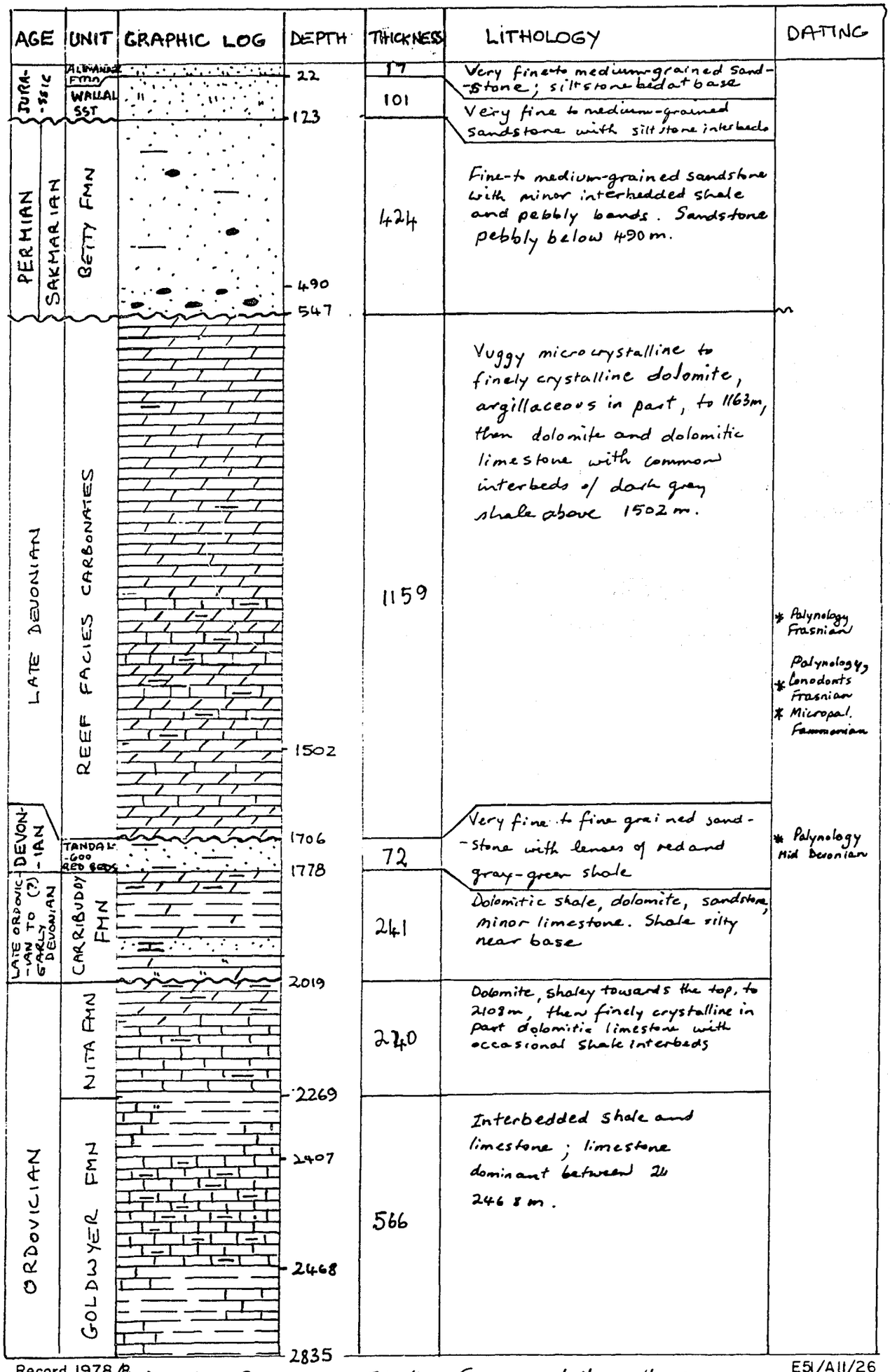
Record 1978/8

E51/A11/25

Interpretation by BMR Basin Studies Group and the authors.

Fig 15 TOTAL MATCHES SPRINGS No 1

Scale :- 10 mm = 120 m



Record 1978/8

Interpretation by BMR Basin Studies Group and the authors

E51/A11/26

Fig 16 WAPET MAY RIVER No 1

Scale :- 10mm = 100m.

AGE	UNIT	GRAPHIC LOG	DEPTH (m)	THICKNESS (m)	LITHOLOGY	DATING
	Alluvium		20		Laterite.	
Triassic	Blina Shale		37	126	Siltstone, sandy ; minor fine sandstone. Sandstone, fine to medium, micaceous, lignitic, minor siltstone, grey, carbonaceous, sandy	
PERMIAN Sakmarian	Liveringa Group		163	276	Siltstone, grey, soft, finely micaceous, lignitic, pyritic, sandy; minor sandstone grey, fine, calcareous. Limestone, coquinoidal.	bryozoans, brachiopods
	Artinskian Noonkanbah Fm		439	82	Sandstone, fine to medium; Limestone, fossiliferous, sandy (Nura Nura Mbr)	bryzoa, brachiopods
	Poole Sst		521	159	Interbedded sandy, grey siltstone and fine well sorted sandstone, Medium - coarse, pebbly sandstone	
	Group Carolyn Fm		680	106	Shale, grey, fissile, finely micaceous; minor sandy siltstone; very fine sandstone.	
	Winifred Fm		786	183	Sandstone, fine-medium to v.coarse, poor sorting, calcareous in places; minor siltstone, shale; slightly lignitic.	
LATE CARBONIFEROUS TO EARLY PERMIAN	Grant Group Betty Fm.		969	203	Interbedded sandstone and siltstone : sandstone - coarse to very coarse, mod. well sorted, massive siltstone - multicoloured, micaceous, carbonaceous, sandy.	
CARBONIFEROUS	Anderson Fm.		1172	230	Interbedded siltstone and fine, silty, mi sandstone ; minor sandy limestone. Interbedded grey, fossiliferous limestone, and grey sandstone; minor black micaceous siltstone and shale	brachiopods, palecypods * polynology Early Carbonaceous
	Laurel Fm		1402	101	Interbedded fine to coarse, friable sandstone and microcrystalline dolomite & quartz grains	* rare spores.
DEVONIAN	Yellow Drum Sst.		1503	76	Limestone, dolomite, and minor shale	x rare fossils
	Gum-hole Fm.		1579	63	Interbedded and interlaminated dolomitic Sandstone, siltstone, shale	
	Reef Complex		1642	36	Schist	
Precambrian	Basement		1678			

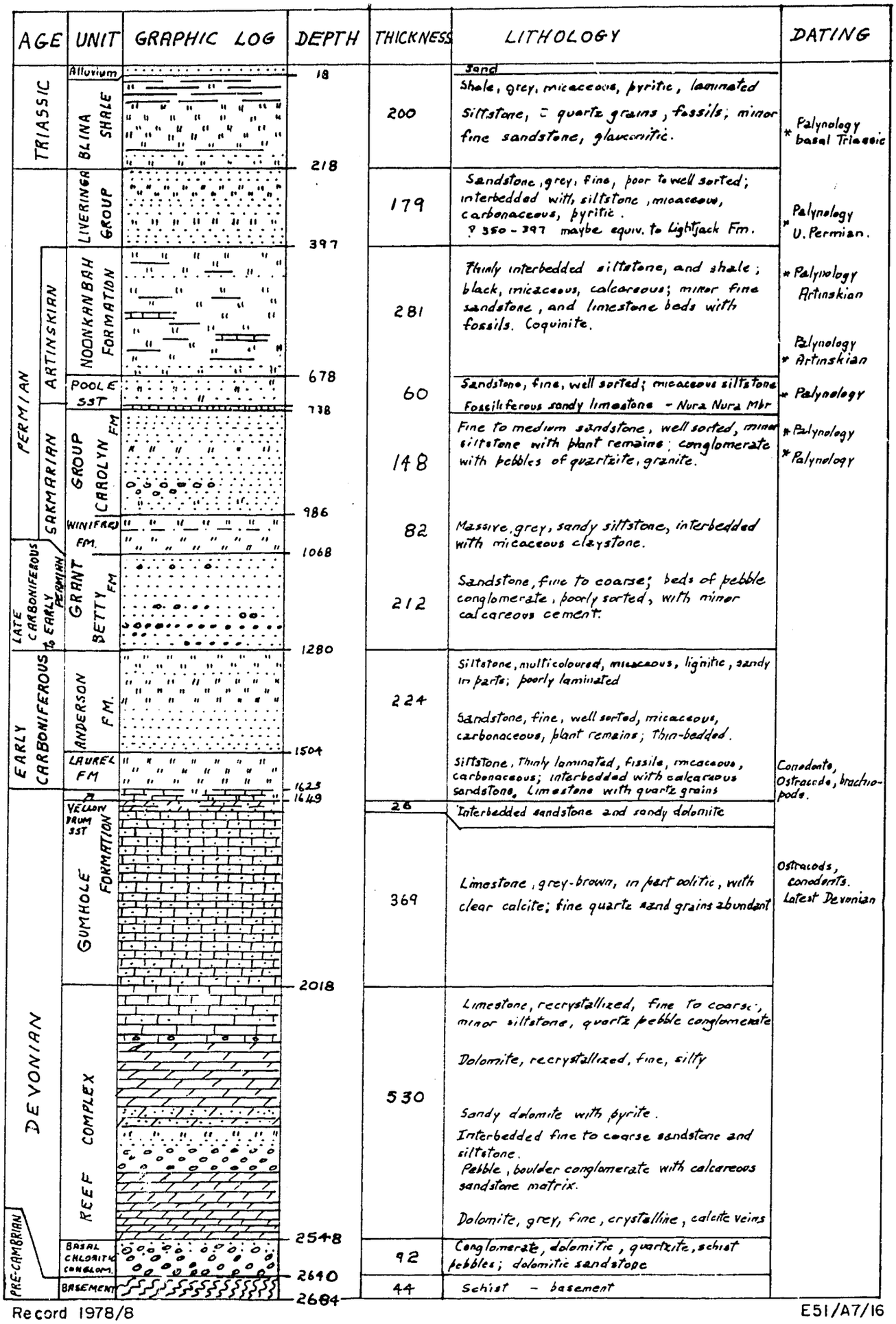
Record 1978/8

E51/A7/15

Interpretation by BMR Basin Study Group, Druce & Radke (in prep), and the authors.

Fig 17 WAPET Meda No 1

Scale : 10mm. = 120 m.



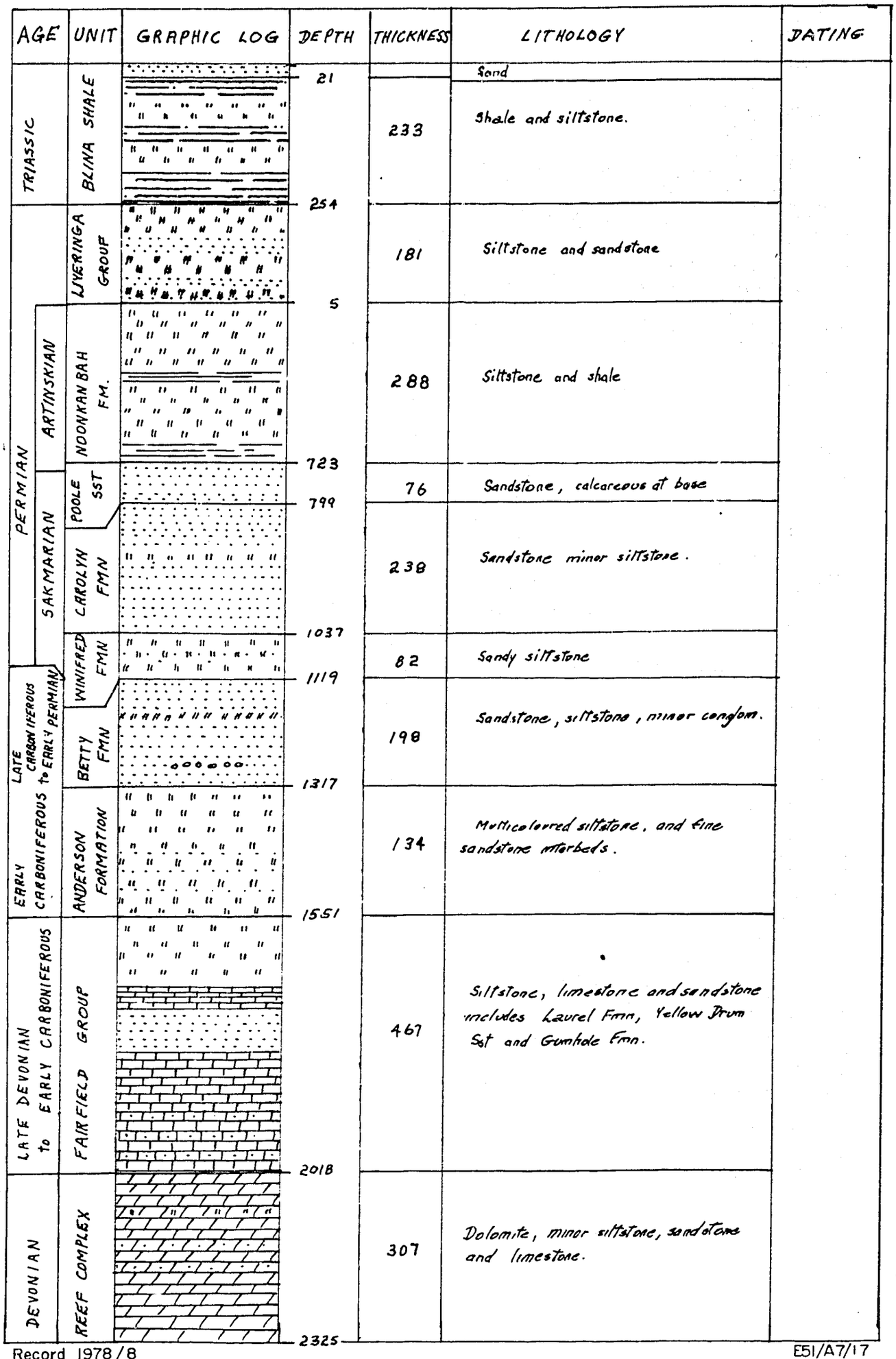
Record 1978/8

E51/A7/16

Interpretation by BMR Basin Study Group; Druce & Radke (in prep.); and the authors

Fig 18 WAPET Meda No. 2

Scale : 10mm = 100m.



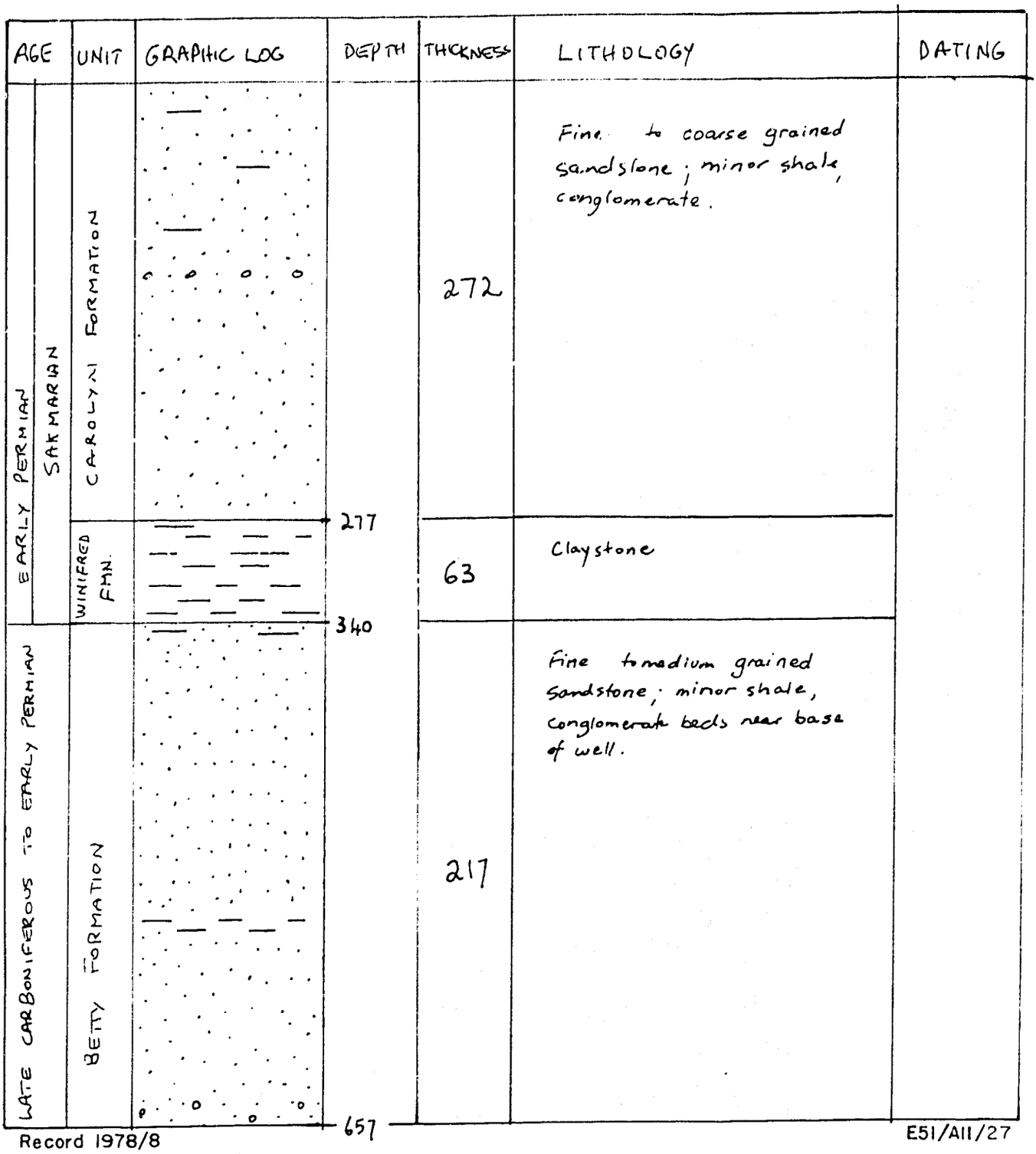
Record 1978/8

E51/A7/17

Interpretation by BMR Basin Study Group

Fig 19 FKO Mt. Wynne No 3

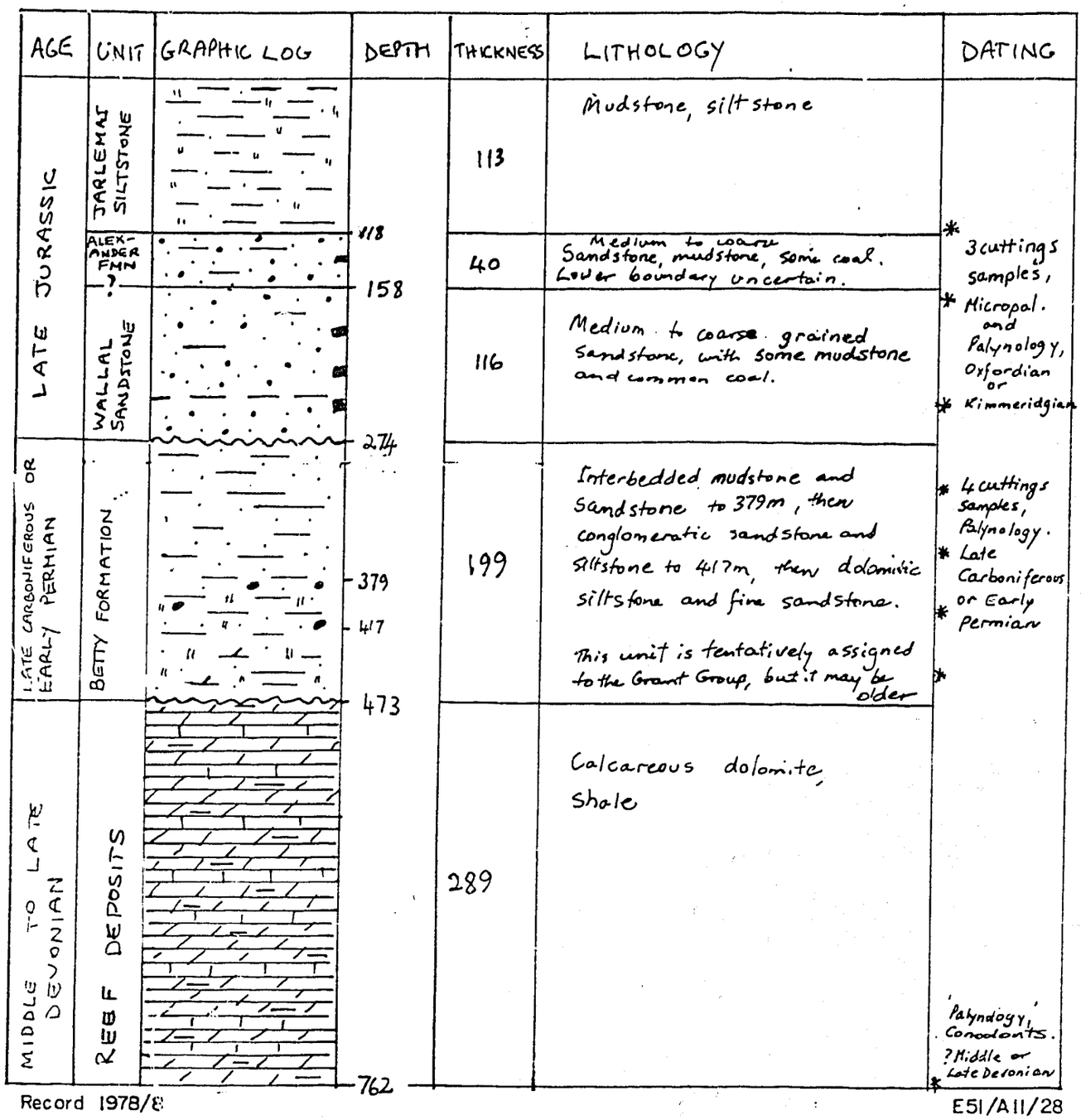
Scale : 10mm = 40m



Interpretation by BMR Basin Studies Group and the authors.

Fig 20 TOTAL Mowla No 1

Scale: 10mm = 50m

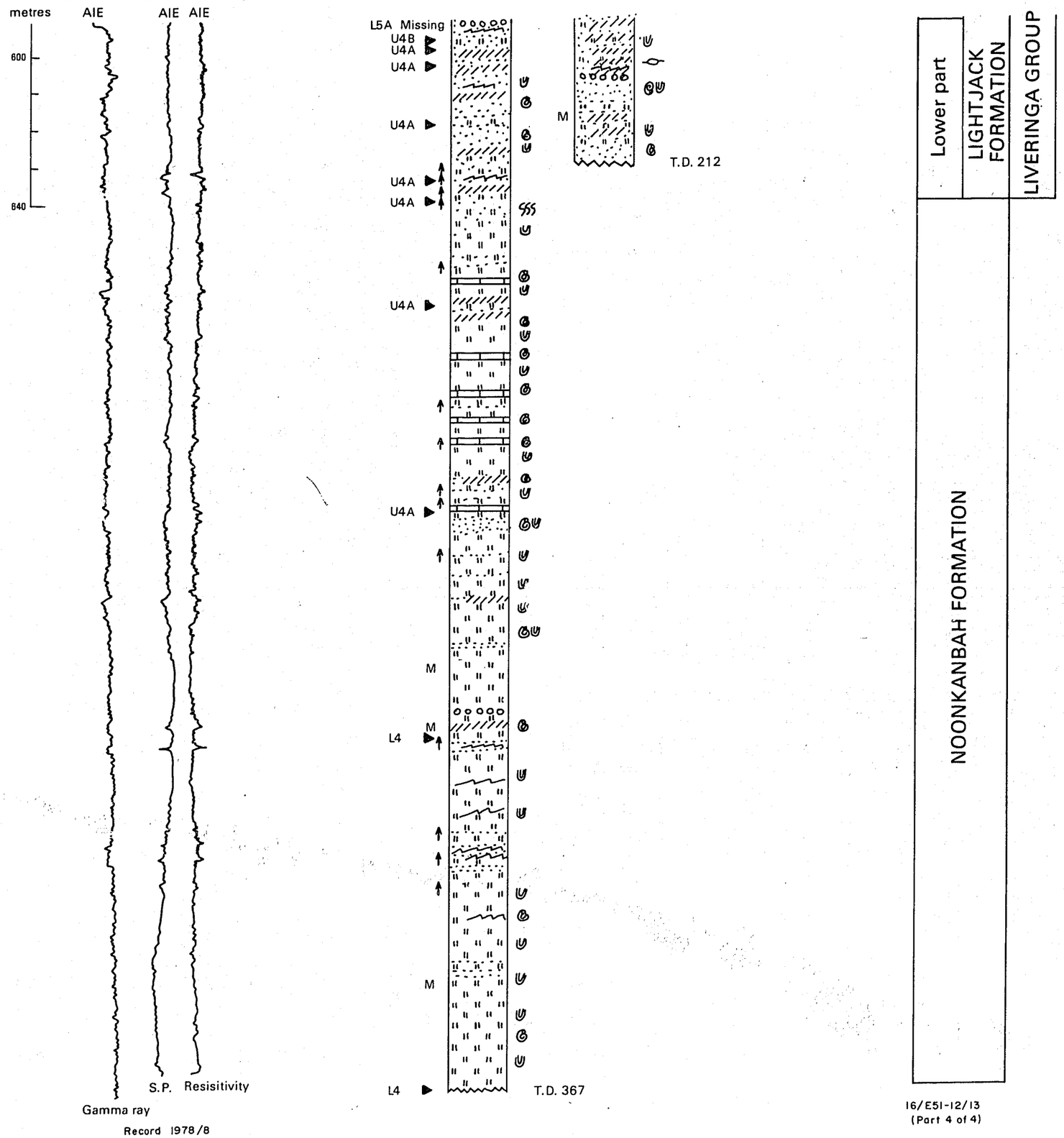


Record 1978/8

E51/A11/28

Interpretation by the authors and BMR Basin Studies Group. Jurassic dating by Backhouse (written communication), Carboniferous or Permian dating by Kemp (written communication).

Enclosure No.1 (cont.)

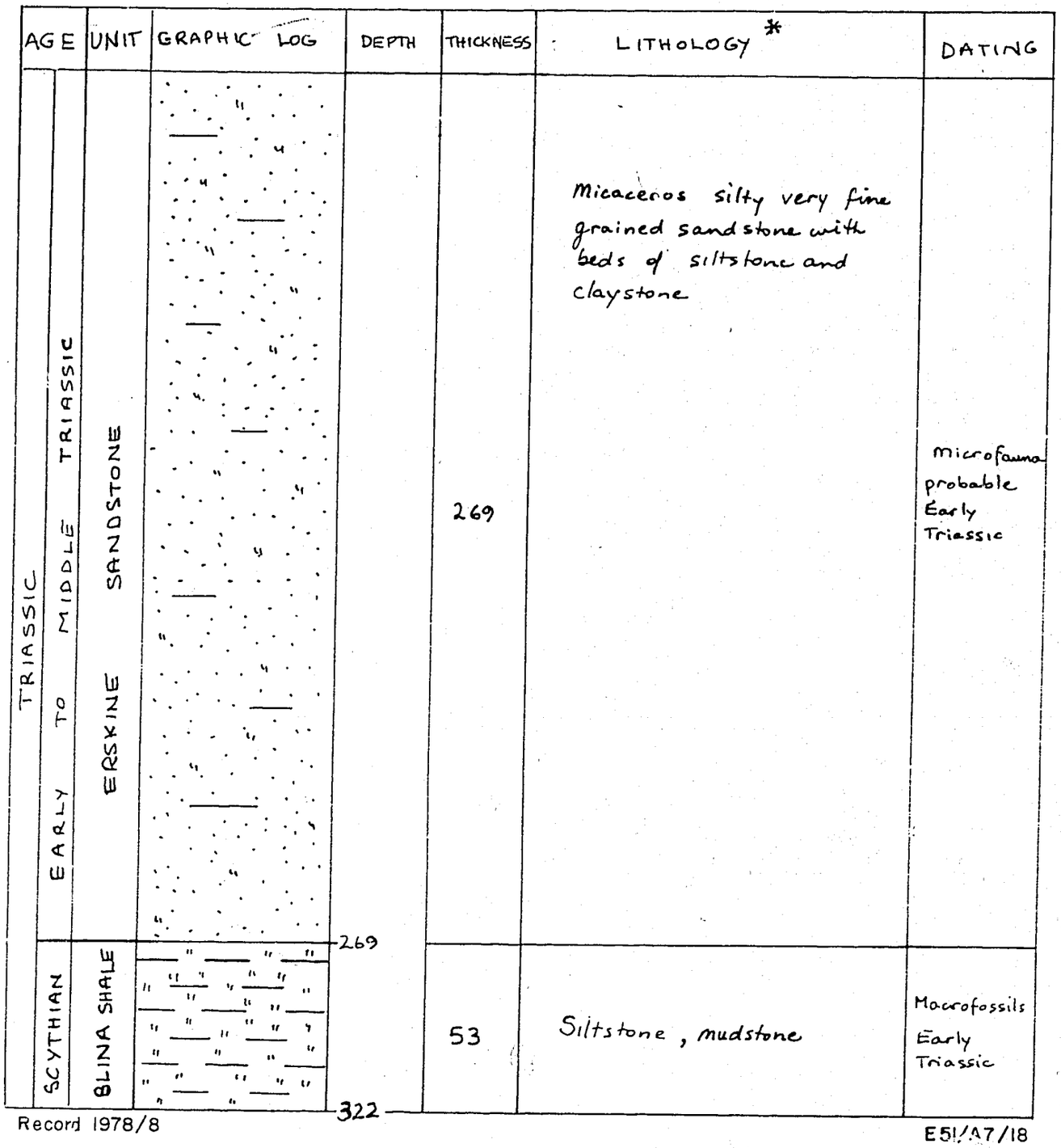


16/E51-12/13
(Part 4 of 4)

Australian inland exploration Paradise Boreholes composite log of Liveringa Group

Fig 21 MYALLS BORE

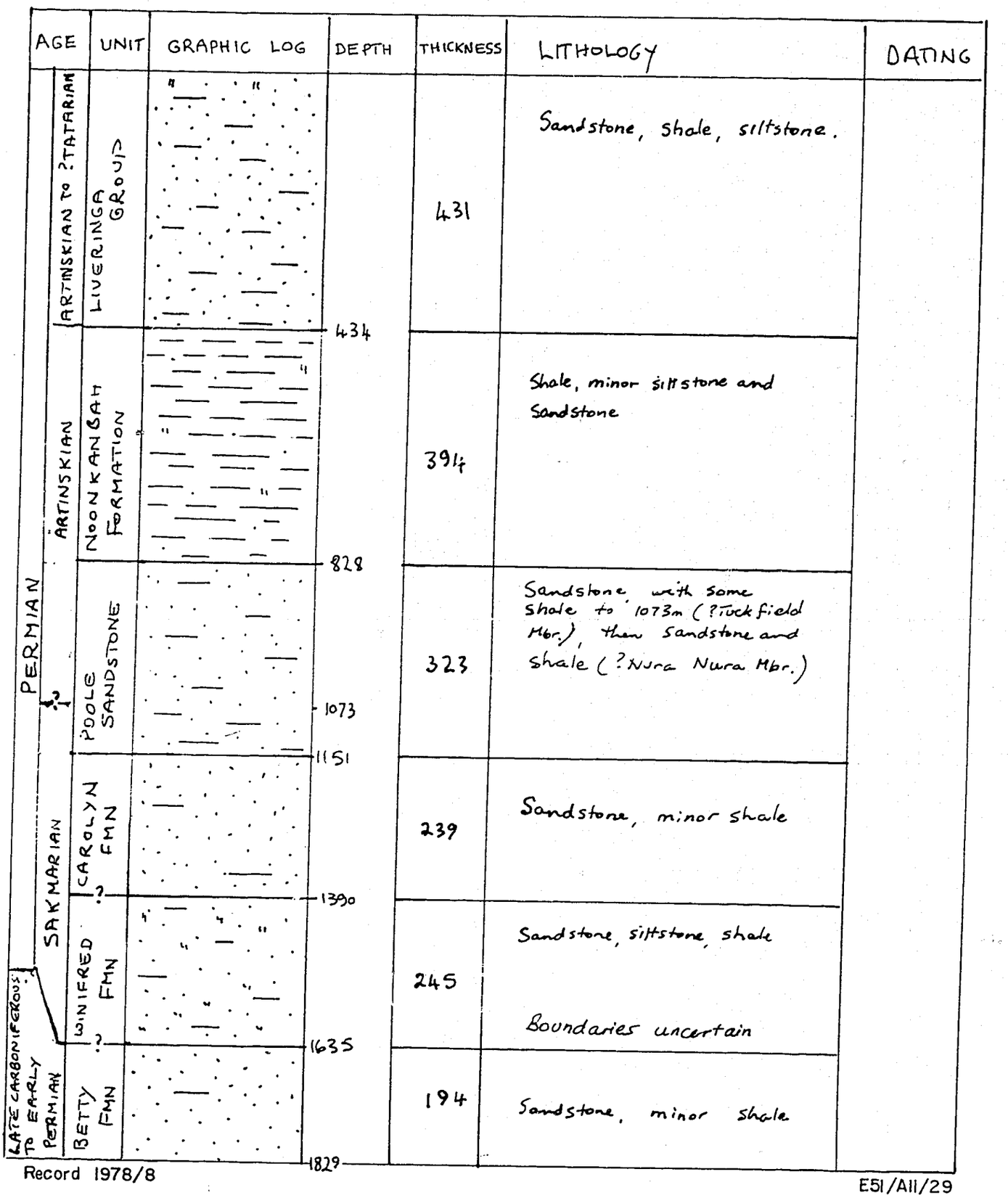
Scale : 10mm = 20m



* Based on driller's log and cores.
Interpretation by Playford (1957)

Fig 22 AFO Myroodah No 1

Scale: 10mm = 100m



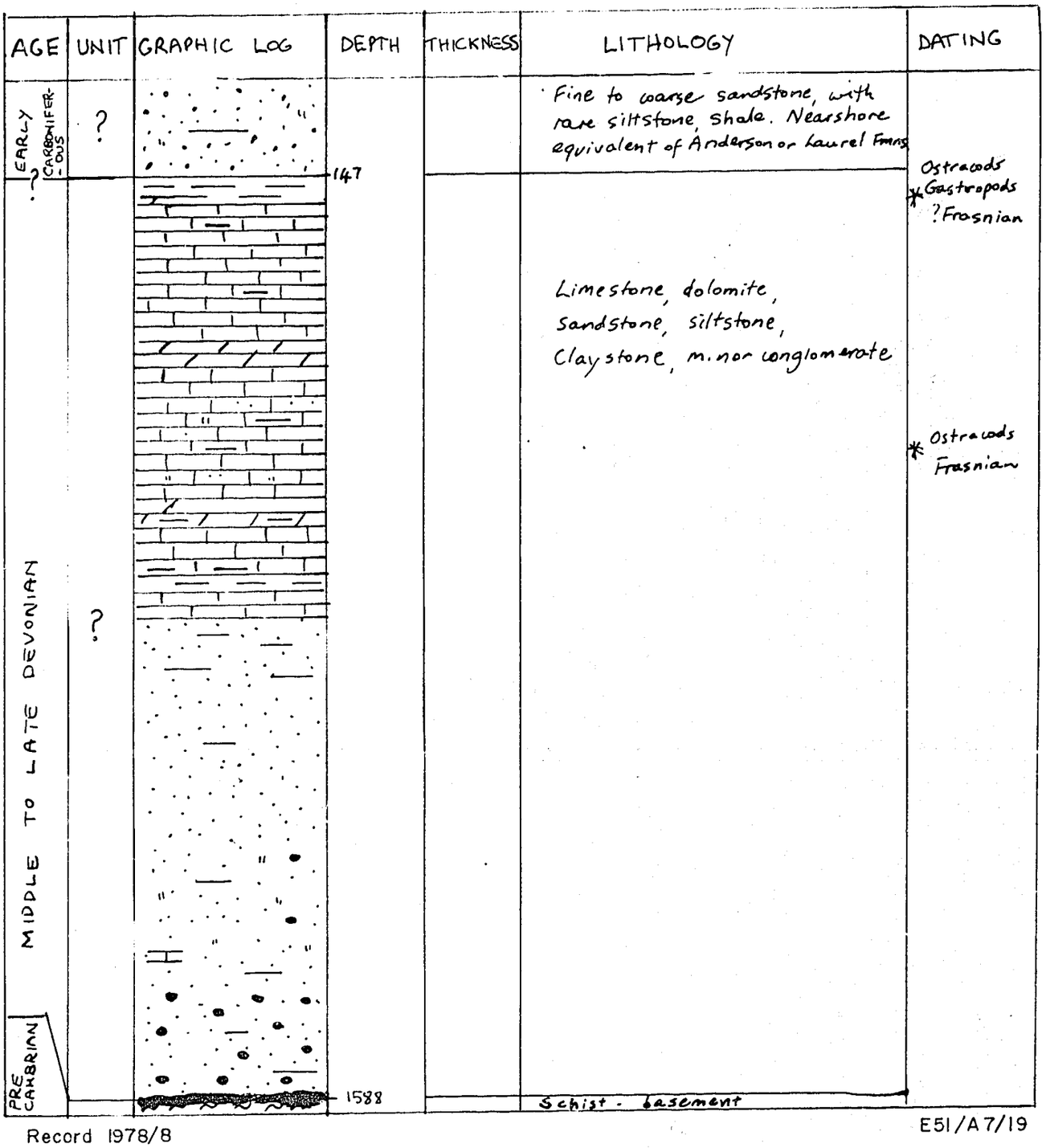
Record 1978/8

E51/A11/29

Interpretation by BMR Basin Studies Group and the authors

Fig 23 : LENNARD Napier No 2

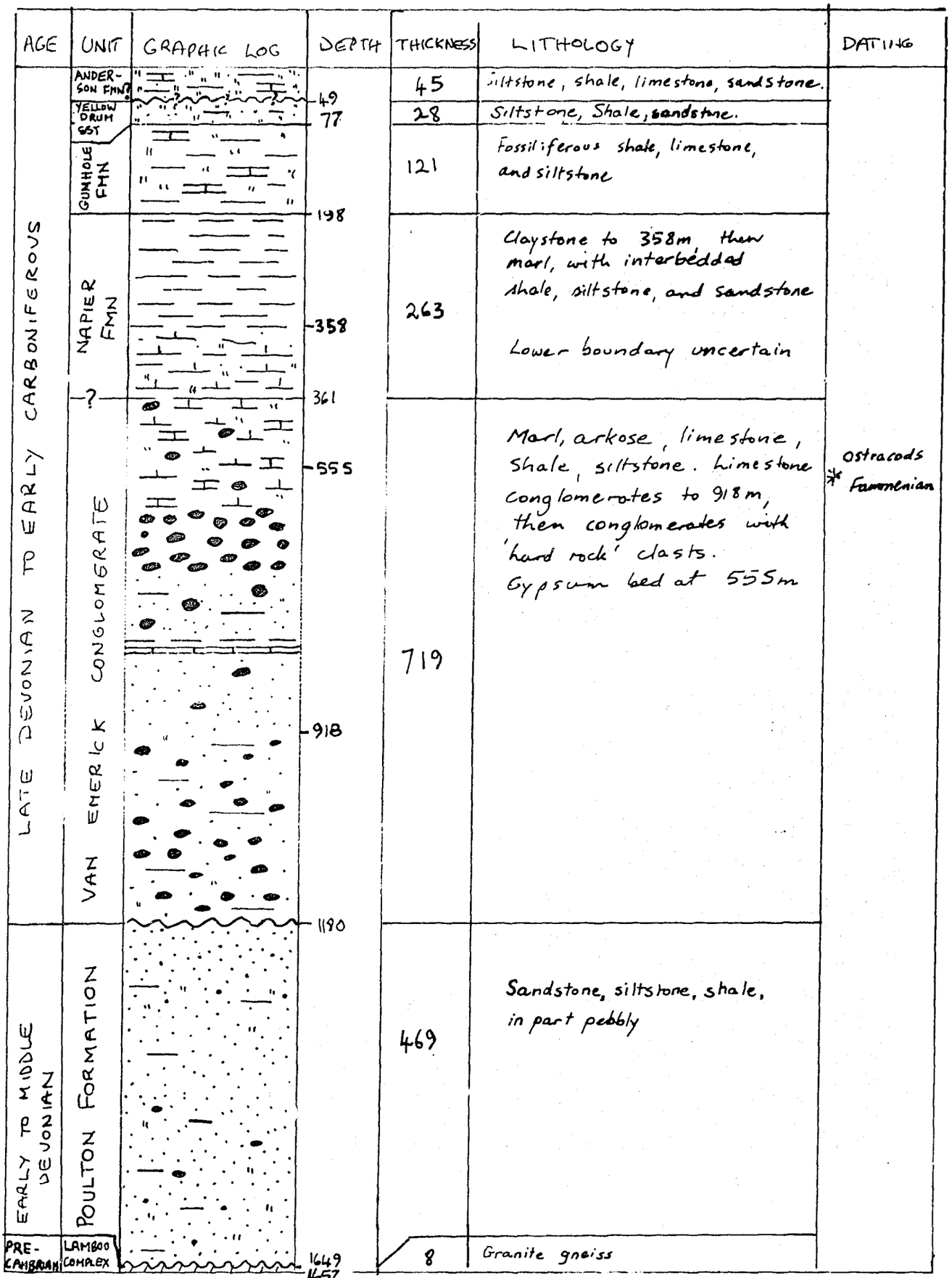
Scale: 10mm = 100m



Interpretation by BMR Basin Studies Group, Druce & Radke (in prep.), and the authors

Fig 24. LENNARD Napier No 5

Scale : 10 mm = 80m



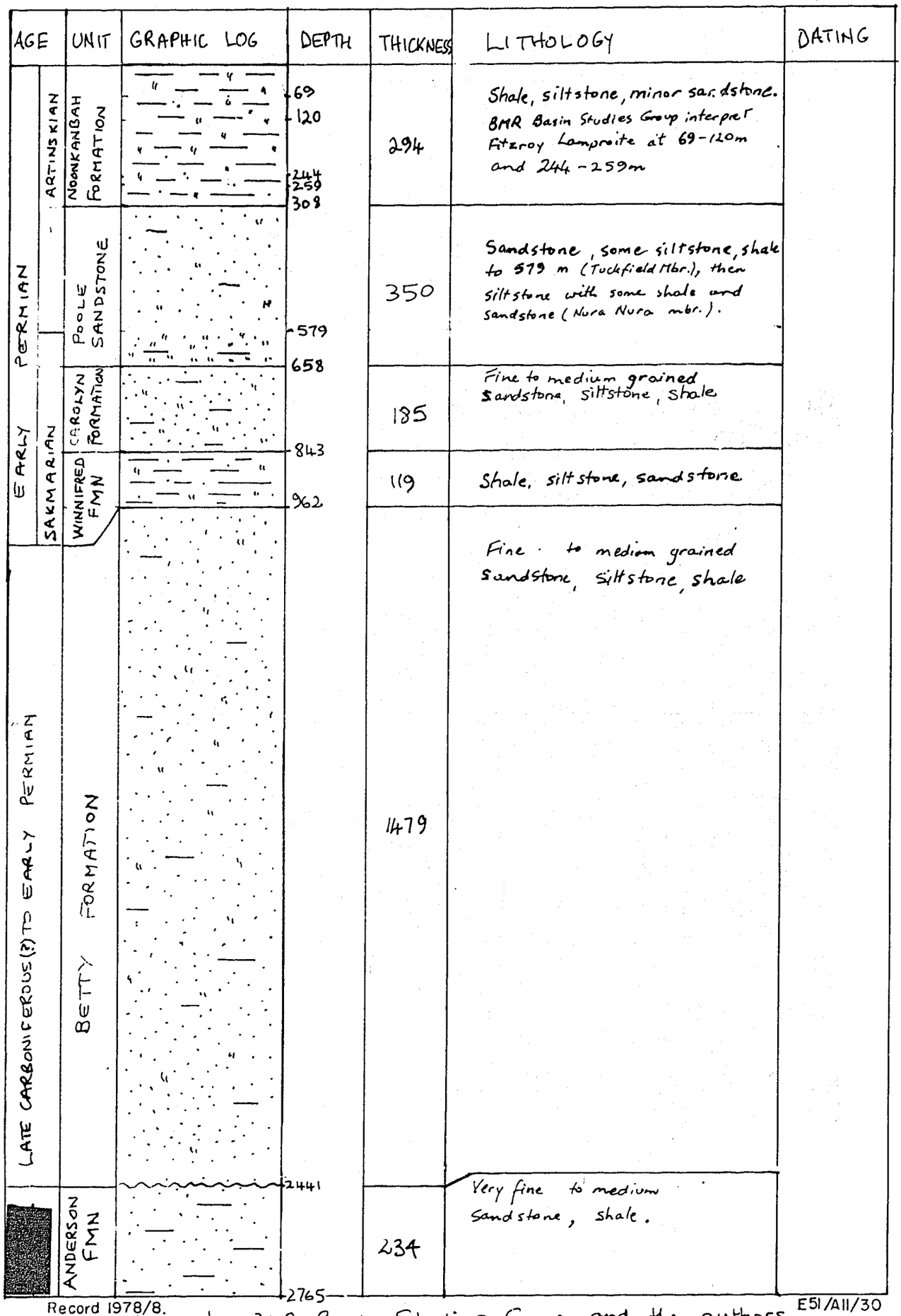
Record 1978/8

E51/A7/20

Interpretation by BMR Basin Studies Group, Druce + Radke (in prep.), and the authors.

Fig 25 AFO Nerrima No 1

Scale : 10mm = 120m



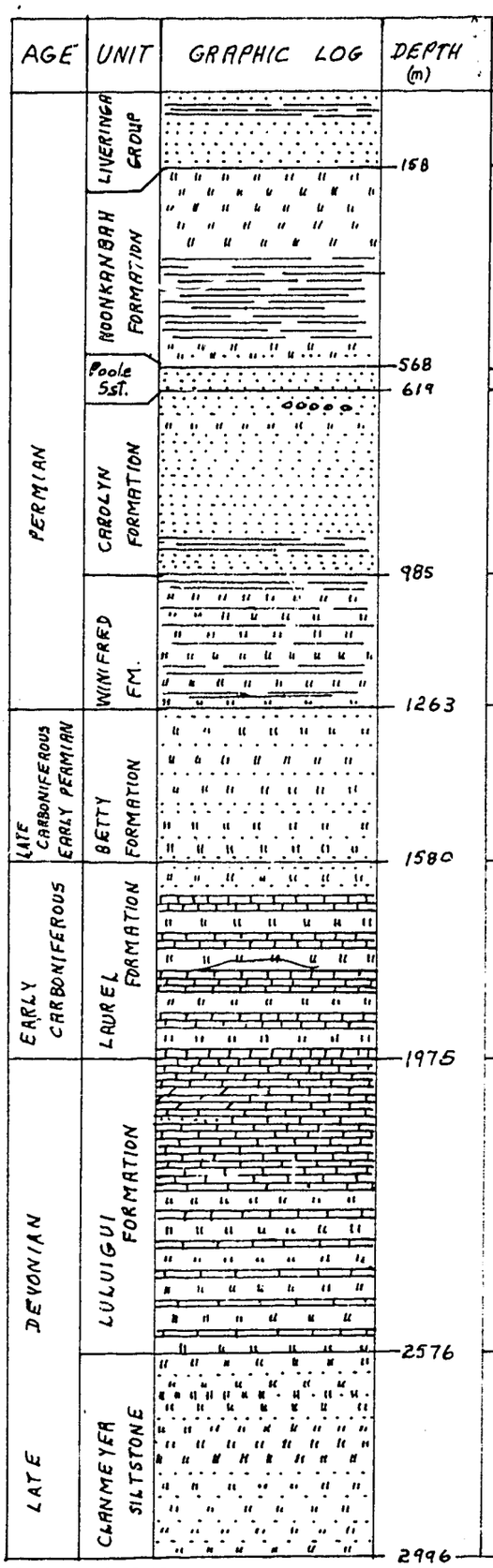
Record 1978/8. E51/A11/30

Interpretation by BMR Basin Studies Group and the authors

Log of FKO Nerrima No 1 is difficult to interpret, but it appears to have intersected the same formations as above at similar depths. It bottomed in the Betty Formation at 1362m.

Fig 26 AFO Sisters No. 1

Scale :- 10mm = 150m



AGE	UNIT	THICKNESS (m)	LITHOLOGY	DATING
PERMIAN	LIVERINGA GROUP	158	Sandstone, quartz, fine to coarse, subangular to subrounded grains; Shale, silty, micaceous, black, poorly laminated.	
	NOONKANBAH FORMATION	410	Siltstone, black, poorly laminated, micaceous, slightly sandy Shale, grey, black, micaceous, laminated Interbeds, shale, siltstone and fine, calcareous sandstone.	
	Poole Sst.	51	Sandstone, fine, well sorted.	
	CAROLYN FORMATION	366	Sandstone, fine to medium, well sorted, micaceous; minor conglomerate, and siltstone, poorly bedded. Interbed sandstone and shale, grey	
	WINIFRED FM.	278	Interbedded shale, siltstone, sandy siltstone and minor fine sandstone.	
LATE CARBONIFEROUS EARLY PERMIAN	BETTY FORMATION	317	Interbedded sandstone, fine to coarse, subangular to subrounded, and siltstone, grey, micaceous, sandy, pyritic	
EARLY CARBONIFEROUS	LAUREL FORMATION	395	Interbedded sandstone, medium, m. and siltstone, light brown, micaceous; minor microcrystalline limestone. Interbedded grey, microcrystalline, fossiliferous limestone and calcareous siltstone; minor silty sandstone.	
DEVONIAN	LULUIGUI FORMATION	601	Limestone, grey-brown, crystalline, hard, silty, pyritic, fossiliferous; minor fissile siltstone, and fine sandstone. Interbedded limestone, grey, soft, silty fossiliferous and siltstone, grey, fissile, carbonaceous, micaceous, pyritic	
LATE	CANMEYER SILTSTONE	420	Siltstone, grey, fissile, micaceous, carbonaceous fossiliferous, minor interbeds of sandstone and limestone. Interbeds, siltstone, dark grey, fissile, and sandstone, grey, fine-grained, silty, micaceous, rare fossils	

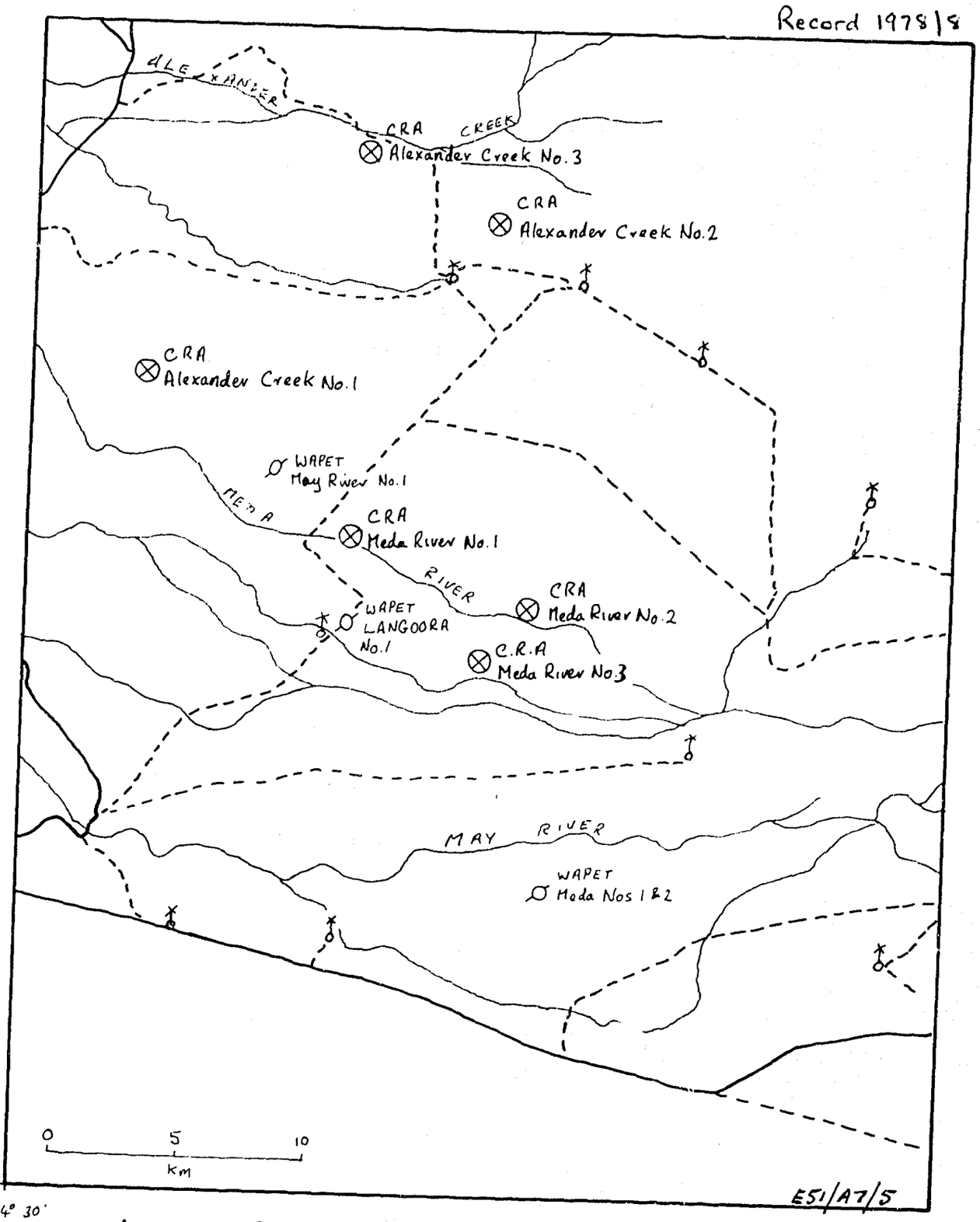
Record 1978/8

E51/A7/21

Interpretation by BMR Basin Study Group.

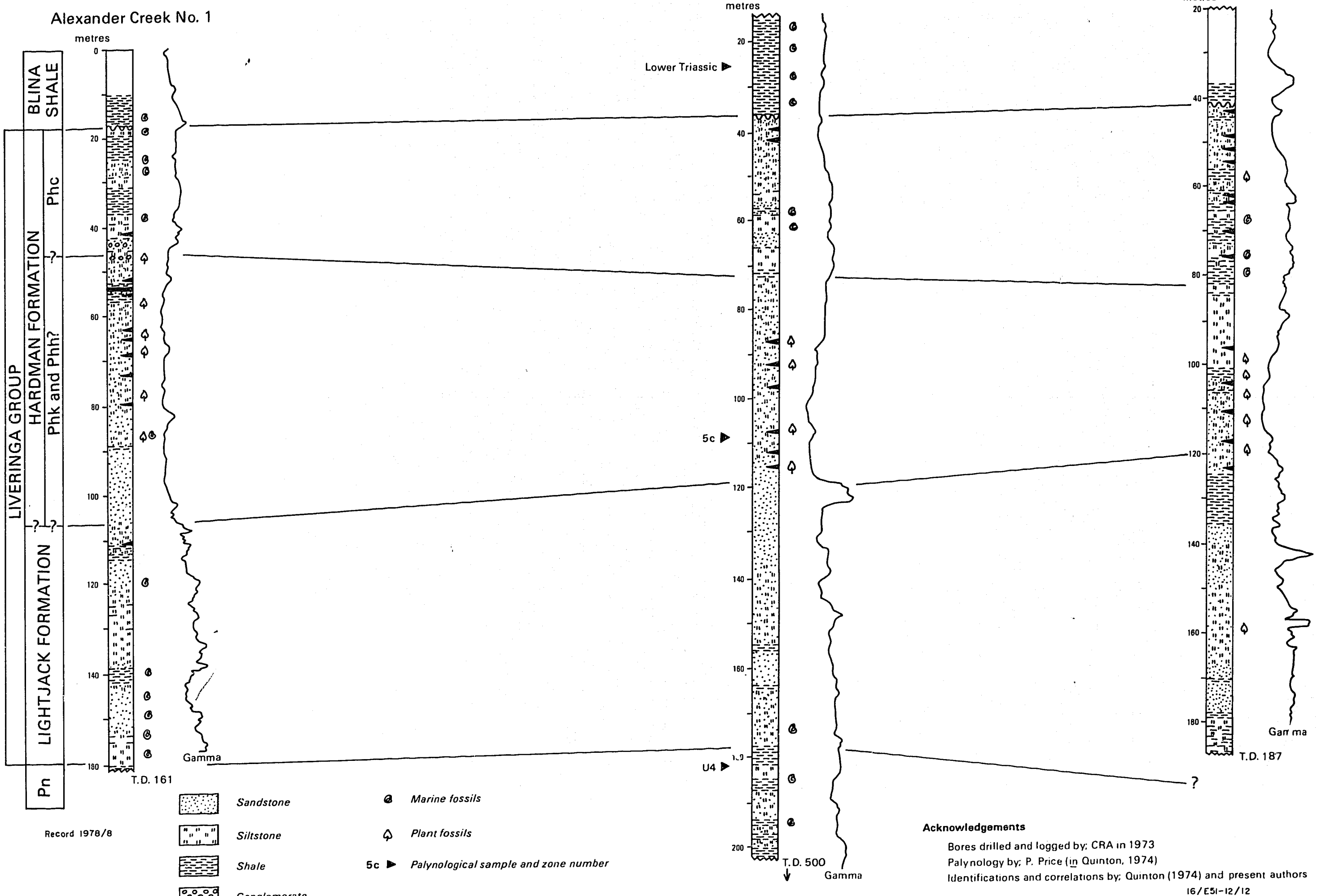
ENCLOSURE NO. 2

Record 1978/8



LOCATION SKETCH SHOWING POSITIONS OF CRA BORES

Enclosure No. 2 (cont.)



Record 1978/8

Acknowledgements

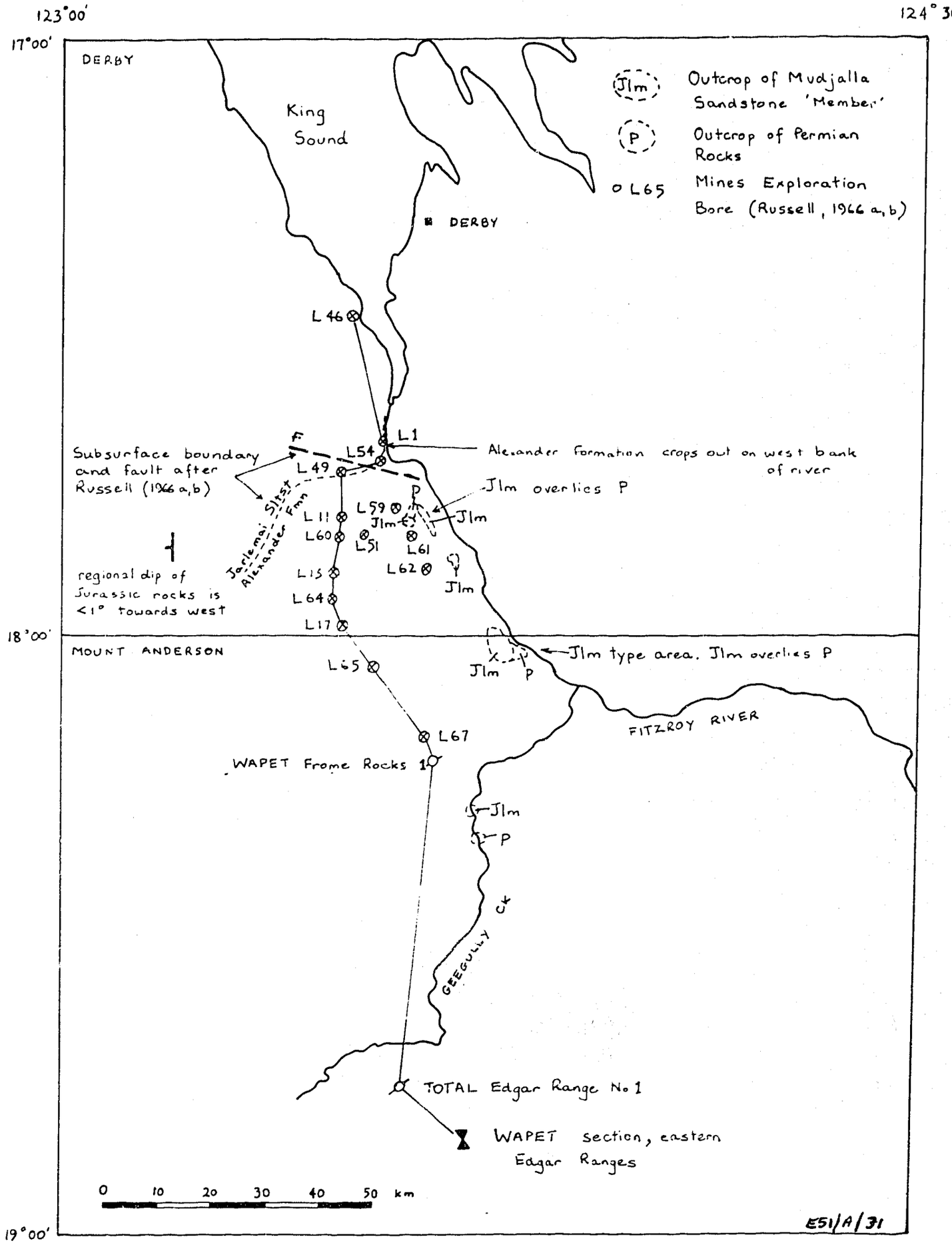
Bores drilled and logged by; CRA in 1973
Palynology by; P. Price (in Quinton, 1974)
Identifications and correlations by; Quinton (1974) and present authors

16/E5I-12/12

Conzinc Riotinto of Australia, Alexander Creek and Meda Creek Bores
Correlation of Liveringa Group

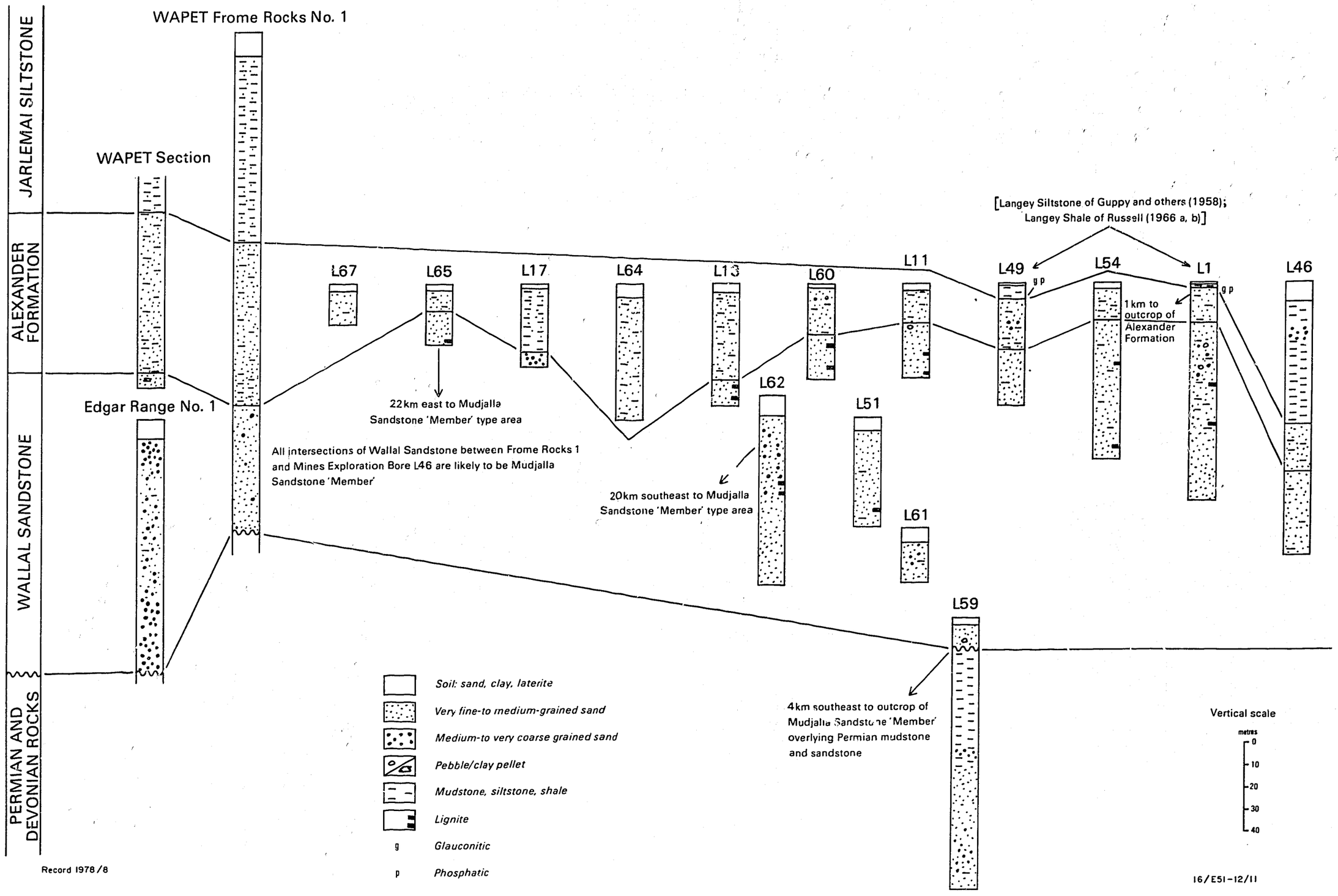
ENCLOSURE No. 3

Record 1978/8



LOCATION SKETCH SHOWING POSITIONS OF BORES AND SECTION

Enclosure No. 3



Record 1978/8

16/E51-12/11

Correlation of Jurassic units from the Edgar Ranges to King Sound

RECORD 1980/30

GEOLOGY OF LATE CARBONIFEROUS AND YOUNGER ROCKS OF THE ONSHORE WESTERN CANNING BASIN, WESTERN AUSTRALIA

by

R.R. Towner & D.L. Gibson

CONTENTS

	Page
ABSTRACT	
INTRODUCTION	1
Location and access	1
Development	2
Climate	3
Flora	3
Survey Methods	4
PREVIOUS INVESTIGATIONS	5
Geological	5
Geophysical	6
Drilling	15
STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF UNITS	19
Late Carboniferous to Early Permian	19
Grant Group	19
Betty Formation	20
Winifred Formation	20
Carolyn Formation	21
Early to Late Permian	21
Paterson Formation	21
Poole Sandstone	23
Noonkanbah Formation	24
Triwhite Sandstone	25
Chirup Formation	25
Liveringa Group	25
Triassic	26
Blina Shale	26
Jurassic to Cretaceous	26
Wallal Sandstone	27
Alexander Formation	28
Jarlemai Siltstone	28
Callawa Formation	29
Mowla Sandstone	30
Broome Sandstone	30
Melligo Sandstone	31
Parda Formation	32
Frezier Sandstone	33

Page

Emeriau Sandstone 34
Anketell Sandstone 34
Cretaceous to Tertiary 35
Lake George Beds 35
Tertiary 35
Borda Sandstone 35
Cainozoic 35
Oakover Beds 35
Poondano Formation 36
Bossut Formation 37
Alluvium 38
Calcrete 38
Lake deposits 39
Supratidal deposits 40
Intertidal deposits 40
Laterite 41
Aeolian sand 42
STRUCTURAL GEOLOGY 42
GEOLOGICAL HISTORY 45
ECONOMIC GEOLOGY 45
Petroleum 45
Surfacewater 47
Groundwater 48
Heavy Mineral Sands 49
Iron Ore 49
Phosphate 50
ACKNOWLEDGEMENTS 50
REFERENCES 51

APPENDIXES

1. The 'Jowlaenga Sandstone'
2. Graphic logs of petroleum exploration wells

Figures

A1. WAPET Roebuck Bay 1
A2. WAPET Wallal Core Hole 1
A3. BMR Wallal 4 & 4A
A4. WAPET Samphire Marsh 1
A5. WAPET Goldwyer 1
A6. WAPET Thangoo 1
A7. WAPET Thangoo 1A
A8. WAPET Barlee 1
A9. WAPET Parda 1
A10. WAPET Willara 1
A11. Gewerkschaft Elwerath Yulleroo 1
A12. Total McLarty 1
A13. Total Kemp Field 1
A14. WAPET Willara Hill 1
A15. WAPET Chirup 1
A16. WAPET Tappers Inlet 1
A17. WAPET Munda 1
A18. WAPET Pender 1
A19. WAPET Munro 1
A20. WAPET Thangoo 2

3. Measured sections

Reference to symbols

1. Callawa Formation, N. of Cabbage Tree Hill
2. 'Type Section' of 'Cuncudgerie Sandstone' (Poole Sandstone), Paterson Range.
3. Interfingering Parda Formation and Frezier Sandstone, Karrobridill Hill.
4. Paterson Formation, Paterson Range.

FIGURES

1. Location and Geographic Setting
2. Observation Sites visited during Survey
3. Interpretation of Solid Geology

4. Aeromagnetic Surveys
5. Gravity Surveys
6. Seismic Surveys
7. Conglomerate bed in Callawa Formation
8. Crossbedded sandstone and conglomerate in Callawa Formation
9. Scour and fill structures in the Broome Sandstone
10. Bioturbated Broome Sandstone overlain by thin-bedded Melligo Sandstone
11. Silicified Melligo Sandstone
12. Channel of Parda Formation cut into Melligo Sandstone
13. Channel infill of Parda Formation
14. Joints in Parda Formation
15. Joint infilling of sandstone and mudstone
16. Anastomosing ridges of Frezier Sandstone
17. Canning Basin Structures
18. Palaeogeographic base map
19. Stephanian-Sakmarian palaeogeography
20. Early Permian (early Sakmarian?) palaeogeography
21. Early Permian (mid Sakmarian?) palaeogeography
22. Early Permian (late Sakmarian-early Artinskian) palaeogeography
23. Early Permian (Artinskian) palaeogeography
24. Early to Late Permian (upper Artinskian-Kungurian) palaeogeography
25. Late Permian palaeogeography
26. Early Triassic palaeogeography
27. Middle to earliest Late Jurassic palaeogeography
28. Late Jurassic (Oxfordian) palaeogeography
29. Late Jurassic (Kimmeridgian-Tithonian) palaeogeography
30. Early Cretaceous (Neocomian) palaeogeography
31. Early Cretaceous (early Aptian?) palaeogeography
32. Early Cretaceous (early-middle Aptian?) palaeogeography
33. Early Cretaceous (middle-late Aptian?) palaeogeography
34. Early Cretaceous (late Aptian?) palaeogeography
35. Stratigraphic relationships of rock units

TABLES

1. Geophysical Surveys in West Canning Basin
2. Wells drilled in the West Canning Basin
3. Betty Formation
4. Winifred Formation
5. Carolyn Formation
6. Paterson Formation
7. Poole Sandstone
8. Noonkanbah Formation
9. Triwhite Sandstone
10. Chirup Formation
11. Liveringa Group
12. Blina Shale
13. Wallal Sandstone
14. Alexander Formation
15. Jarlemai Siltstone
16. Callawa Formation
17. Mowla Sandstone
18. Broome Sandstone
19. Melligo Sandstone
20. Parda Formation
21. Frezier Sandstone
22. Emeriau Sandstone
23. Anketell Sandstone
24. Lake George Beds
25. Borda Sandstone
26. Oakover Beds
27. Poondano Formation
28. Bossut Formation
29. Geological history
30. Heavy-mineral analyses.

ABSTRACT

The exposed succession is dominated by Mesozoic sedimentary marine and fluviatile rocks with some marine Permian rocks exposed along the southwest basin margin. Large expanses of Cainozoic aeolian sand and laterite separate sparse outcrops in most of the area, while the coastal intertidal, supratidal, and beach deposits confine older rock exposures to small headlands and capes along the northern part of the coastline.

Permian sedimentation commenced with lacustrine, fluvial, and marine deposits that were laid down mainly under glacial conditions (Paterson Formation, Grant Group); this was followed by mainly marine sediments (Poole Sandstone, Noonkanbah Formation, Liveringa Group, and Chirup Formation). Shallow-marine conditions continued to prevail in the Early Triassic (Blina Shale) although confined to the Fitzroy Graben and the Wallal Embayment. A period of tectonism, probably in the Early Jurassic, was followed by a regional marine transgression from the northwest. In the north, a single phase of this transgression is recognised, but in the southwest two phases are identified; this probably resulted from local variation in the up and downwarping which probably was associated with the breaking away of the Australian continent from a landmass to the northwest.

A minor transgression northwards from the Officer Basin, probably in response to a rise in sea level during the Early Cretaceous, initiated the final phase of deposition in this area.

In the Cainozoic, deep chemical weathering and lateritisation occurred and extensive river systems developed. Eventually, as conditions became arid, sand plains and dunes were formed. Along the coastline, nearshore marine and continental deposits were laid down, probably in response to fluctuating sea levels.

The area is considered to have low potential for oil accumulations but is prospective for groundwater, especially in the southwest. Heavy-mineral sands are present along the far north coastline, and Tertiary iron ore is present in the far southwest.

INTRODUCTION

The information in this report is derived from part of a program of regional reconnaissance mapping at a scale of 1:250 000 which was designed to map the Phanerozoic rocks that make up the Canning Basin. It was carried out jointly by the Bureau of Mineral Resources (BMR) and the Geological Survey of Western Australia (GSWA). The program began in 1972, and up to the end of 1976, 20 of the 31 sheet areas to be covered by the program had been mapped and corresponding reports written (Yeates & others, 1975b; Crowe & Towner 1976a; Tower & others, 1976; Crowe & others, 1978).

This report described the Phanerozoic rocks of the final eleven Sheet areas mapped in 1977, namely Pender, Broome, La Grange, Mandora, Port Hedland, Yarrie, Anketell, Munro, McLarty Hills, Joanna Spring, and Paterson Range Sheet areas (hereafter designated in capital lettering throughout the text). Several exposures in the Yampi Sheet area (Gellatly & Sofoulis, 1973) were also examined. The adjoining rocks of the Pilbara Block (exposed in PATERSON RANGE, YARRIE, and PORT HEDLAND) were mapped by the Geological Survey of Western Australia (Williams & others, 1976; Hickman & Chin, 1976; Hickman, 1977). Explanatory Notes which briefly describe the geology of each 1:250 000 Sheet area are being published.

The mapping was carried out by R.R. Towner and D.L. Gibson (BMR), and R.W.A. Crowe (GSWA).

The exposed Phanerozoic rocks are described according to the classification of Gilbert (in Williams & others, 1958). Grainsize is classified on the Wentworth scale and the terms used for bedding thickness are those of Ingram (1954). The classification of cross-bedding follows McKee & Weir (1953), and that of flaser and lenticular bedding follows Reineck & Wunderlich (1968). The subsurface units are described according to the terms used in the petroleum exploration company reports.

Location and access

Geographically, the areas lie in Western Australia between latitudes 16° and 22°S and longitudes 118°30' and 124°30'. It extends for approximately 530 km along the coast, and inland for approximately 480 km in the south and less than 40 km in the north. It is bounded on the west by the Indian Ocean (Figure 1).

Geologically, the area is bounded in the northeast by the Precambrian rocks of the Halls Creek Province (Gellatly & others, 1968), and in the southwest by the Precambrian rocks of the Pilbara Block (Williams & others, 1976; Playford & others, 1975).

Access to the area is by the gravel-surfaced Great Northern Highway which runs roughly parallel to the coastline. Various segments of the highway were being sealed during 1977. In the Dampier Peninsula, a beef road connects Broome with the outlying aboriginal settlements of Beagle Bay, Lombadina, and One Arm Point, and with a lighthouse at Cape Leveque.

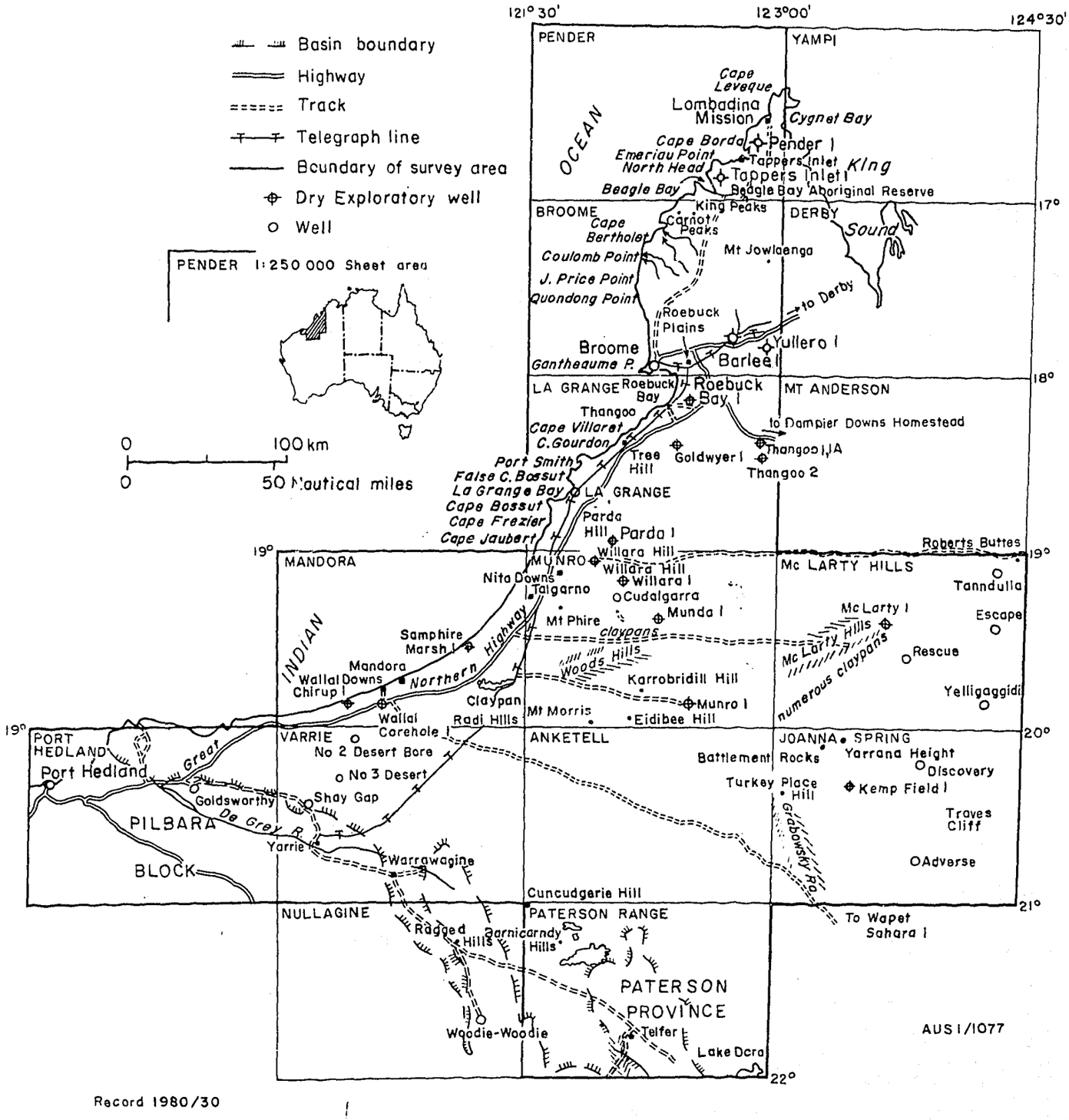
A disused gravel road branches southeast from the Great Northern Highway 230 km northeast of Port Hedland. This road runs southeast across MANDORA, YARRIE, ANKETELL, southwest JOANNA SPRING, and eventually to the site of WAPET Kidson No. 1 petroleum exploration well (now abandoned) on URAL (immediately southeast of SAHARA). A branch of this road on western ANKETELL runs northeast, weaving its way through and across the dune fields to the site of Total Kemp Field No. 1 well (now abandoned) on JOANNA SPRING. Numerous maintained dirt roads connect the Great Northern Highway with the various homesteads in the area. Station tracks, running between the station bores are abundant west of the highway. Some access to other parts of the area away from these tracks is facilitated by graded seismic lines which, however, quickly become overgrown through disuse.

A formed gravel road which connects Shay Gap township (YARRIE) with the Great Northern Highway, gives access to the basin margin in that area. A main track giving access to the southeastern part of YARRIE and to PATERSON RANGE turns off the Port Hedland to Woodie Woodie Road near Ragged Hills on NULLAGINE and heads east-southeasterly to Telfer. Tracks in the vicinity of this township provide some reasonable access to outcrop location, but elsewhere vehicular travel is slow and uncomfortable in the sand dune and spinifex country.

Development

Broome and Port Hedland are the main towns in the area. Port Hedland has a population of about 10 000. It is chiefly an outlet for iron ore from Mount Newman, Mount Goldsworthy and Shay Gap, and for salt from Port Hedland itself. By tonnage handled, Port Hedland is the largest port in Australia. Broome (population about 400) is one of the main tourist centres of the north, and is well known for its beef export facilities and now declining pearling industry.

Both towns are served by an airline which operates services to Perth and Darwin daily. The Royal Flying Doctor Service uses Port Hedland as its base to service the Pilbara area and stations in the southern part of the area mapped.



Record 1980/30

Fig. 1 Location and Geographic Setting

The coastal strip between Port Hedland and Broome is occupied by the cattle stations de Grey, Pardoo, Wallal Downs, Mandora, Anna Plains, Nita Downs, Frazier Downs, Thangoo, and Roebuck Plains; Frazier Downs also carries sheep. The grazing area extends only 8 to 16 km inland. There are three grazing stations north of Broome (Country Downs, Kilto, and Waterbank). Cultured pearls are farmed at localities near Port Smith (LA GRANGE) and Cygnet Bay (PENDER, YAMPI). Fishing takes place off the various capes and points scattered along the coast, especially north of Cape Frezier.

Four aboriginal settlements are located within the area - La Grange along the central coast, and Beagle Bay, Lombadina, and One Arm Point in the northern part of Dampier Peninsula.

Climate

The climate of the area varies from semi-arid in the north to arid in the southern and western parts of the area. The average annual rainfall is about 750 mm in PENDER, 300 mm in PORT HEDLAND, and 200-250 mm in JOANNA SPRING. The rainfall is unreliable. The heaviest falls occur between November and March, and are associated with cyclones and thunderstorms; sporadic falls occur during the winter months. The days are hot and the nights are cool. In January, the average daily minimum and maximum temperature are about 22°C and 40° respectively; and in July 5°C and 25°C. In the south of the area annual evaporation exceeds 4000 mm (Australian Bureau of Statistics, 1978, p. 46).

Flora

The area falls within two quite distinct regions, each having a characteristic landscape and associated vegetation. The Northern Botanical Province occupies the coastal strip from Port Hedland to Dampier Peninsula; and the rest occurs within the Eremaea Botanical Province (Gardener, 1942; Beard 1969). The latter author, in a synoptic treatment of the desert areas of Western Australia, has suggested a subdivision of the botanical districts of the Eremaea Province into four botanical districts one of which, the Canning Botanical District, covers all of the report area except the coastal strip (Beard & Webb, 1974).

In the Canning Botanical district, sand dunes are the most conspicuous feature, and their vegetation is the principal feature of the plant cover. Dune vegetation is simple in species and structure, is extremely consistent throughout the area, and differs from the vegetation of the interdune flats. The

flanks of the dunes are normally thickly vegetated with spinifex hummock grass, and scattered shrubs, but the crests are often somewhat bare and exposed to the wind. Dense rounded clumps of the genus Plectrachne is the universal species of spinifex hummock grass, while Grevillea and Acacia are the dominant shrubs. Irregularly scattered to thick pockets of eucalypts may be present on the sides of the dunes. The vegetation of the interdune areas is primarily influenced by the amount of sand present and is commonly composed of a mixture of shrubs with no trees. On deep sand, the genus Plectrachne is the dominant grass but on shallow sand or bare laterite gravel, the spinifex genus Trioda is common. Species of Acacia, Grevillea, and Hakea are the dominant shrubs.

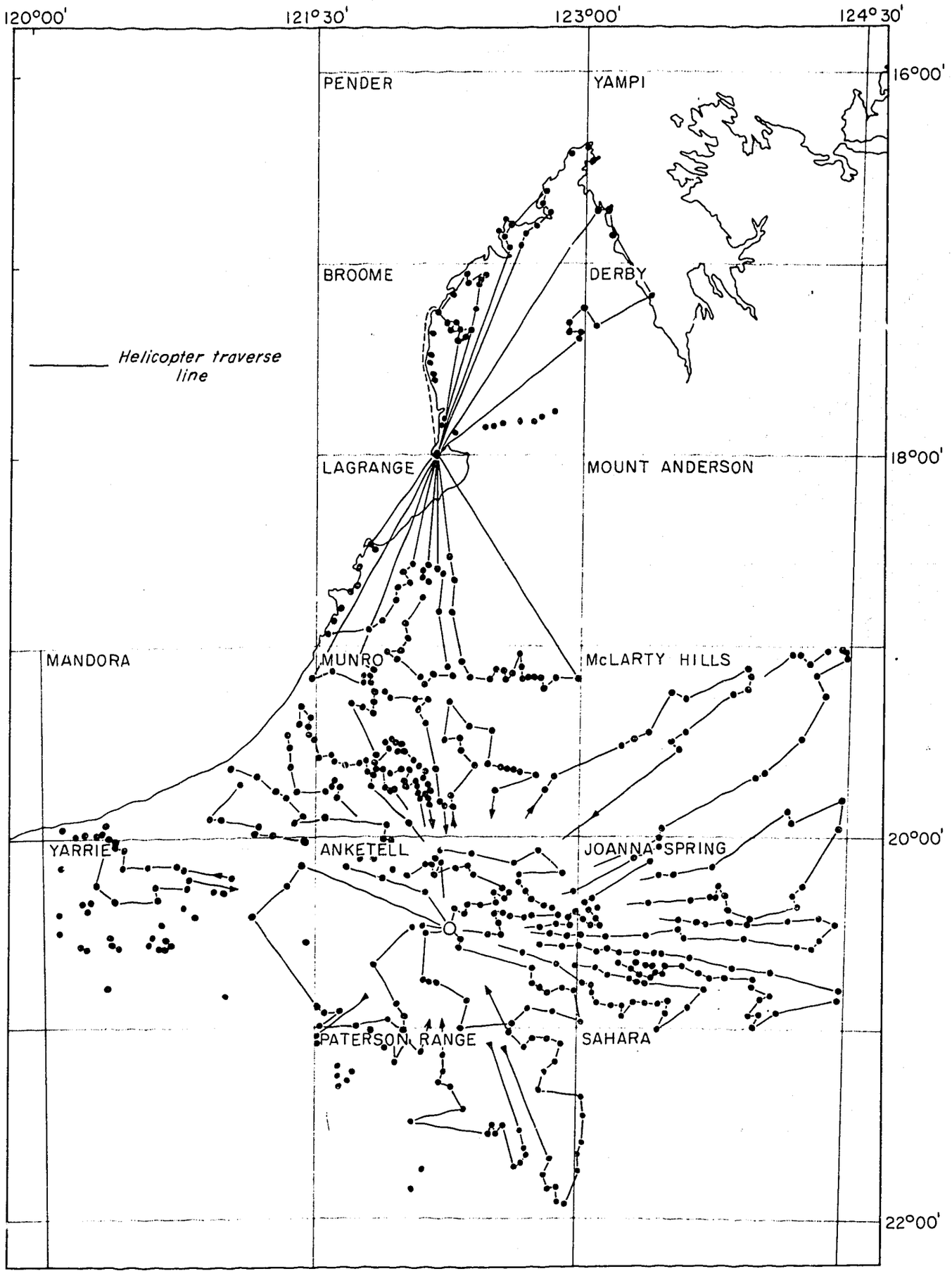
The vegetation of Dampier Peninsula, and down the coast to Anna Plains homestead, is characterised by Pindan. Pindan is essentially a grassland wooded by a sparse upper layer of trees and a dense thicket-forming middle layer of phyllodal acacias (Beard, 1967). This latter layer is frequently destroyed by fire, but regenerates from seed. Hence the appearance of the Pindan varies according to the length of time since the last fire.

A thin strip of grass savanna is present along the coastal plain, occurring on mainly silty and clay soil lying between the coastal dunes and the Pindan-covered higher ground. The grasses are perennial but strongly seasonal in their growth, flowering during the rainy season but becoming dry during the dry season. When in full growth the grasses provide a continuous ground cover, though actually growing in scattered clumps (Beard & Webb, 1974). Small prostrate succulent plants or 'samphires' are generally present also. A detailed study of the vegetation of the coastal fringe, particularly in the section along Eighty mile Beach, has been made by Burbidge (1944).

Survey methods

Mapping was begun using four-wheel-drive vehicles in the more accessible areas. These included the area in the vicinity of Paterson Range, Barnicarndy Hills, and Cuncudgerie Hill (PATERSON RANGE), around the hills north of Callawa Station, and Shay Gap Mine (YARRIE), and the narrow area between the Great Northern Highway and the coast on PORT HEDLAND, MANDORA, and LA GRANGE. On BROOME and PENDER, outcrops at the various points and capes were also visited by vehicle, including James Price Point, Coulomb Point, Cape Borda and Cape Leveque.

In the more inaccessible areas access was by helicopter. Two base camps were established to carry out this work, one at Broome which covered PENDER, BROOME, LA GRANGE, and northern MUNRO, the other in the central part of ANKETELL, to cover the rest of the area.



Record 1980/30

AUS 1/1091

Fig. 2 Observation sites visited during survey

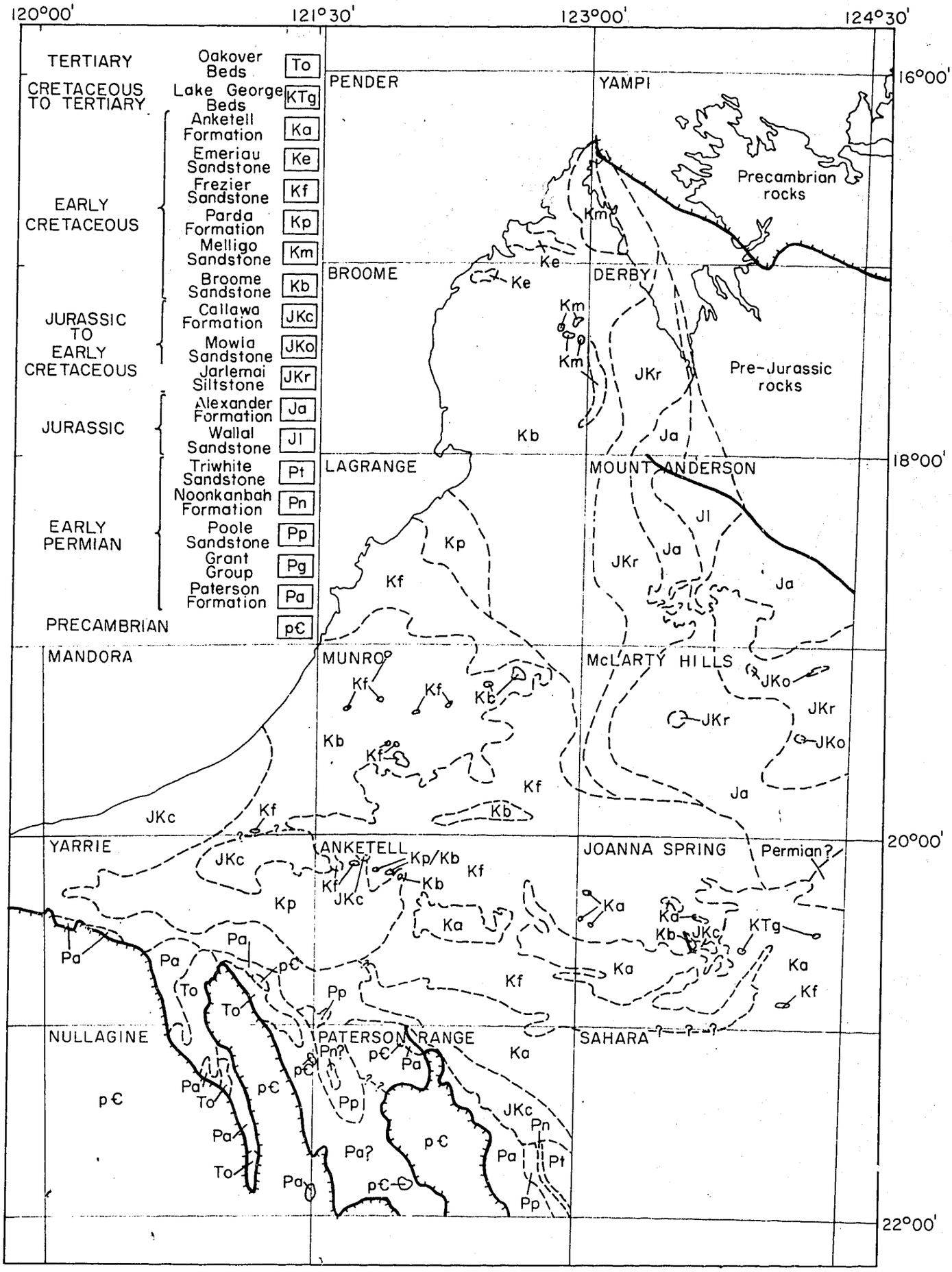


Fig 3 Interpretation of solid geology

Field work was planned using vertical airphotos to assist in the location of, and navigation between, the sparse outcrops. All airphotos used were at a scale of 1:80 000 (taken in 1973) except those of JOANNA SPRING and PATERSON RANGE which were at a scale of 1:50 000 (taken in 1953). All the airphotos are available from the Division of National Mapping, Department of National Development & Energy, Canberra, or the Lands & Survey Department, Perth, W.A.

1:250 000 topographical maps of the Sheet areas show nearly all of the sand dunes and most of the other topographical features and were used for general navigation, particularly in the desert. The topographic base maps prepared in 1961 by the Royal Australian Survey Corps and contoured 1:100 000 maps prepared in 1970 are also available from the same sources.

Observation sites were recorded on the airphotos; their density is shown in Figure 2. Geological data were plotted on either the photographs or transparent overlays, and were later transposed to planimetric sheets at 1:100 000 scale. These compilation sheets were photographically reduced to 1:250 000 scale and in some cases redrawn by a draftsman. Preliminary editions of these geological sheets are available from BMR and GSWA.

During the survey, the mapped distribution of some of the rock units was changed considerably from that shown on the map of Veevers & Wells (1961). The validity of a number of others was questioned, such that some names have been dropped. A preliminary solid geology map of the area (Fig. 3) shows the distribution of the various rock units.

PREVIOUS INVESTIGATIONS

Geological

F.T. Gregory was the first explorer to work in the area covered by this Record, surveying the Nullagine-Oakover Rivers area in 1861 (Feeken & others, 1970). Colonel P.E. Warburton was the first to cross the area from east to west, in 1873-74. He traversed from Alice Springs to the Oakover River, via Joanna Spring, which he discovered and named (Warburton, 1875).

In 1879, Alexander Forrest traversed from the de Grey River to Darwin, travelling along the coast to Beagle Bay, then eastwards to the east coast of the Dampier Peninsula (Feeken & others, 1970). A geologist, Fenton Hill, was a member of this party.

L.A. Wells was the first to cross the area inland from south to north, in 1896-97 (Wells, 1902). W.F. Rudall covered an area in the south of the study area searching for lost members of Wells' party.

R.N. Smith (1898) traversed the Oakover-Nullagine Rivers area to see if artesian water could be discovered. The next geologist to work in the study area was F.G. Clapp, who traversed by tractor from Broome to the McLarty Hills, and also from Wallal Downs Station to Mount Phire (Clapp, 1925).

C. St J. Bremner (1942) made flights over the southern margin of the Canning Basin to delineate the edge of the basin and determine if Devonian limestone was present. F. Reeves (1949) made the first extensive survey of the Canning Basin in 1948, for the Vacuum Oil Company, traversing by vehicle and pack-horse. In the same year, BMR started geological surveys in the area, with field work in the Dampier Peninsula (Guppy & Lindner, 1949). In 1950, Brunnschweiler (Brunnschweiler, 1957) accompanied Mr Hampton Smith (consulting geologist for Ampol) on a more detailed survey of the Peninsula.

In 1954, BMR geologists mapped YARRIE, ANKETELL, and PATERSON RANGE (Traves, Casey & Wells, 1956) as part of a project to map the southwest Canning Basin, and subsequently, explanatory notes were produced for these sheets (respectively: Wells, 1959a; Casey, 1957; Wells, 1959b). Also in 1954, WAPET geologists traversed from Anna Plains Station to the McLarty Hills, and carried out a geological survey in the Dampier Peninsula (Rattigan & Elliott, 1954).

In 1957, BMR geologists made a helicopter survey of some of the eastern part of the area covered in this Record (Veevers & Wells, 1961), and published a 20 miles to the inch geological map of the Canning Basin.

Geophysical

The earliest geophysical investigations (Table 1) of the area were reconnaissance aeromagnetic and gravity surveys carried out by BMR.

Following the introduction of the Commonwealth Petroleum Search Subsidy Act in 1959, when subsidy became available for 50 percent of the acceptable costs of approved geophysical operations and stratigraphic drilling, company investigations began in earnest. Before the Act expired in June 1974, twenty-nine subsidised geophysical operations had been carried out onshore and close offshore from the study area.

Magnetics (Figure 4).

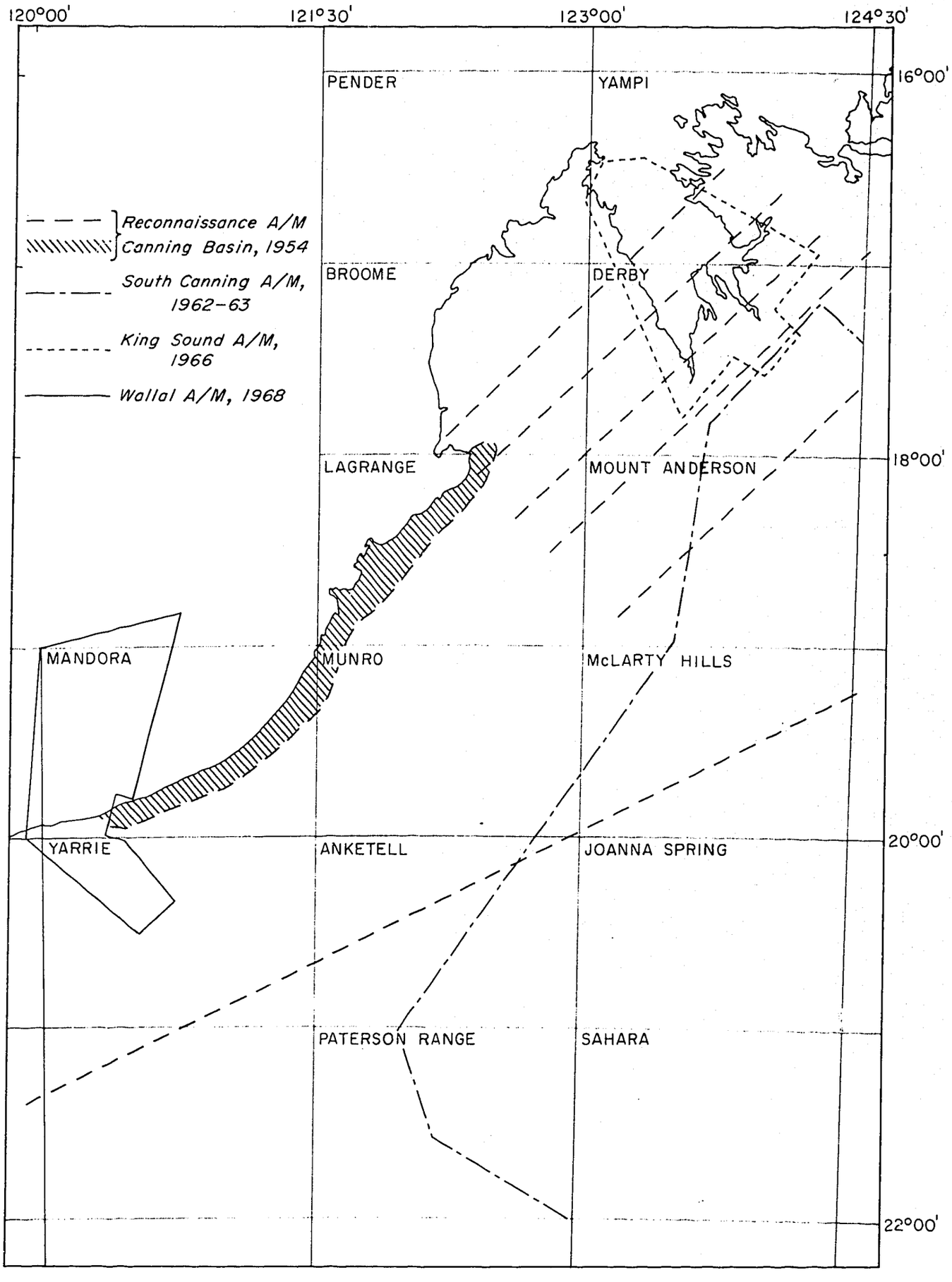
During 1954, BMR flew an essentially reconnaissance aeromagnetic survey consisting mainly of widely-spaced flight lines over the northern and western parts of the Canning Basin, and six closely spaced parallel lines along the coastal strip (Quilty, 1960). The magnetic profiles recorded over Dampier Peninsula on three of the lines indicated a considerable thickness of sediments overlying basement rocks. In the coastal strip, the aeromagnetic results

TABLE 1. BMR AND SUBSIDISED GEOPHYSICAL SURVEYS IN WEST CANNING BASIN

Survey Name/Area	Type	Organizaion	BMR File	Reference
Onslow-Derby	Regional Gravity	BMR	-	Dooley, J.C., 1963
Canning Basin	Regional Aeromagnetic	BMR		Quilty, J.H., 1960
Broome	Seismic	BMR		Vale, K.R., & Williams, L.W., 1955
Derby-Broome-Anna Plains	Regional Gravity	BMR	BMR Grav. File 5505	
La Grange	Seismic	BMR		Smith, E.R., 1960
Broome	Seismic	BMR		Smith, E.R., 1961
Anna Plains	Regional Gravity	BMR	BMR Grav. File 5605	
Barlee	Gravity	WAPET	62/1903	WAPET (1964b)
South Canning	Aeromagnetic	WAPET	62/1728	WAPET (1963a)
Sahara	Seismic	WAPET	63/1539	WAPET (1963c)
Joanna Springs	Gravity	WAPET	63/1908	WAPET (1964c)
Parda	Seismic	WAPET	64/4524	WAPET (1964a)
Dampierland	Semi-detailed Gravity	WAPET	65/4816	WAPET (1965c)
King Sound	Aeromagnetic	WAPET	66/4623	WAPET (1966b)
Roebuck	Seismic	WAPET	66/11115	WAPET (1967c)
Lower Fitzroy	Seismic/Magnetic	Gewerkschaft Elwerath	66/11111	Gewerkschaft Elwerath (1966)
Willara Hills	Seismic	WAPET	66/11081	WAPET (1966a)
Dampierland	Seismic	WAPET	66/11099	WAPET (1966e)
Nita-Willara	Seismic	WAPET	66/11131	WAPET (1966c)
Munro-Arch	Gravity	WAPET	67/4829	WAPET (1967a)
Jamura	Gravity	French Petroleum	67/4832	FRENCH PETROLEUM (1967a)
McLarty	Gravity & Seismic	French Petroleum	67/11145	FRENCH PETROLEUM (1967b)
Wallal	Marine Seismic	WAPET	67/11208	WAPET (1967b)
Baskerville	Seismic	WAPET	68/3023	WAPET (1968c)
Wallal	Aeromagnetic	WAPET	69/3037	WAPET (1969a)
Munro Arch	Seismic	WAPET	69/3042	WAPET (1969b)
Munro R-1	Seismic	WAPET	69/3081	WAPET (1969c)
Pender	Seismic	WAPET	70/817	WAPET (1970a)
King Sound	Marine Seismic	WAPET	70/218	WAPET (1970b)
Broome-Samphire	Seismic	WAPET	70/857	WAPET (1971a)
Anketell	Seismic	WAPET	70/896	WAPET (1971b)
Munro detail	Detailed Seismic	WAPET	70/1000	WAPET (1971c)
Munro D-2	Seismic	WAPET	71/478	WAPET (1971d)
North Broome	Seismic	WAPET	71/252	WAPET (1971e)
North Broome D-2	Seismic	WAPET	72/961	WAPET (1972a)
Sahara II	Seismic	WAPET	73/234	WAPET (1973b)

TABLE 2: WELLS DRILLED IN THE WEST CANNING BASIN (FIGURE 1)

Name of Well	Year Drilled	Latitude	Longitude	Total Depth (m)	Hydrocarbon shows	Reference
Roebuck Bay 1	1956	18°09'30"S	122°27'30"E	1219.2	Nil	WAPET 1956b
Wallal Core Hole 1	1957	19°51'46"S	120°37'00"E	309	Nil	WAPET 1957
Samphire Marsh 1	1958	19°31'08"S	121°10'51"E	2031.2	Nil	WAPET 1961a
Wallal 4	1958	19°44'12"S	120°44'25"E	430	Nil	Henderson & others, 1963
Wallal 4A	1958	19°44'12"S	120°44'25"E	234	Nil	Henderson & others, 1963
Goldwyer 1	1958	18°22'47"S	122°22'58"E	1438.7	Traces of oil	WAPET 1959a
Thangoo 1	1959	18°22'06"S	122°53'22"E	1059.2	Traces of oil	WAPET 1961b
Thangoo 1A	1959-60	18°21'52"S	122°53'09"E	1655.4	Nil	WAPET 1961b
Barlee 1	1960	17°48'25"S	122°42'40"E	2469.1	Methane gas, bitumen	WAPET 1961c
Parda 1	1965	18°56'08"S	122°00'34"E	1907	Slight traces of oil	WAPET 1965a
Willara 1	1965	19°10'48"S	122°04'14"E	3903.3	Methane, ethane gas show	WAPET 1965b
Yulleroo 1	1967	17°51'16"S	122°54'25"E	4572	Gas	Gewerkschaft Elwerath 1967
McLarty 1	1968	19°23'45"S	123°39'30"E	2590.8	Bituminous	TOTAL 1968a
Kemp Field 1	1968	20°19'10"S	123°27'58"E	1181.1	Nil	TOTAL 1968b
Willara Hill 1	1968	19°03'31"S	121°52'45"E	858	Nil	WAPET 1968a
Chirup 1	1968	19°50'54"S	120°25'57"E	762.6	Nil	WAPET 1968b
Tappers Inlet 1	1971	16°51'38"S	122°35'22"E	2856.2	Small traces of oil	WAPET 1971f
Munda 1	1971	19°28'27"S	122°17'32"E	1066.8	Nil	WAPET 1971g
Pender 1	1972	16°40'48"S	122°50'06"E	911.7	Nil	WAPET 1972b
Munro 1	1972	19°51'47"S	122°28'28"E	2116	Nil	WAPET 1972c
Thangoo 2	1973	18°26'32"S	122°54'33"E	1472	Nil	WAPET 1973a



Record 1980/30

AUS 1/ 1093

Fig. 4 Aeromagnetic surveys

indicated depth-to-basement of less than 3000 m beneath the whole area traversed. Depth estimates of between 300 m and 900 m near Wallal Downs homestead were confirmed by the BMR WALLAL boreholes (Henderson & others, 1963).

The first subsidised survey to involve the area was part of the South Canning Basin Aeromagnetic Survey, flown in 1962-63 by Aero Services Limited for West Australian Petroleum Pty Ltd (WAPET, 1963a). This regional reconnaissance airborne magnetometer survey covered the eastern portion of the area, namely McLARTY HILLS, JOANNA SPRING, eastern PATERSON RANGE, eastern ANKETELL, and southeast corner of MUNRO as well as DERBY, MOUNT ANDERSON, and SAHARA (outside the study area). Its objective was to delineate the depth and configuration of the Canning Basin and to reveal, if possible, other structural features in the area. A major basin-like depression ('Joanna Spring Sub-basin') with a maximum depth of over 6000 m below sea level, and an east-west orientation, was interpreted. A basement ridge trending southeast across McLARTY HILLS (Broome Arch) was confirmed by this survey.

A magnetometer survey was carried out in 1966 in conjunction with seismic work in the Lower Fitzroy area (BROOME and LA GRANGE) by Gewerkschaft Elwerath (1966). This showed that magnetic intensity increases to the south in the area.

The detailed 'King Sound Aeromagnetic Survey', comprising 2665 line-miles (3624 line-km) over King Sound, was flown in mid-1966 for WAPET by Adastra Hunting Geophysics Pty Ltd. Its purpose was to find the depth, and indicate the form of, the magnetic basement, and to define any basement highs that might be associated with Devonian reef structures. Depth to magnetic basement increases from the surface outcrops in the north (YAMPI) to about 7000 m below sea level in the south. The dominant structure is the 'Oscar Ridge' which can be traced from the southeast through Point Torment (DERBY) to the western side of King Sound. The survey failed to resolve conclusively whether the structure of the 'Oscar Ridge' is faulted or monoclinal on its southern flanks (WAPET, 1966b).

WAPET conducted the Wallal Aeromagnetic Survey of 1410 line-miles (2270 line-km) covering about 14 800 km^2 in 1968 in YARRIE and MANDORA. Its main aim was to delineate the offshore extension of the 'Wallal Platform' and the 'Wallal Embayment' and the faults separating these features, and to define the depth to basement and the basement configuration. The survey indicated the existence of four main zones and faults associated with them. Two of the zones were considered the extensions of the 'Wallal Embayment' and 'Wallal Platform' (WAPET, 1969a).

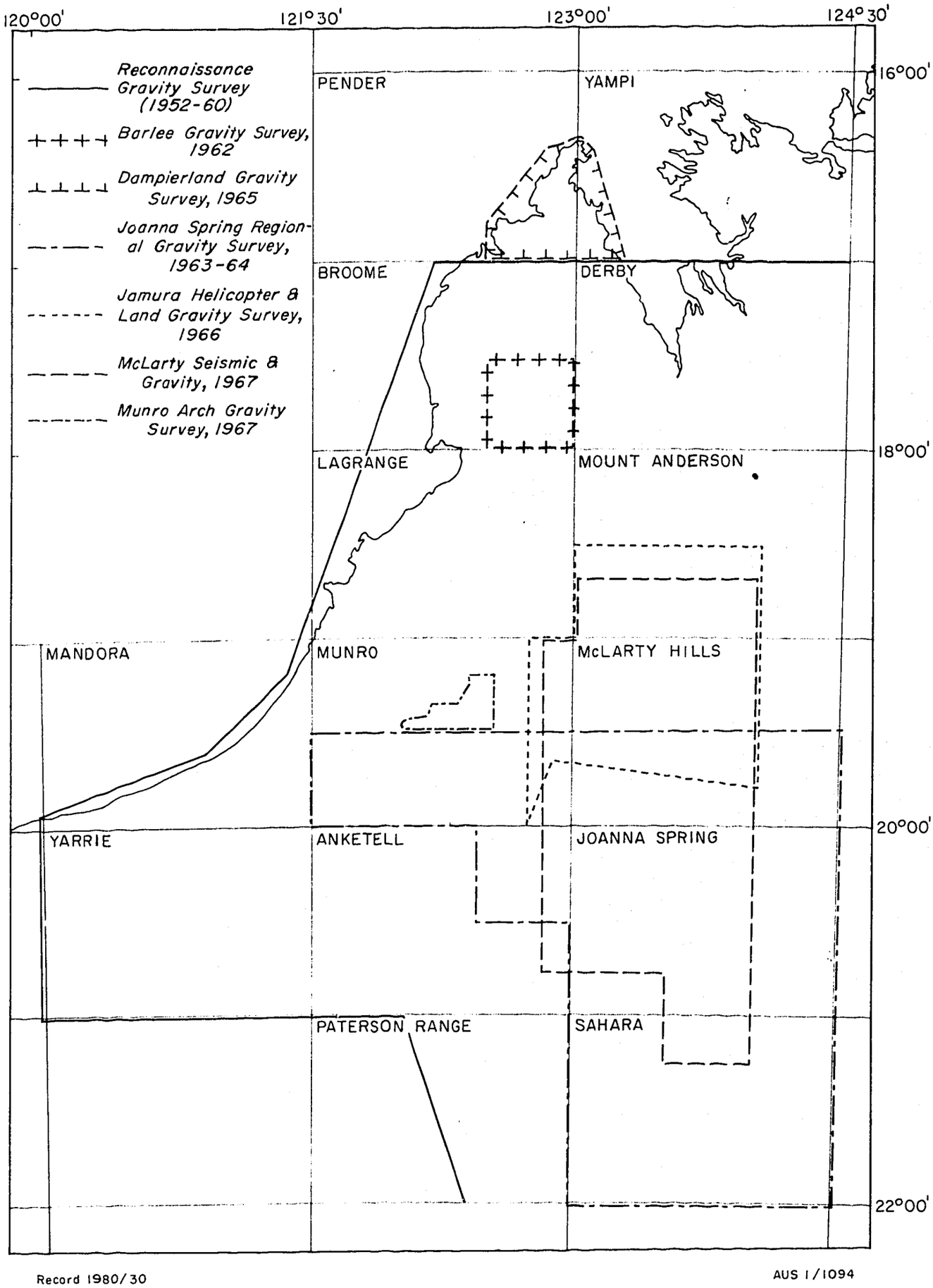
Gravity (Figure 5). BMR began gravity investigations in the Canning Basin in 1952, and by 1960 most of the basin had been covered (Flavelle & Goodspeed, 1962). However, the density of the gravity stations varies greatly owing to the remoteness of some areas. Numerous gravity features were delineated, including 'Broome Gravity Depression', 'La Grange Platform', 'Anketell Gravity Ridge', 'Wallal Platform' and 'Wallal Gravity Depression'.

In 1953, gravity-meter and barometer readings were taken at intervals of about 35 km along the old Great Northern Highway from Onslow to Derby. The brief survey conclusions were tentative in the absence of definite information on rock densities in much of the area (Dooley, 1963).

In 1959, a detailed gravity survey about a proposed drillhole location situated on the complex, faulted anticlinal Barlee Structure was carried out to evaluate the possibility that a salt intrusion could be associated with this structure. It also involved the integregation of all available geophysical data to determine the most reasonable interpretation of this complicated structure. The conclusion obtained from the survey was that no appreciable mass of intrusive salt underlies the area, although a uniform thickness of bedded salt may be present at depth under the structure (WAPET, 1964b).

In 1963-64, WAPET carried out the Joanna Spring Gravity Survey, over JOANNA SPRING and portions of McLARTY HILLS and MUNRO (WAPET, 1964c). The survey was the northern continuation of the Sahara Gravity Survey (WAPET, 1963b) and had the objective of extending the regional gravity coverage over the 'Joanna Spring Sub-basin' portion of the Canning Basin, in the hope of finding gravity anomalies attributable to sedimentary structures. The dominant features observed in the results were: a large east-west gravity positive trend across northern JOANNA SPRING attributed to changes within the basement rocks; a broad gentle northwest negative trend which marks the axis of the Kidson Sub-basin, diagonally across the eastern portion of JOANNA SPRING; and east-west gravity positive, the 'Mellinjerie Swell', at the junction of SAHARA and JOANNA SPRING, which correlates roughly with some magnetic features as well has having expression in the sedimentary section; and a discontinuous northwest positive trend, the 'Kemp-Percival' trend, diagonally across both JOANNA SPRING and SAHARA.

In 1965 Wongela Geophysical Pty Ltd conducted the Dampierland semi-detailed gravity survey for WAPET, covering PENDER and western YAMPI, with the object of supplementing information obtained from the previous aeromagnetic survey (Quilty, 1960) and helping to delineate structural units within the area. The results interpreted in conjunction with the aeromagnetic results suggested that the mapped Bouguer anomalies largely reflect density changes within the



Record 1980/30

AUS 1/1094

Fig. 5 Gravity surveys

basement. Three areas of possible local sedimentary thickening were also indicated (WAPET, 1965c).

During 1966, French Petroleum Co. (Australia) Pty Ltd conducted the Jamura Helicopter and Land Gravity Survey, involving LA GRANGE, MOUNT ANDERSON, McLARTY HILLS, and MUNRO. Its aim was to extend the gravity coverage northwards of the area previously covered by WAPET's Joanna Spring Gravity Survey. The regional results were dominated by two features: one was a large northwest-trending gravity low on the southern edge of the survey area, and the other was a gravity high located along the western central portion of the survey with high trends extending to the southeast and east. The size and magnitude of these two features indicate that they could be of regional origin, caused by good density contrasts between basement and the overlying sediments (Darby & Fraser, 1969). A number of local anomalies of possible oil-bearing interest were also detected in the survey area (French Petroleum, 1967a). This was followed in 1967 by further gravity work in the area, combined with the McLarty Seismic Survey (French Petroleum, 1967b).

In 1967, Wongela Geophysical Pty Ltd conducted the Munro Arch Gravity Survey for WAPET in MUNRO. Its objectives were to evaluate the stratigraphy and structure of the Munro Arch area which separated the 'Joanna Spring Sub-basins' and the 'Parda Sub-basin' (see Seismic below). Data from this survey, together with other available geological and geophysical information from adjacent areas enabled certain sedimentary depressions, faults, and basement high areas to be interpreted and named. Seismic work and follow-up drilling were recommended to enable more information to be obained from these gravity data for a better quantitative appraisal (WAPET, 1967a).

The gravity contours that will be printed on the First Edition maps for this area are based on survey data by Wongela in 1968, processed by Darby & Fraser (1969), and by Wongela in 1969, processed by Fraser (1974), together with revision of the earlier work of Flavelle & Goodspeed (1962) and by Darby & Vale (1969). These gravity contours outline parts of four gravity provinces: the Anketell Regional Gravity High, the Munro Regional Gravity Platform, the South Canning Regional Gravity Low, and the Fitzroy Regional Gravity Complex.

Seismic (Figure 6). A seismic reflection and survey was conducted by BMR during 1955 in the La Grange area, with the aim of investigating the sedimentary development of the basin south of the Fenton Fault, where very little geological information was available. A sedimentary section of at least 1350 m, and possibly as much as 2100 m to 2400 m was indicated.

A very limited survey was conducted in 1954 by a BMR seismic party in the vicinity of Broome, while waiting for the flooded Fitzroy River to recede. It indicated a considerable thickness of probably folded sediments (Vale & Williams, 1955). In the following year, another seismic reflection survey of that same area was conducted. This work indicated a sedimentary thickness of at least 1800 m, and possibly as much as 3000 m. The subsurface formations showed some structural relief which could not be observed from visible features at the surface (Smith, 1961).

WAPET began seismic operations in the area with several surveys in BROOME and LA GRANGE (WAPET 1956a, 1959b, 1960). These surveys located several anticlinal structures, and WAPET Roebuck Bay 1, and WAPET Thangoo 1 and 1A wells were subsequently drilled on two of these structures.

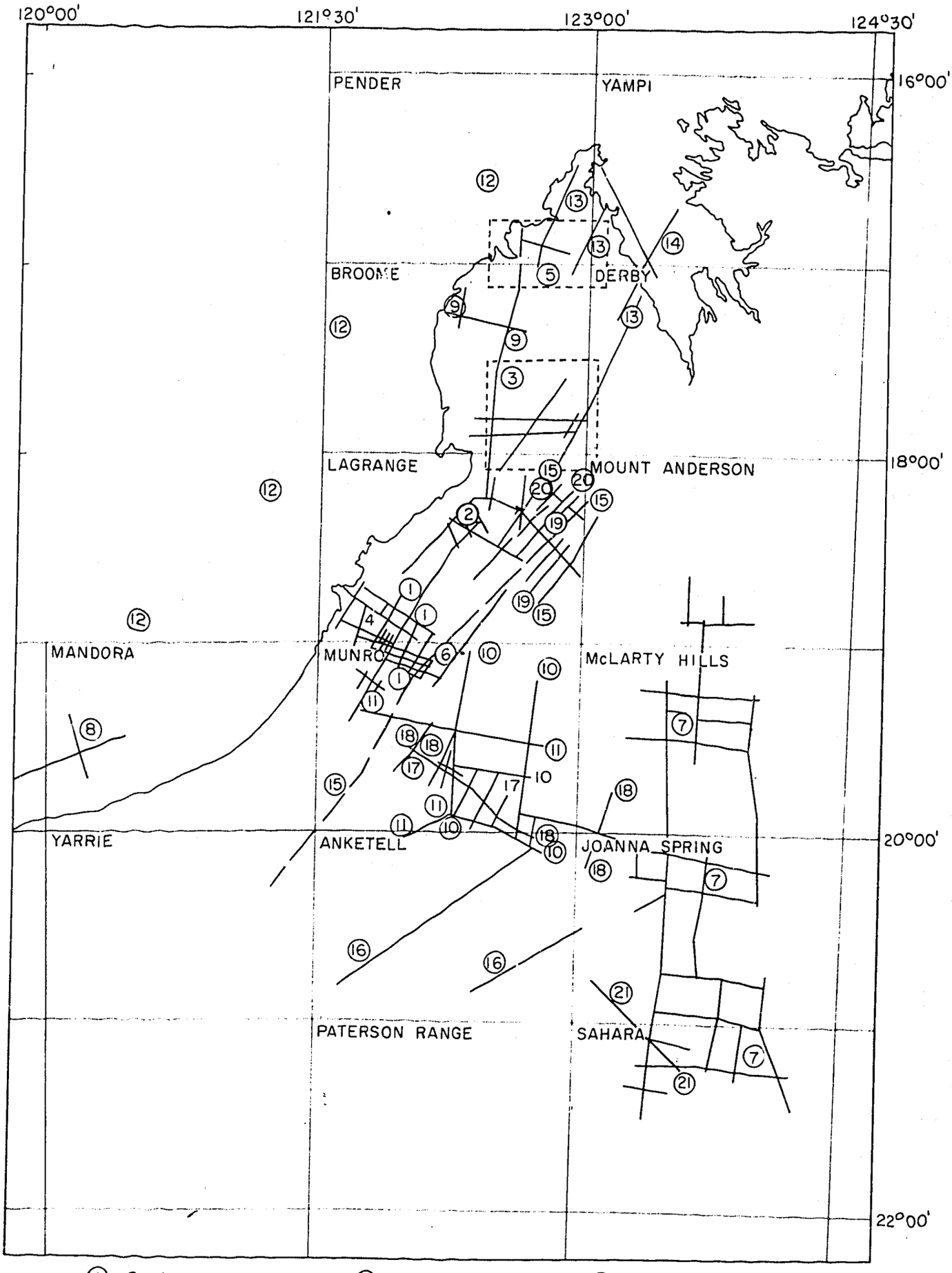
The Parda Seismic Reconnaissance Survey (WAPET, 1964a), the first subsidised survey in the area, was located east of Frazier Downs and Nita Downs homesteads on southern LA GRANGE and northern MUNRO. Its objectives were to investigate a possible sedimentary basin ('Parda Sub-basin') as interpreted from aeromagnetic data, to determine the significance of the 'Gourdon Bay' and 'Admiral Bay' Bouguer Gravity maximum trends, and finally to indicate a drilling location to test the pre-Permian stratigraphy. The seismic data were considered generally reliable, and the results showed the existence of a basin (Parda Sub-basin) with at least 3000 m of sediments.

The Dampierland seismic survey of 1966 (WAPET, 1966e) gave some useful structural information in the Dampier Peninsula, but failed to indicate any closed structures.

The Lower Fitzroy seismic survey (Gewerkschaft Elwerath, 1966) delineated several closed structures in southeastern BROOME and northeastern LA GRANGE.

The reflection seismic survey of the Willara Hill Project was conducted in March-April 1966 near the coast on southern LA GRANGE and northern MUNRO. Its purpose was to ascertain the regional dip of the northwestern half of the Admiral Bay Fault, to investigate anomalies, and to locate a drill site on the Willara Hill Structure in the Admiral Bay Fault. Two horizons were mapped in the Ordovician units, while two anticlinal noses in Permian rocks plunge to the southeast. These structures were located parallel to, but on opposite sides of, the Admiral Bay Fault, but further seismic work is required to define them accurately (WAPET, 1966a).

The objective of the Nita-Willara Seismic Survey (WAPET, 1966c) was to locate a shallow drilling target; such a target, in the Permian Grant Group, was proposed on a structure near Nita Downs homestead. A possible drilling site was defined and two new structures were suggested for further seismic investigation.



1. Parda
2. Roebuck
3. Lower Fitzroy
4. Willara Hills
5. Dampierland
6. Nita-Willara
7. McIarty
8. Wallal Marine
9. Baskerville
10. Munro-Arch
11. Munro R-1
12. Bedout Marine
13. Pender
14. King Sound
15. Broome-Samphire
16. Anketell
17. Munro-detailed
18. Munro D-2
19. North Broome
20. North Broome D-2
21. Sahara II

Record 1980/30

Fig 6 Seismic surveys (subsidised)

AUS 1/1095

In late 1966-early 1967, two reflection seismograph survey parties carried out the Roebuck Seismic Survey in north-central LA GRANGE. The principal objective was to provide regional coverage of a portion of the Broome Arch between Goldwyer 1 and Roebuck Bay 1 well sites, with the secondary objective of investigating anomalies thought to represent carbonate build-ups within the Ordovician Goldwyer Formation. Data produced by the survey were of poor quality in some areas, particularly in the tidal flats. Several features considered favourable to the accumulation of hydrocarbons were mapped (WAPET, 1967c).

The McLarty Seismic and Gravity reconnaissance survey was conducted by Ray Geophysics (Australia) Pty Ltd for French Petroleum (Australia) Pty Ltd, over an area covering McLARTY HILLS, JOANNA SPRING, and western MUNRO. Its main purpose was to locate prospective drill sites in the central part of the Canning Basin. Two seismic markers in pre-Devonian rocks were mapped. Two geological structures were established, both of which were confirmed by seismic and gravity techniques (French Petroleum, 1967b).

During 1968, WAPET conducted a short reconnaissance survey, the Wallal Marine Seismic Survey, to determine whether a structural embayment occurs southwest of the Wallal Platform. The survey results confirmed that a small structural embayment does occur (referred to by WAPET as 'Wallal Embayment', see Fig. 17) and that it is bounded in the northeast by a fault and in the southwest by thinning of the section adjacent to an upthrown fault block. The thickest sedimentary section is on the downthrown (northeast) side of the major fault. Three structural traps with fault closures were indicated (WAPET, 1967b).

WAPET also carried out the Baskerville Seismic Survey (WAPET, 1968c) in northern BROOME, to check a major structural high originally suggested by aeromagnetic and gravity work in the northwestern part of the Fitzroy Trough, and also to connect the Dampierland Seismic Survey in the north with a previous survey, by Gewerkschaft-Elwerath (the lower Fitzroy Survey), to the south. The survey results outlined two major anticlines, but reflection quality was poor, and hence further detailed work is required to properly delineate them.

The Munro Arch seismic survey (WAPET, 1969b), located on MUNRO and northern ANKETELL, was conducted by Geophysical Service International in 1969 for WAPET. There were two objectives. The first was to confirm that a structurally high area, the 'Munro Arch', existed between the Willara (Parda) and Kidson Sub-basins as suggested by gravity and aeromagnetic data. The second was to define the trend of the faulted hinge line (Admiral Bay Fault) that forms the boundary between the Willara Sub-basin and the Broome Platform. Seven lines were shot, five east-west and two north-south. Three horizons were mapped:
Horizon A -

within the Permian upper Grant Group, Horizon B - within the Ordovician Goldwyer Formation, and Horizon C - within the Ordovician Thangoo Limestone. A structurally high area trending north-south was mapped to the west of the predicted position of the 'Munro Arch'. Since this high area is of lesser magnitude than that indicated by aeromagnetics, it was therefore considered that the survey failed to confirm the existence of the 'Munro Arch' (but see below). The results also indicated that the Admiral Bay Fault is more likely to continue across the area in an easterly direction rather than swing to the south as suggested by earlier aeromagnetic and gravity interpretation. A drill site was recommended 6 km north of Willara 1 well.

The primary objective of the Munro R-1 seismic survey (WAPET 1969c) located in MUNRO and northern ANKETELL was to more clearly outline the configuration of the Willara Sub-basin. The secondary objective was to investigate the manner in which the sedimentary section overlaps the Anketell Regional Gravity High. Two lines were shot, three horizons being identified: Horizon A - within the Permian Grant Group, Horizon B - within Ordovician Goldwyer Formation, and Horizon C - within the Ordovician Thangoo Limestone. An isopach map of the interval between horizons A and B was prepared. Four lines from the Munro Arch seismic survey were incorporated in the mapping. The results confirmed a basement ridge corresponding to the Anketell Regional Gravity High but added little to the knowledge of the configuration of the Willara Sub-basin.

In April, 1969, WAPET conducted the Bedout Marine Seismic Survey (WAPET, 1969d) in the Point Samson-Cape Leveque area. The objectives were to determine structure and thickness of strata, to map the offshore extension of the Fitzroy Trough and the Baskerville Anticline, and to obtain information on the thickening of Jurassic-Cretaceous sediments in the southern part of the offshore Canning Basin. The results were generally good. Although the northern limit of the Fitzroy Trough offshore could not be defined, the southern limit (Dampier Fault) was shown to extend offshore and it was demonstrated that the Baskerville Anticline plunges northwest through the area surveyed. The Jurassic-Cretaceous sediments seemed to be an offshore extension of the Willara Sub-basin. Nineteen structural anomalies were mapped and there were numerous other stratigraphic anomalies (pinch-outs, truncations etc.).

The Pender Seismic survey (WAPET, 1970a) was located on the Dampier Peninsula, in PENDER and DERBY. Its objectives were to provide reconnaisance seismic coverage in this part of the Canning Basin, and to define the westerly extension of the Lennard Shelf and its southern margin in this area. The survey consisted of three widely spaced (35-km) parallel southwest-trending

lines. Three horizons were mapped: Horizon A - near the base of the lower Triassic Blina Shale, Horizon B - near the top of the Grant Group, and Horizon C - near the base of the Laurel Formation. The westerly extension of the Lennard Shelf was confirmed, with a southward thickening of the sediments on it. No prospective hydrocarbons traps were discovered, but these could still occur between the widely spaced traverses.

The WAPET King Sound seismic reconnaissance survey was designed to elucidate the structure between an area of Precambrian strata cropping out to the north and an area of sediments cropping out on the southern margin of the Lennard Shelf. The results confirmed the presence of a comparatively thin undisturbed sequence thickening southwards and cut by major faults; indications of structural growth were confined to the Carboniferous and older sediments (WAPET, 1970b).

The Broome-Samphire Seismic Survey (WAPET, 1971a) provided regional reconnaissance control over an area extending from the Wallal Platform in the south to the northern part of the Broome Platform in LA GRANGE, MANDORA, northern ANKETELL, and YARRIE. Two seismic horizons were mapped in the northern portion and four in the south. The results of the survey provided reliable data which could be carried across the Broome Platform and the Willara Sub-basin to the Anketell Ridge (Anketell Shelf) where the stratigraphic section thinned markedly. In the northern part of the project area a broad anticlinal ridge was mapped trending northwest to west.

A reflection seismic survey - the Anketell Seismic Survey (WAPET, 1971b) - was conducted for WAPET in late 1970-early 1971 in the northwestern portion of the Kidson Sub-basin, on ANKETELL. Its aim was to investigate the structure and stratigraphy of this portion of the sub-basin as well as the tectonic elements which border it. Three seismic horizons were mapped: base of the Grant Group, top of the Goldwyer Formation, and the top of the Thangoo Limestone. The results confirmed the northeast regional dip from the Anketell Ridge into the Kidson Sub-basin and revealed a series of northwest-trending faults between the Anketell Ridge and the Munro Arch. A broad anticlinal trend - the Chirit anticlinal trend - with features favourable to the accumulation of hydrocarbons was mapped.

The Munro detailed seismic survey (WAPET, 1971c) was carried out in early 1971 in the southeastern section of the Willara Sub-basin (central MUNRO). The objectives were to delineate the Munro Structural Trend (Munro Arch), and the Munro Fault, and to site a well location. The three horizons mapped were identified as near the top of the Cuncudgerie Sandstone (now the Grant Group), the Goldwyer Formation (Ordovician), and the Thangoo Limestone (Ordovician).

The best-quality data were obtained from the Goldwyer Formation. The data from this survey were integrated with approximately 480 line-km of data from earlier surveys in the area. The two structures under investigation were identified on the Ordovician horizons. The Munro Fault was defined as a northwest-trending normal fault, downthrown to the southwest, and diminishing in magnitude to the northwest. Sediments younger than the Goldwyer Formation do not appear to be affected by the faulting which was apparently active throughout Ordovician times. The Munro Arch was defined as an elongated northwest-trending anticline with a number of postulated separate culminations on the upthrown side of the fault. The configuration on the 'Cuncudgerie Sandstone' horizon suggested possible development of shallow salt solution structures. Further seismic work was recommended before a well could be sited.

The Munro D-2 survey (WAPET, 1971d) was conducted in 1971 to confirm the closure on the Munro Arch, and to investigate a strong gravity maxima trend situated to the east of it. Data quality of the three horizons mapped was generally fair on all of them. The survey confirmed an elongated northwest-trending anticlincal structure along which four separate culminations were defined, two of which were recommended as well locations. The structure as a whole is closed to the northeast by the regional dip and to the southwest by the Munro Fault. It has minimum vertical closure of approximately 150 milliseconds and an areal extent of about 260 km^2 at the level of the Thangoo Limestone horizon. Line B of the survey revealed that the gravity maximum was not associated with any significant structural relief. WAPET Munda 1 well was sited on one of the culminations on the Munro Arch.

In mid-1971, a detailed seismic survey - the North Broome Seismic - was conducted for WAPET in the northwestern portion of the Broome Platform, with the aim of detailing major structural leads resulting from previous seismic surveys in order to locate a well site. Included in the interpretation were data from original and reprocessed sections from approximately 368 line-km of previous surveys. Two horizons were mapped: the unconformity surface at the base of the Permian, and on horizon near the top of the Thangoo Limestone (Ordovician). A large, faulted and eroded Ordovician anticlinal structure was detailed. The faulting, which is of small magnitude, has mainly affected the northern flanks of the structure. Near the crest of this structure, two prospective features, located 6 1/2 km south and 13 km southwest respectively of Thangoo 1 and 1A wells, were delineated (WAPET, 1971e).

In 1972, the North Broome D-2 seismic survey located between latitude $18^{o}10'$ and $18^{o}40'$ and longitude $122^{o}35'$ and $123^{o}05'$, was conducted by Digicon (Australia) Limited for WAPET. Its objectives were to detail the most

promising local structural closures and to locate a well site on the most attractive of these closures in order to test the hydrocarbon potential of the Ordovician Willara and Goldwyer Formations. Two seismic horizons - one near to Willara Formation, and the unconformity at the base of the Permian - were mapped. Five structural features were defined but only one in sufficient detail for a well to be sited. The survey also demonstrated that Thangoo 1, which has oil shows, and Thangoo 1A, with no indication of hydrocarbons, were sited on separate fault blocks (WAPET, 1972a).

The Sahara II seismic survey (WAPET, 1973b) was located in the central-southern part of the Canning Basin over the southwestern part of the Kidson Sub-basin (JOANNA SPRING). It consisted of a single seismic line 64 km long, extending from WAPET Sahara 1 well in a northwesterly direction along the trend of the 'Chirit Anticline'. The aim of the survey was to provide seismic control along the strike of the 'Chirit' structural trend and locate any possible closures. The quality of the data obtained was generally good, especially near WAPET Sahara 1 well, but deteriorated towards the northwest because of the surface sand dunes. These data were incorporated with data from previous surveys to produce contour maps on three horizons: horizon A - near base of Grant Group (pre-Permian unconformity); horizon B - near base of Tandalgoo Beds (Devonian); and horizon C - near top of Willara Formation. Horizon A and B were tied to WAPET Sahara 1, while horizon C, which was not penetrated in that well, was identified on reflection character and velocity data derived from WAPET Munro 1 well. The 'Chirit' anticlinal trend was revealed as trending northwest with a plunge to the southeast at Ordovician depths. Closure was established in several places along the axis.

Drilling (Figure 1). To aid in the determination of the age and the nature of the regional stratigraphy and to evaluate the hydrocarbon potential of the Ordovician limestones as well as other rocks within the area, 21 petroleum exploration wells have been drilled, 16 by WAPET, 2 by Total Exploration Australia Oil Company, two by BMR and one by Gewerkschaft Elwerath (Table 2).

WAPET Roebuck Bay 1 (WAPET, 1956b), the first well to be drilled in the area, tested the Broome Arch. It was completed without any hydrocarbon shows at a depth of 1222.2 m, and Devonian limestones, or so it was thought, were intersected. The limestones are now interpreted to be of Ordovician age. A summary of the stratigraphy is given in Appendix 2, A1.

In 1957, a stratigraphic hole, WAPET Wallal Core Hole 1 (WAPET, 1957), was spudded in along the coastal part of the South Canning Basin to check a zero basement contour on maps prepared from an aeromagnetic survey flown in 1955.

The well, which produced good quality artesian water, was completed as a water well for Wallal Downs Station after reaching a depth of 309.1 m. The stratigraphy is summarised in Appendix 2, A2.

In the same year, the first Petroleum Search Subsidy Act was brought in, to encourage the search for petroleum in Australia. From 1958, most petroleum wells drilled in the Canning Basin were Government subsidised. In 1958, WAPET drilled Samphire Marsh 1 (WAPET, 1961a), the first of the wells in the Canning Basin to be subsidised under this new scheme. It penetrated Precambrian gneissic granite at 2014.7 m. No part of the sequence (Appendix 2, A4) was considered likely to be a source for hydrocarbon accumulations and there were no hydrocarbons in the well. In the same year, two stratigraphic holes, BMR Wallal Nos. 4 and 4A (Henderson & others, 1963), were drilled. Water inflow forced the abandonment of No. 4 well; No. 4A well reached basement of granitic gneiss at 677.9 m. Data from these wells (Appendix 2,A3), when added to that obtained from Samphire Marsh 1 and from seismic surveys, established a possible structural framework for this area of the basin.

The Broome Arch was further tested by WAPET in 1958 with the drilling of Goldwyer 1 well (WAPET, 1959a). This well reached granitic basement at 1432.6 m, and was plugged and abandoned (Appendix 2,A5). The drilling of this well showed that the Ordovician formations in the Canning Basin contain potential oil source rocks, and may also retain sufficient porosity to provide reservoirs suitable for hydrocarbon accumulations.

In November 1959, WAPET spudded in Thangoo 1 well (WAPET, 1961b). The well was located on a seismic culmination situated between WAPET Dampier Downs 1 and Goldwyer 1 wells and its objective was the porous Ordovician limestones intersected in the neighbouring wells. Collapse of this hole led to its abandonment at 1059.2 m in the Grant Group (Appendix 2,A6). WAPET Thangoo 1A (WAPET, 1961b), located nearby, drilled through the Ordovician limestone which was the target, into the Precambrian basement (Appendix 2,A7). Although traces of oil were encountered throughout the Ordovician section, as well as in the Grant Group, the results in general from Thangoo 1A were held to downgrade the potential of the Ordovician rocks in that part of the basin.

A structure detected by BMR seismic and WAPET aeromagnetic surveys in the Barlee area was the site for WAPET Barlee 1 well (WAPET, 1961c) with target set as the Upper Devonian limestones. The well was drilled in 1960 to a depth of 2469.2 m (Appendix 2,A8), where it was abandoned in a dolerite intrusive in the Anderson Formation; slight gas traces were detected in this formation. The unexpectedly thick Carboniferous sequence showed that the well was not located on the Jurgurra Terrace as had been expected, but in the Fitzroy Trough, which was found to extend south to the Dampier Fault, and that the structure drilled

may have been formed by an igneous intrusion.

In 1965, there was a resurgence of drilling activity in the Canning Basin. WAPET Parda 1 (WAPET, 1965a) was drilled on the southern margin of the Broome Arch, in a regionally favourable position between the shaley source rocks of the Willara Sub-basin to the south and Ordovician limestones encountered in wells on the Broome Arch. The primary objectives of the well were to test the hydrocarbon potential of Ordovician limestones, and the top of the Permian Grant Group. The well provided valuable information on a stratigraphically untested part of the Canning Basin (Appendix 2,A9). Also, in the same year, WAPET Willara 1 (WAPET, 1965b) was drilled in the Willara Sub-basin, about 24 km south of Parda 1. Its aim was to explore and to evaluate the hydrocarbon potential of the 'Willara Structure', a seismically defined north-south elongated domal structure which is bounded to the north by a major down-to-the-south-fault, and which is within the Willara Sub-basin. The well encountered a 620-m-thick evaporite-redbed-carbonate sequence overlying the marine Ordovician and underlying the Permian. A thick section of predominantly shaly beds in the Ordovician (Appendix 2,A10), compared with the limestone of the Parda 1 sequence and other areas on the Broome Arch, suggests that the Willara Sub-basin existed as a sedimentary basin during Ordovician time.

In 1967, Gewerkschaft-Elwerath of Germany, in a farm out agreement with WAPET, spudded in Yulleroo 1 (Gewerkschaft-Elwerath, 1967) on the southeastern flank of the seismically defined Yulleroo structure in Palaeozoic rocks under flat lying Mesozoic sediments. The main objectives of the well were to examine the stratigraphy and facies of the pre-Late Carboniferous sequence in the western Fitzroy Trough and to evaluate the hydrocarbon potential of the Early Palaeozoic. The well was plugged and abandoned at 4574.7 m (Appendix 2,A11) the deepest well in the Canning Basin, after having passed through an unexpectedly thick Carboniferous sequence with only a few insignificant shows of gas.

In 1968, a drilling program of five wells was started by Total Exploration Australia Pty Ltd (Total), the name by which French Petroleum Company was called after May of that year. These holes were the outcome of the intensive survey work carried out by the Company in the west-central part of the Canning Basin, and all of the wells were located on seismically determined structures on or near the Broome Arch. Two of these wells occur within the area of this report. The first of these, McLarty 1 well (Total, 1968a), was drilled in order to provide stratigraphic information in a poorly known area and to test the pre-Permian Palaeozoic sequences. It was located on the eastern flank of a

closed structure with a minimum closure of 30 m and a closed surface area of 424 sq. km. The well was plugged and abandoned at a depth of 2590.8 m (Appendix 2, A12) after confirming that the Permian sequence was eroded down to the Grant Group, and that the Goldwyer Formation was an excellent source rock; however, no reservoir rocks were developed in the area.

The Kemp Field 1 well (the third in the series of five wells by Total) was designed to test all reservoirs above the Carribuddy Formation, and in particularly to test the possible development of reefal facies in the Mellinjerie Limestone in a zone of poor seismic reflection at the deeper horizons (Total, 1968b). It was also programmed to provide data for correlation between WAPET Sahara 1 to the south and Total McLarty 1 to the north. The drilling of the well indicated that the Tandalgoo Red Beds are an excellent reservoir but that they pinch out below the Permian unconformity north of the well. It confirmed the Mellinjerie Limestone to be of Devonian age, that no reservoirs are developed in it, and a reef facies occurs within it at this locality (Appendix 2, A13).

Also in 1968, WAPET drilled two wells in the region, Willara Hill 1 (WAPET, 1968a) and Chirup 1 (WAPET, 1968b). The first well, located on the northern margin of the Willara Sub-basin, was drilled on a Permian high on the Admiral Bay Fault in anticipation that hydrocarbons encountered in the Grant Group in WAPET Willara 1, south of the hinge, may have accummulated up-dip in this structural high. The target point proved to be deeper than anticipated and there was a lack of fine-grained sediments to provide cap rocks for hydrocarbon accumulations. Hence the well was plugged and abandoned at 858 m (Appendix 2, A14). The second well, Chirup 1, located in the Wallal Embayment, was the only unsubsidised WAPET well in the area. The well was drilled to a depth of 762.6 m (Appendix 2, A15) and proved that a definite sub-basin exists south of the Wallal Platform, extending offshore, and that it contains a favourable Permian section.

No wells were drilled in the area during 1969 and 1970.

WAPET resumed its drilling program in 1971 with the spudding of Tappers Inlet 1 (WAPET, 1971f). This well was proposed as a test well on the westerly extension of the Lennard Shelf to extend the sub-surface stratigraphic control of one of the major hydrocarbon objectives of the Canning Basin, the Devonian carbonates, and to test the hydrocarbon potential of possible Ordovician sediments on a closed anticlinal structure. The well encountered minor hydrocarbon shows in the Devonian sequence. It was plugged and abandoned at 2856.2 m (Appendix 2, A16). Information from the well did suggest that the southern boundary of the Lennard Shelf was far more complex than the simple fault line structure previously proposed.

WAPET Munda 1 well (WAPET, 1971g), was the last well of WAPET's 1971 corehole programme in the Canning Basin. Its aim was to investigate the nature of the salt solution structures, and to explore the Permian stratigraphy as a hydrocarbon objective, within the Willara Sub-basin. The well reached total depth of 1066.8 m in an evaporite sequence (Appendix 2, A17). There were no indications of hydrocarbons.

In 1972, WAPET drilled Pender 1 corehole to a total depth of 911.7 m on a small seismically defined anticline at a location on the western end of the Lennard Shelf (WAPET, 1972b). The primary objective of the well was to establish the presence or absence of Ordovician or Devonian carbonates in the area. There were no indications of significant hydrocarbon accumulations. All the porous strata above basement were water-saturated and hence flushed of any original hydrocarbon accumulations (Appendix 2, A18). The prospects in the area were downgraded as no pre-Grant rocks were encountered.

Also, in that year, WAPET Munro 1 well (WAPET, 1972c) was drilled in the southern part of the area on a basement-controlled high separating the Kidson and the Willara Sub-basins; it was thought that carbonate rocks of the Ordovician formations may contain traps in drapes over the high. The well was drilled to basement at a depth of 2105.9 m and plugged and abandoned (Appendix 2, A19). No significant hydrocarbons were found.

WAPET Thangoo 2 (WAPET, 1973a), drilled in 1973, was designed to test the hydrocarbon potential of the Ordovician Willara Formation on a faulted, low-relief anticlinal feature near the crest of the Broome Arch. This was considered a favourable site for hydrocarbon accumulation. The only indication of hydrocarbons was a minor oil shale in a sandstone of the Grant Group. Drilling confirmed the source rock potential of the Goldwyer Formation as good, and also confirmed the presence of significant porosity in the Willara Formation (Appendix 2, A20).

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF UNITS

Fig. 35

LATE CARBONIFEROUS TO EARLY PERMIAN

GRANT GROUP

The Grant Group (Guppy & others, 1952; Crowe & Towner, 1976b) consists of a sequence of sandstones with a well-defined middle mudstone section. The Grant Group is made up of three formations, the lower Betty Formation, the

middle Winifred Formation, and the upper Carolyn Form tion (Crowe & Towner, 1976b). With the exception of an exposure in the northwest of PATERSON RANGE which has been tentatively assigned to the Winifred Formation, the formations are only known in a number of petroleum exploration wells in the area (Appendix 2).

Betty Formation (Table 3)

The Betty Formation unconformably overlies Early Ordovician (WAPET Roebuck Bay 1, WAPET Samphire Marsh 1), Middle Ordovician (WAPET Thangoo 1A), Late Ordovician to Early Devonian (WAPET Parda 1, WAPET Willara 1), Middle Devonian (Total Kemp Field 1), Late Devonian (WAPET Tappers Inlet 1) and Early Carboniferous rocks (Gewerkschaft Elwerath Yulleroo 1). The basal unconformity boundary is a seismic reflecting horizon which has been mapped over much of the area. Crowe & Turner (1976b) believe that the formation laterally interfingers with and conformably overlies the Paterson Formation (Table 6), along the southern margin of the basin (Towner & others, 1976). The formation is absent in WAPET Barlee 1, probably having been removed by pre-Jurassic erosion.

The great variety of shapes and sizes of clasts in the basal part of the Betty Formation that are evidently derived from Precambrian igneous terrain implies that the clasts could be dropstones, suggesting a glacial environment. As the nearest Precambrian source for these igneous clasts is up to 100 km away, the most likely means of transport was by floating ice. The glauconitic sediments in WAPET Parda 1 indicate marine deposition. However, the scarcity of glauconite, which is formed in times of slow sediment influx (Cloud, 1955), may indicate rapid sediments supply.

The extensive distribution of this formation, its thickness, and the presence of allochthonous clasts, suggest glaciomarine environment.

Winifred Formation (Table 4)

At latitude 21°03'S and longitude 121°48'E, on PATERSON RANGE, a 20-m cliff exposure, fringed by a long scree slope, rises above the sand plain. The cliff is composed predominantly of sandy mudstone with minor fine-grained quartz wacke. The sequence has a massive appearance, although bedding becomes more definite nearer the top where it is medium-bedded. The sediments are bioturbated, and a few vertical burrows have been preserved.

The nature of the cliff outcrops, and the fine-grained lithology, are closely similar to the exposures of the Jarlemai Siltstone in the Edgar Range (MOUNT ANDERSON). However, in considering the whole stratigraphy of the area (mainly the nearby exposures of the Poole Sandstone and the Paterson Formation),

Table 3.

Unit	Map Symbol	Defined by
Betty Formation	Pb	Crowe & Towner (1976b)

Distribution

In subsurface, the unit occurs throughout the area except in WAPET Barlee 1 on BROOME. It is thought not to crop out.

Lithology

Consists predominantly of white to light grey sandstone, fine to coarse-grained; minor conglomerate and siltstone. Contains some calcareous and pyritic zones; beds of limestones are rare but occur in WAPET Goldwyer 1; In McLarty 1 well, a basal polymict conglomerate with clasts (1 mm to 10 cm diameter) of igneous, metamorphic and sedimentary origins set in a fine sandstone matrix is present. In Thangoo 1 well, the matrix is a mudstone. Glauconite occurs in WAPET Parda 1.

Facies Variation

No facies have been mapped.

Thickness

Maximum thickness recorded in the area is 555.6 m in WAPET Willara 1 (Appendix 2,A10)

Type Section Locality

Between 1058 and 1657 m in WAPET Lake Betty 1 (MOUNT BANNERMAN: Lat. 19°34'10"S, Long. 126°19'52"E).

Age and Criteria

Late Carboniferous to Sakmarian based on palynological evidence. On the Broome Arch, Willara Sub-basin and Anketell Shelf, the unit is Sakmarian. The Late Carboniferous age for the · it is confined to the Fitzroy Trough.

Fossils

Marine fossils were recovered from some wells, but only the microfossils were identifiable:- including acritarchs (Parda 1); fish remains, gastropods, pelecypods, and foraminifera (Yulleroo 1); brachiopods and acritarchs from Willara 1.

Relationships

Unconformably overlies the pre-Permian rocks and is conformably overlain by the Winifred Formation.

Subdivisions

None defined although there are fine-grained parts of the sequence that may be mappable in the subsurface.

Nature of Exposure

None.

Remarks

None.

Table 4.

Unit	Map Symbol	Defined by
Winifred Formation	Pw	Crowe & Towner (1976b)

Distribution

Exposed only in northwest PATERSON RANGE (see main text). Intersected in the subsurface except in southwest BROOME where it is cut out by the Jurassic unconformity.

Lithology

Predominantly grey, sandy siltstone with thin interbeds of fine-grained, micaceous sandstone. Unit is calcareous in parts. Grey, pyritic shale is dominant in WAPET Willara Hill 1.

Facies Variation

None observed.

Thickness

Maximum intersection is 288 m in WAPET Samphire Marsh 1 (Appendix 2,A4).

Type Section Locality

Near Well 26 (TABLETOP: Lat: 22°52'40"S, Long 123°36'20"E).

Age and Criteria

Sakmarian (sensu lato) based on palynological determinations (WAPET Munda 1; WAPET Pender 1).

Fossils

Only macrofossils recorded are unidentified fragments of crinoids and bryozoans which occur in thin limestone beds in this unit in WAPET Sahara 1 (SAHARA) to the south of the area (WAPET, 1966d).

Relationships

Interpreted to be conformable between the Carolyn and the Betty Formations. In WAPET Chirup 1, the Winifred Formation is disconformably overlain by the Poole Sandstone (WAPET, 1968b). In some wells (e.g. WAPET Munda 1, Total McLarty 1), the unit is unconformably overlain by the Jurassic Wallal Sandstone (WAPET, 1971g; Total 1968a).

Subdivisions

None

Nature of Exposure

See text.

Remarks

May be a cap rock for petroleum.

this outcrop is tentatively assigned to the Winifred Formation, which is otherwise known only from petroleum exploration wells.

The solid geology compilation of the area (Fig. 3) suggests that the Winifred Formation overlies the Paterson Formation. Crowe & Towner (1976b) proposed that the Paterson Formation in the Oakover River valley area may be partly equivalent laterally to the Winifred Formation and that these two formations probably interfinger with each other along the southern margin of the Canning Basin.

Compared with the Betty Formation, the finer overall grainsize of the Winifred Formation indicates deposition in deeper or quieter water. Towner & others (1976) interpreted that part of the Winifred Formation which is exposed elsewhere in the south Canning Basin as being varved, thus supporting deposition in deeper or quieter water and also that the glacial climate still prevailed. However, the fossils and bryozoans in the Winifred Formation indicate that the environment was at least partly marine and that the climate may not have been as cold as during deposition of the Betty Formation.

Carolyn Formation (Table 5)

This formation is confined to the subsurface and has been identified in only half of the petroleum exploration wells drilled in the area. Its thickness varies quite extensively over the whole survey area.

Very little can be stated about the environment of deposition. Crowe & others (1978) postulated that, for the bulk of the sequence below the Wye Worry Member of the Formation in the Fitzroy Trough, a shallow sea was the most likely environment. They also considered that the Wye Worry Member, and Millajiddee Member above it, immediately to the north and east of the area, may represent near-shore conditions, with either an oscillating shoreline or one in which offshore sand bars developed during a retreat of the sea. A cold water fauna (Dickins & others, 1978) and the presence of tillites with striated and facetted pebbles and boulders (Crowe & others, 1978) attest to a glacially influenced climate over the region.

EARLY TO LATE PERMIAN

Paterson Formation (Table 6)

The Paterson Formation is mainly restricted to the southern part of the Canning Basin; it is extensive in the Officer Basin (Jackson & van de Graaff, in press).

Its outcrop extent in the area is shown in Figure 3. Outliers are widely scattered in PATERSON RANGE and NULLAGINE, indicating that the formation may at one stage have extended over wide areas of Precambrian terrain that adjoin the Canning Basin.

The basal unit of the Paterson Formation is a poorly sorted unstratified conglomerate and tillite with a clayey to sandy matrix. The clasts range from small pebbles to boulders 2 m in diameter of quartzite and granitic rocks, with rare chert and gabbro. Most of the clasts are rounded or spherical, but some are facetted and striated. Some of these clasts are derived locally, others have been transported at least 75 km from the closest known source. Glaciated pavements are observed on NULLAGINE and RUDALL (immediately south of PATERSON RANGE).

Approximately 6 km northwest of Cabbage Tree Well (YARRIE: 20°36'S, 120°24'E), varved shale with dropstones and graded sandy units overlie the conglomerate sequence (Hickman & Crain, 1977).

The Paterson Formation also includes the sediments of the 'Braeside Tillite' - a unit of unsorted boulders, cobbles, and pebbles set in a mudstone matrix that occurs in the Oakover River valley in YARRIE and NULLAGINE. Since these outcrops are not significantly different lithologically from the Paterson Formation, the term 'Braeside Tillite' was discarded by Crowe & Towner (1976b).

A sequence of cross-bedded sandstone and conglomerate overlies the tillitic unit. The sandstone is medium to coarse-grained, poorly sorted, and composed dominantly of quartz. The matrix is clay. Concentrations of well-rounded quartz and quartzite clasts commonly forms lenses and beds.

In the northern portion of PATERSON RANGE, the sandstone is folded into zones of disharmonic, tight, concentric folds which are commonly cut by faults.

The thickness of the Paterson Formation ranges up to 250 m in the Canning Basin, a figure recorded in the drillhole 16 km east of Warrawagine homestead (drilled by Sentinel Mining Company); the formation lenses out completely at the margins of the Oakover Valley and the Canning Basin.

The lack of sorting in the lower facies, the mud matrix, the presence of facetted and striated clasts, and the great variety of rock types present as clasts (some of which have been transported many kilometres from their source) indicate that this facies is a tillite. In the adjacent NULLAGINE and RUDALL areas, glaciated pavements underlie similar rocks. Many of the clasts are rounded, probably owing to transport in rivers with subsequent re-incorporation of the clasts by ice, and then final deposition as tillite.

Table 5.

Unit	Map Symbol	Defined by
Carolyn Formation	Pc	Crowe & Towner (1976b)

Distribution

Not exposed in the area. In the subsurface, the unit is present in the deeper parts of the area (e.g. Fitzroy Trough, Willara Sub-basin) but has been removed by post-Permian erosion in the shallower areas except in the vicinity of WAPET Roebuck Bay 1 and the WAPET Thangoo wells.

Lithology

Medium to coarse-grained, moderate to well sorted sandstone; minor fine-grained sandstone, siltstone and conglomerate; siliceous, kaolinitic in places.

Facies Variation

None observed in subsurface.

Thickness

Maximum thickness in the area - 219.5 m in WAPET Tappers Inlet 1 (Appendix 2,A16).

Type Section Locality

Composite section (NOONKANBAH: Lat. 18°44'20"S, Long. 124°54°30"E and Lat. 18°41'53'S, Long. 124°54'30"E).

Age and Criteria

Palynological determinations indicate a Sakmarian (sensu lato) age (WAPET, 1971b). Marine macrofossils collected from unit in NOONKANBAH give a Late Sakmarian (sensu lato) age (Dickins & others, 1978).

Fossils

Eurydesma? sp. ind., Deltopecten lyonensis, Etheripecten cf. tenuicollis, Streblopteria sp., Keenia? sp. ind., rare plant-fossils of Glossopteris outside the area.

Relationships

Lower boundary with Winifred Formation is believed to be conformable in well sections in the area. The contact with the Poole Sandstone is considered to be disconformable except possibly in the Fitzroy Trough where Poole Sandstone unconformably overlies the Carolyn Formation (Crowe & others, 1978). Unit is cut out by the Jurassic unconformities on the Broome Arch. Probably interfingers with the Paterson Formation on the southern margin.

Subdivisions

In the Fitzroy Trough on DERBY and MOUNT ANDERSON, the units is divided into:-

Millajiddee Member
Wye Worry Member
Undivided lower part.

Nature of Exposure

None

Remarks

Table 6.

Unit	Map Symbol	Defined by
Paterson Formation	Pa	Talbot, 1920 Traves & others (1956)

Distribution

Occurs as scattered outliers resting on Precambrian rocks in YARRIE and PATERSON RANGE. Also occurs as outcrops along the southern margins of the Canning Basin, especially southeastern YARRIE and PATERSON RANGE, and northern PATERSON RANGE.

Lithology

Mudstone, massive to poorly bedded, very poorly sorted containing abundant dropstones ranging up to boulder size; minor fine-grained, quartz wacke, thin-bedded. Overlain in many places by a sequence of cross-bedded quartz wacke and mudstone which contains lenses of pebbles and boulders of Precambrian rocks. Cross-bedding is planar, some ripple cross-bedding and scour-and-fill structures present. Some beds are bioturbated.

Facies Variation

Only a lower, fine-grained, massive facies and an upper coarse-grained cross-bedded facies are known.

Thickness

At type section, the unit is 33 m thick (Appendix 3, No.4). Ranges up to 250 m in Canning Basin.

Type Section Locality

In Paterson Range (PATERSON RANGE: Lat 21°45'00"S, Long, 122°10'00"E).

Age and Criteria

Late Sakmarian on palynological grounds from exploration bores in the Oakover River Valley (YARRIE & NULLAGINE: J. Backhouse (writ. comm.)). However, in the Officer Basin and to the east of area in WAPET Sahara 1 it is of Early Sakmarian age (Kemp, 1976; WAPET, 1966d).

Fossils

Microfossils described by J. Backhouse (writ. comm.) and Kemp (1976). e.g. Punctatisporites gretensis, Microbaculispora tentula, Monocoipate pollen, Lophotriletes.

Relationships

Lies unconformably on Precambrian rocks and in the subsurface of Devonian and possibly other Early Palaeozoic rocks. Disconformably overlain by Poole Sandstone; interfingers with the Grant Group; unconformably overlain by Callawa Formation.

Subdivisions

Upper: coarse-grained, cross-bedded conglomeratic quartz wacke.

Lower: massive, mudstone with dropstones.

Nature of Exposure

Very poor; the mudstone is characteristically leached yellow and white.

Remarks

Includes 'Braeside Tillite' (see Crowe & Towner, 1976b).

The evenly and continuously bedded, graded, siltstone facies with dropstones (mostly recognised outside the area: Towner & others, 1976) is interpreted as a varved deposit, which is indicative of freshwater (lacustrine) environments.

The coarse-grained to conglomeratic sandstone facies is interpreted as a fluviatile deposit on the basis of the moderate to poor sorting, and cross-bedding. The lack of facies such as fining up sequences indicates that the streams depositing the sandstone and conglomerate had a low sinuosity (Allen, 1965) and were most likely braided. The predominance of quartzose material in the fluviatile facies demonstrates either a very significant abrasion of the mechanically less resistant material or chemically weathering of this material.

The folding and slumping in the formation in the Paterson Range area is attributed to slumping of sediments made unstable by the melting of ice which either supported or bound the sediments.

The palynomorph assemblages described by Kemp (1976) indicate the possibility of some marine influence on the deposition of the formation.

In conclusion, it appears that the Paterson Formation was initially deposited in lakes during an early stage of glaciation. These lakes were probably connected with a sea into which the rivers flowed, still under the influence of a glacial climate.

The Paterson Formation is not recognised in many wells in the Canning Basin, but is probably a correlative of parts of the Grant Group. WAPET have tentatively identified a basal conglomerate in the Grant Group as the Braeside Tillite in WAPET Kidson 1 and SAHARA 1 wells (outside the area).

Poole Sandstone (Table 7)

Exposures of the Poole Sandstone are mainly confined to PATERSON RANGE. The formation has been identified in petroleum exploration wells drilled on the northern side of the Broome Arch and in the Fitzroy Trough. It is interpreted to be present in southeast PATERSON RANGE, based on information from TABLETOP (immediately south of SAHARA) (Yeates & Chin, 1979).

The Poole Sandstone has been subdivided by Crowe & Towner (1976a,b) into three members, based on work in the Fitzroy Trough. The basal unit, the Nura Nura Member, originally defined by Guppy & others (1958) but extended by Crowe & Towner (1976a), has limited distribution in the area, having been recognised only in WAPET Tappers Inlet 1 and in WAPET Roebuck Bay 1. In these two wells, the member is composed of calcareous sandstone and limestone. The widespread middle portion of the Poole Sandstone is the Tuckfield Member. However, this term will not be used in this report even though the member can readily be recognised in the few wells which penetrated the Poole Sandstone.

The uppermost unit, the Christmas Creek Member, has not been recognised in the area.

In the south Canning Basin, Traves & others (1956) mapped outcrops of Cuncudgerie Sandstone. Later, Towner & others (1976) were able to show that these outcrops could be correlated with the sections of Poole Sandstone intersected in the nearby petroleum exploration wells, and they suggested that the term Cuncudgerie be dropped. During the 1977 field season we confirmed this correlation, and established that fossils collected from the Cuncudgerie Sandstone are similar species to those found in the Nura Nura Member in the Fitzroy Trough (Guppy & others, 1958; Crowe & Towner, 1976a). It would seem therefore, that the Cuncudgerie Sandstone is a more clastic facies equivalent of the Nura Nura Member. We prefer not to use the term 'Cuncudgerie Sandstone', and refer instead to these rocks as the 'Cuncudgerie facies' of the Poole Sandstone.

Mapping of the section exposed at Cuncudgerie Hill has revealed that less than half of it as measured by Traves & others (1956) actually belongs to the Poole Sandstone. The rest of the section we have mapped as the Jurassic Callawa Formation, based on its coarse-grained nature and the abundance of pebbles set in a dark ferruginised sandstone matrix.

The fossils found in the Poole Sandstone indicate a marine environment. The ripple-marked, thin interbeds of sandstone and mudstone are interpreted as having been deposited in a shallow sea (probably above wave base). The small scour-and-fill structures, bioturbation, and flaser and lenticular bedding are features common in a shallow-water environment. The large-scale planar and trough crossbedding indicates deposition in channels and as magaripples. The clay-pellet intraformational conglomerate lenses at the base of the cross-sets suggest current deposits laid down in channels.

Therefore, the Poole Sandstone was probably laid down in a shallow sea, possibly as it transgressed over the area.

Noonkanbah Formation (Table 8)

The Noonkanbah Formation is very poorly exposed within the area, where it is confined mainly to the Kidson Sub-basin and the Fitzroy Trough. Post-Permian erosion has removed it from areas of the Broome Arch and the Willara Sub-basin.

The presence of a very rich marine fauna in outcrops outside the area indicates an unrestricted marine environment. The abundance of fine calcareous mudstone in the sequence suggests continuous deposition in a quiet standing body of water. The pyritic zones indicate some reducing anaerobic conditions.

Table 7

Unit	Map Symbol	Defined by
Poole Sandstone	Pp	Wade, 1936 Guppy & others, 1952)

Distribution

Occurs at Cuncudgerie Hill, Barnicardy Hills, in a plateau-like outcrop 16 km east southeast of Cuncudgerie Hill and in the area north of Lake Waukarlycarly (PATERSON RANGE).

In subsurface, the formation is confined to the Fitzroy Trough and extreme northern part of BROOME ARCH.

Lithology

Predominantly of fine-grained quartz wacke with interbeds of mudstone. It is thin to medium-bedded, lenticular and flaser bedded; small and large scale trough and planar cross-bedding have maximum set size of 50 cm. The unit is extensively bioturbated with large burrows (2 cm diameter). Clay pellet conglomerate occurs at base of beds; mud stringers within beds common.

In the subsurface, the unit consists mainly of fine to very fine sandstone interbedded with siltstone; partly calcareous, pyritic, massive limestone occurs at base of sequence.

Facies Variation

Thickness

26 m measured near type section (Appendix 3, No.2); 33 m exposed at type section (Traves & others, 1956). In WAPET Roebuck 1, 71 m intersected (Appendix 2,A1).

Type Section Locality

Southeast Grant Range (MOUNT ANDERSON: Lat. 18°04'30"S Long. 124°08'30"E).

Age and Criteria

Microfossils from type section (Dickins & Thomas in Traves & others, 1956) occur in Faunal Stage B of Dickins (1970), and indicate a Late Sakmarian age. Microflora from the well sections of the unit indicate Stage 3 (Evans, 1969) and denote an Artinskian age.

Fossils

The fauna is varied, with bivalves (including Nucula, Astartila and Streblochondria), gastropods, brachiopods (including Spiriferellina and Neospirifer), and Conularia. (Dickins & Thomas, 1955; Dickins in Towner & others, 1976).

Relationships

Poole Sandstone is unconformable on the Grant Group and where present has a gradational contact with the overlying Noonkanbah Formation. Where the basal Nura Nura Member is absent, the Grant and Poole appear gradational, but the similarity of lithology obscures the contacts. However, the time break between the units suggests at least a disconformable relationship. The Poole Sandstone disconformably (?) overlies the Paterson Formation.

Subdivisions

Outside the area -
Christmas Creek Member
Tuckfield Member
Nura Nura Member

Nature of Exposure

Well exposed in the section 16 km ESE of Cuncudgerie Hill. Elsewhere exposures are scree covered.

Remarks

Table 8

Unit	Map Symbol	Defined by
Noonkanbah Formation	Pn	Wade (1938); Guppy & others (1952)

Distribution

Only recognised in the vicinity of Lake Dora in southeastern PATERSON RANGE. The unit is present in three wells drilled in the area: WAPET Tappers Inlet 1, Roebuck 1, Total Kemp Field 1.

Lithology

In outcrop, consists of poorly bedded and laminated mudstone. In the subsurface mainly grey, micaceous, partly pyritic siltstone interbedded with silty sandstone and fine to medium-grained sandstone, calcareous matrix, thin-bedded. Minor aphanitic to finely crystalline, grey, fossiliferous limestone interbeds occur throughout the unit. Glauconite is reported in some wells (e.g. WAPET Sahara 1).

Facies Variation

None observed.

Thickness

6 m exposed; 36.6 m in Tappers Inlet 1 (Appendix 2,A16) and 54.6 Kemp Field (Appendix 2,A13).

Type Section Locality

Near Bruten Hill (NOONKANBAH: Lat 18°44'35"S, Long. 125°30'E).

Age and Criteria

Macrofossils indicate the unit is Artinskian (Guppy & others, 1958); contains the D1 fauna of Dickins (1963). Palynomorph assemblage confirms this date (Balme, 1967) and falls within Stage 4 microflora of Evans (1969). Crespin (in Traves & others, 1956) assigned a Permian age to a foraminifera species collected from unit at northern end of Lake Dora.

Fossils

Outside the area, the unit contains a very rich fauna of brachiopods, bryozoans, corals, crinoids, foraminifera, molluscs, ostracods.

Relationships

The unit grades down into the Poole Sandstone, and is overlain conformably by the Triwhite Sandstone on PATERSON RANGE, but elsewhere it is overlain unconformably by Jurassic Wallal Sandstone.

Subdivisions

None.

Nature of Exposure

Very poor; occurs as low mounds and small cliffs near edge of claypans.

Remarks

According to Reineck & Singh (1973) such conditions can only be maintained 'in the absence of turbulence or current activity, with a low rate of deposition, and almost no reworking of sediment'.

Therefore, the Noonkanbah Formation was probably deposited in an extensive shallow sea below wave base, under mainly reducing conditions.

Triwhite Sandstone (Table 9)

The Triwhite Sandstone is confined mainly to the Kidson Sub-basin and the southern Anketell Shelf. It crops out predominantly along the margin of the basin.

Litholigically, the Triwhite Sandstone is similar to the Lightjack Formation in the Fitzroy Trough (Yeates & others, 1975b), but since continuity between these two formations has not been established, the name Triwhite Sandstone has been retained (Towner & others, 1976).

Owing to the poor preservation of the exposures of the Triwhite Sandstone, a detailed interpretation of its depositional environment cannot be attempted. However, on TABLETOP, to the southeast, Towner & others (1976) have postulated that the gradual upward increase in grainsize from mudstone of the Noonkanbah Formation to sandstone of the Triwhite Sandstone indicates a shallow-water regressive marine environment for the formation.

Chirup Formation (Table 10)

This formation occurs entirely in the subsurface and is restricted to the Wallal and Samphire Embayments. Palynological evidence seems to indicate that the formation may be equated with the upper part of the Hardman Formation in the Fitzroy Trough.

The Chirup Formation contains well preserved plant fragments, spores, and pollens which are considered to be from plants inhabiting coastal marshes (J. Gorter, BMR, pers. comm. 1979). There are no marine fossils. The fine-grained carbonaceous sediments may represent a swamp or marsh deposit, located landward of a coastline which was somewhere off the present day shoreline (J. Gorter, BMR, pers. comm., 1979). The Chirup Formation probably represents part of a transgressive cycle which occurred in the Late Kazanian or Early Tatarian in a small area in the southern coastal region similar to the one represented by the Hardman Formation (Crowe & others, 1978).

Liveringa Group (Table 11)

The three formation which comprise the Liveringa Group do not crop out in this area, nor have they been intersected in any of the petroleum exploration wells drilled in this area. However, evidence for the presence of the Liveringa

Group has been obtained from seismic work in BROOME and PENDER.

TRIASSIC

Blina Shale (Table 12)

The portion of the Blina Shale which has been intersected in BMR Wallal 4A has been equated with the basal facies of the Blina Shale present in WAPET Blackstone 1, WAPET Meda 1, WAPET Langoora 1 (Gorter, 1978). This facies is characterised by a general fining-upward sequence, the presence of glauconite, and marine fossils (acritarchs and lingulids).

The form of the acritarchs in this sequence indicates shallow-marine, nearshore environments (Sarjeant, 1974). The great abundance of these acritarchs is interpreted by Dolby & Balme (1976) to indicate immature ecosystems which are to be expected in a transgressive situation. Gorter (1978) believes that the Blina Shale in the Samphire Embayment area represents an early Triassic transgression over a peneplained surface. The broad tidal flats that were present were colonised by halophytic lycopods and coastal gymnosperm groups of plants. The predominantly shallow-marine conditions which characterised much of the Blina Shale in the northeast Canning Basin appear to be absent in this area (Gorter, 1978).

JURASSIC TO CRETACEOUS

We consider the Jurassic to Cretaceous sequence of the Canning Basin in the study area, apart from the Aptian(?) Anketell Sandstone, to be the result of deposition prior to, during, and after a regional marine transgression from the northwest, with little or no depositional hiatus between the different rock units. In the north, a single phase of transgression and regression is recognised, but in the southwest of the area two phases are recognised. It is possible that the first regression, and second transgression and regression in the southwest occurred while a more simple regression occurred in the north. This could be a result of local variations in up- and downwarping.

The climax of the first transgression in the Jurassic-Cretaceous of the Canning Basin occurred in late Jurassic (Kimmeridgian to Tithonian) times, which is earlier than the regional transgression in the Great Australian Basin in Aptian-Albian times (generally accredited to a eustatic rise in sea level). Hence we attribute this phase of deposition to downwarping of the northwestern Canning Basin, which may have resulted from the breakup of the Australian continent from another landmass to the northwest (see Powell, 1976).

Table 9

Unit	Map Symbol	Defined by
Triwhite Sandstone	Pt	Traves & others (1956)

Distribution

Only occurs in PATERSON RANGE, as isolated mounds, hills and small mesas in the southeastern corner, and along the margin of Lake Dora. The unit was not intersected in any of the petroleum-exploration wells.

Lithology

Consists of fine to medium-grained quartz wacke; interbedded with mudstone and minor intraformational claystone conglomerate; laminated to thin-bedded; wave and interference ripples, flaser and lenticular bedding, wavy bedding. Low angle planar cross-bedding is common.

Facies Variation

None observed.

Thickness

No section measured; no more than 8 m exposed in the area. In WAPET Kidson 1 well, it is 77.2 m thick (URAL) (WAPET, 1966f).

Type Section Locality

1.6 km east of Dunn Soak (TABLETOP: Lat. 22°04'00"S, Long. 123°10'00"E).

Age and Criteria

Early Permian based on macrofossils collected outside the area (Dickins in Towner & others, 1976; Dickins & Thomas, 1955; Dickins, 1963).

Fossils

Astartila blatchfordi, Atomedesma mytiloides, Warthia cf micromphala, Ptychomphaline maitlandi, Mourlonia sp. collected from outside the area.

Relationships

Overlies conformably the Noonkanbah Formation and is overlain unconformably by Callawa Formation.

Subdivisions

None proposed.

Nature of Exposure

Crops out as low mounds and isolated hills. No good section exposed in the area.

Remarks

Fossils are similar to those from the upper Noonkanbah Formation or lower Lightjack Formation (Dickins, 1963).

Table 10

Unit	Map Symbol	Defined by
Chirup Formation (new name)	Pi	Gorter & others (1979)

Distribution

Occurs in BMR Wallal 4A and WAPET Chirup 1 in the Wallal and Samphire Embayments (MANDORA, YARRIE). Probably originally present in western Willara sub-basin and probably present beneath Triassic rocks offshore in Bedout Sub-basin.

Lithology

Interbedded shale, lignite and sandstone. Shale, light to dark brown, black, sandy, non to very carbonaceous; lignite is brown-black, partly pyritic, with woody fossils; sandstone, light to medium grey, fine to conglomeratic, grains mainly subrounded, frosted; abundant chert layers.

Facies Variation

None observed.

Thickness

38 m thick in WAPET Chirup 1 (APPENDIX 2,A15) and 31 m in BMR Wallal 4A (Appendix 2,A3).

Type Section Locality

Between 449 m and 537 m in WAPET Chirup 1 (MANDORA Lat. 19°51'S, Long. 120°26'E).

Age and Criteria

Late Permian based on palynological evidence (Balme, in Henderson & others, 1963; in WAPET, 1968b).

Fossils

Microfossils, including Indospora clara and Microreticulatisporites bitriangulatus (Stage 5, microflora), are abundant.

Relationships

Overlies Grant Group unconformably in WAPET Chirup 1 and BMR Wallal 4A, and is unconformably overlain by Jurassic Wallal Sandstone and conformably by Triassic Blina Shale?

Subdivisions

Nature of Exposure

Not exposed.

Remarks

Possible that the upper Hardman Formation in the Fitzroy Trough can be correlated with the Chirup Formation.

Table 11

Unit	Map Symbol	Defined by
Liveringa Group	Pl	Guppy & others (1958) Yeates & others (1975b)

Distribution

In the subsurface, the unit is confined to the Fitzroy Trough on BROOME and PENDER.

Lithology

A sequence of interbedded siltstone, sandstone and minor conglomerate occurs in outcrops to the east (Crowe & others, 1978).

Facies Variation

None observed in the area; outside the area a number of coarsening upward cycles can be mapped.

Thickness

Approximate 500 m thick in northern BROOME (according to seismic data).

Type Section Locality

Liveringa Ridge (MOUNT ANDERSON: Lat. 18°08'S, Long. 124°E).

Age and Criteria

Late Artinskian in the Lightjack Formation to late Tatarian in the Hardman Formation, based on macro- and micro fossils (Guppy & others, 1958; Thomas, 1954; Coleman, 1957; Dickins, 1963; Balme, 1967).

Fossils

Fossils have been collected from all the formations of the Liveringa Group, and include brachiopods, pelecypods, gastropods, scaphopods, trace fossils, and plants.

Relationships

Conformably overlies Noonkanbah Formation, and is unconformably overlain by the Jurassic Wallal Sandstone.

Subdivisions

Three formations
- Hardman Formation
- Condren Sandstone
- Lightjack Formation

Nature of Exposure

None.

Remarks

In accordance with the suggestion by Crowe & Towner (1976b) and Crowe & others (1978), the Condren Sandstone is probably absent in the area.

Unit Blina Shale — **Map Symbol** Rb — **Defined by** Reeves (1951); Brunnschweiler (1954)

Distribution
The Blina Shale is confined to the subsurface in the Samphire Embayment adjacent to the Anketell Shelf (MANDORA), in the southwest of the area. It has been intersected in BMR Wallal 4A.

Lithology
Carbonaceous, shaley, micaceous siltstone with streaks of very fine-grained sandstone.

Facies Variation
None.

Thickness
25 m in BMR Wallal 4A. (Appendix 2,A3).

Type Section Locality
Erskine Range (DERBY: Lat. 17°51'25"S, Long. 124°21'40"E).

Age and Criteria
Early Triassic age based on microfossils (Balme *in* Henderson & others, 1963).

Fossils
Microplankton abundant. A list of spores and pollen grains is given by Balme *in* Henderson & others (1963).

Relationships
Conformably overlies the Chirup Formation and is unconformably overlain by the Jurassic Wallal Sandstone.

Subdivisions
No subdivisions proposed.

Nature of Exposure
None.

Remarks

We consider that the Anketell Sandstone was deposited in the Canning Basin as a response to rising sea level in the Early Cretaceous. There is evidence (Jackson & van de Graaff, in press) that this third transgression came into the area from the south via the Officer Basin; regional upwarping in the northwestern Canning Basin may have prevented the sea from entering the area from the northwest.

We consider the sequence, apart from the Anketell Sandstone, to be essentially continuous, though we cannot deny the possibility of several depositional hiatuses, as have been found in the sequence offshore (see Powell, 1976). Firm evidence of depositional hiatus onshore is limited to the Langey Crossing area (DERBY), where palynological examination of three borehole samples from 7 m of section has given ages ranging from Kimmeridgian-Oxfordian to Middle (?) Tithonian (B. Ingram, GSWA, pers. comm., 1978). This interval is characterised by phosphatic sediments, which also suggest slow deposition.

Wallal Sandstone (Table 13)

The Wallal Sandstone is the name applied to a sequence of continental to shallow-water marine sandstone, with minor conglomerate, siltstone, claystone and lignite, at the base of the Canning Basin Jurassic-Cretaceous sequence; in the study area it is known only from wells. It is conformably or disconformably overlain by the Alexander Formation, and where this is not recognised, the Jarlemai Siltstone. Along the southwest margin of the basin, it is probably overlain disconformably or unconformably by the continental Callawa Formation. As the lithologies of the two units are similar, this contact has not been recognised in drillholes or outcrop. Further away from the basin margin they are separated by the Jarlemai Siltstone. For mapping purposes, it has been assumed that the Wallal Sandstone is overlapped by the Callawa Formation, and that there is no outcrop of the Wallal Sandstone along the basin margin.

The only known outcrops of Wallal Sandstone in the Canning Basin are outside this study area in DERBY and MOUNT ANDERSON. Here, two members have been mapped (Gibson & Crowe, in prep.), but these are recognised only in outcrop, not in the subsurface.

GSWA groundwater bore 9D (Leech, 1979) (PORT HEDLAND) bottomed in 5 m of hard, non-marine claystone which has been dated as late Early(?) to Middle Jurassic (J. Backhouse, GSWA, written communication, 1978). As all other palaeontological determinations of the Wallal Sandstone in the immediate area indicate a Late Jurassic (Oxfordian) age (J. Backhouse, written communications, 1974-76), it is possible that there is a hiatus between this claystone and the Wallal Sandstone. However, as little is known about the distribution and age of

the claystone, it has been tentatively placed within the Wallal Sandstone.

Alexander Formation (Table 14)

The Alexander Formation is a shallow-marine sandstone, with interbedded siltstone and mudstone. The only known outcrops in the study area are in McLARTY HILLS where it consists of ferruginised sandstone with abundant shelly fossil casts in places. In petroleum exploration and stratigraphic wells, a sequence of interbedded sandstone and mudstone with marine microfauna, which lies between the fine-grained Jarlemai Siltstone and the Callawa Formation, is identified as Alexander Formation. This sequence, however, is not present in some wells near the basin margin, or in GSWA groundwater bores (Leech, 1979) in PORT HEDLAND and YARRIE. In these wells are bores, the Alexander Formation is thought to be absent.

The Alexander Formation is conformably overlain by the Jarlemai Siltstone in MOUNT ANDERSON (Crowe & others, 1978), and micropalaeontological determinations from petroleum exploration wells in the study area suggest this relationship applies throughout the study area.

Jarlemai Siltstone (Table 15)

The Jarlemai Siltstone is a fine-grained deposit which was laid down at the height of the Jurassic-Cretaceous transgression in the Canning Basin. It crops out only in McLARTY HILLS in the study area, where it consists of interbedded very fine to fine-grained sandstone and mudstone, with ripple marks and cross-bedding. This is in contrast to the type section on MOUNT ANDERSON, which consists of massive (probably completely bioturbated) sandy mudstone with rare beds of coarse sandstone (Crowe & others, 1978). However, the overall variation and average grainsize of the formation in McLARTY HILLS is similar to that at the type section, and it is possible that the type section would be similar to the outcrops on McLARTY HILLS if it had not been bioturbated. The outcrops in McLARTY HILLS have a similar white photo-pattern to the type section.

The Jarlemai Siltstone has been recognised in most of the petroleum exploration and stratigraphic drillholes in the study area. In these, it consists of sandy mudstone, mudstone, and fine to very fine silty sandstone. GSWA groundwater drilling in PORT HEDLAND and YARRIE (Leech, 1979) shows that the Jarlemai Siltstone pinches out near the southwestern margin of the basin, between the Callawa Formation and Wallal Sandstone. This may be due to depositional thinning, or it is possible that the Jarlemai Siltstone was eroded before the continental Callawa Formation was deposited. The latter possibility has been shown on the Port Hedland and Yarrie Preliminary Edition sheets.

Table 13

Unit	Map Symbol	Defined by
Wallal Sandstone	J1	McWhae in WAPET (1961a)

Distribution

Present in the subsurface over almost all the Canning Basin in the study area; generally absent near basin margins.

Lithology

Quartzose sandstone, with minor siltstone, conglomerate, claystone, and lignite. Accessory pyrite, mica.

Facies Variation

None known in the area.

Thickness

Maximum known 402 m in WAPET Munro 1 (Appendix 2,A19). 308 m in 'type section' (Appendix 2,A3).

Type Section Locality

BMR 4A (WALLAL) Stratigraphic Well, 279-587 m. (MANDORA).

Age and Criteria

Early ? to Late Jurassic (Oxfordian), based on palynological determinations from petroleum exploration, stratigraphic and groundwater wells.

Fossils

Palynomorphs, microfauna, fossil wood.

Relationships

Unconformably overlies Triassic and older rocks. Conformably or disconformably overlain by Alexander Formation and Jarlemai Siltstone. Probably unconformably or disconformably overlain by Callawa Formation near the south-west margin of the Canning Basin.

Subdivisions

None in study area.

Nature of Exposure

None in study area.

Remarks

5 m of late Early ? to Middle Jurassic hard non-marine claystone at the base of GSWA groundwater bore 9D; tentatively placed within Callawa Formation. Generally an excellent aquifer.

Table 14

Unit	Map Symbol	Defined by
Alexander Formation	Ja	Brunnschweiler, 1954

Distribution

Present in the subsurface over much of the Canning Basin in the area; crops out in central McLARTY HILLS.

Lithology

Quartzose sandstone, interbedded siltstone and mudstone. Accessory pyrite, glauconite, pebbles.

Facies Variation

Siltstone and mudstone sometimes absent. Contains pebbles of ferruginous limestone in WAPET Thangoo 1.

Thickness

Ranges from 20 - 92 m.

Type Section Locality

At Mount Alexander (MOUNT ANDERSON: Lat. 18°41'S, Long. 123°39'E).

Age and Criteria

Late Oxfordian to Early Kimmeridgian, based on macro- and microfossils from petroleum exploration wells and outcrop.

Fossils

Microflora, microfauna, belemnites, pelecypods, ostracods; ammonites, brachiopods and ophiuroids found outside area.

Relationships

Conformably or disconformably overlies Wallal Sandstone conformably overlain by Jarlemai Siltstone.

Subdivisions

None.

Nature of Exposure

Low hills and breakaways in McLARTY HILLS. No other outcrops known in study area.

Remarks

Cannot be recognised in some petroleum exploration wells, especially near the margins of the basin, or in water bores in PORT HEDLAND and YARRIE.

Table 15

Unit	Map Symbol	Defined by
Jarlemai Siltstone	JKr	Brunnschweiler (1954)

Distribution

Crops out in eastern McLARTY HILLS; elsewhere it is present in the subsurface over most of the Canning Basin in the study area.

Lithology

Very fine to fine sandstone with interbedded mudstone, ripple-marked and cross-bedded in outcrop in northeast McLARTY HILLS. Elsewhere, glauconitic mudstone, sandy in places, minor sandstone.

Facies Variation

See above

Thickness

259 m thick in WAPET Barlee 1. (Appendix 2,A8)

Type Section Locality

At Mt Jarlemai (MOUNT ANDERSON: Lat. 18°43'S, Long. 123°49'E).

Age and Criteria

Late Oxfordian to lowermost Cretaceous (?) - based on numerous micropalaeontological determinations from petroleum exploration, stratigraphic and groundwater wells, and macrofossils outside the area.

Fossils

Microfossils, pelecypods, belemnites, ammonites, brachiopods.

Relationships

Conformably overlies Alexander Formation. Conformably overlain by Broome Sandstone, Mowla Sandstone. Probably unconformably or disconformably overlain by Callawa Formation.

Subdivisions

None.

Nature of Exposure

Mesas and breakaways in McLARTY HILLS. No other exposures known in study area.

Remarks

Recognised in petroleum exploration wells and water bores over most of study area. Thins towards depositional limits, and pinches or is eroded out along southwest margin of basin.

Table 16

Unit	Map Symbol	Defined by
Callawa Formation	JKc	Reeves (1951); amended by Traves & others (1956).

Distribution

Occurs within 150 km of southwest margin of the Canning Basin on PORT HEDLAND, YARRIE, ANKETELL and MANDORA.

Lithology

Very fine to coarse sandstone, conglomerate; cross-bedded; minor siltstone.

Facies Variation

Conglomerate is commonest near the margin of the basin in YARRIE.

Thickness

At type section, 52 m is exposed; elsewhere 80 m +

Type Section Locality

At Callawa Hills (YARRIE: Lat. 20°32'S, Long. 120°21'E).

Age and Criteria

Late Jurassic to Early Cretaceous. It overlies Jarlemai Siltstone dated as Oxfordian to Kimmeridgian, and is laterally equivalent to the Broome Sandstone, Parda Formation, and Frezier Sandstone, which may be as young as Aptian. Plant fossils are Late Jurassic or Early Cretaceous (White in Veevers & Wells, 1961).

Fossils

Plant Fossils.

Relationships

Unconformably overlies Paterson Formation and Precambrian basement; Disconformably or unconformably overlies Wallal Sandstone and Jarlemai Siltstone. Disconformably overlain by, and may be partly equivalent to Parda Formation. Partly equivalent to Broome Sandstone and Frezier Sandstone.

Subdivisions

None.

Nature of Exposure

Good exposure in hills near southwest margin of basin.

Remarks

Elsewhere, the Jarlemai Siltstone (as used in this record) is overlain by the Broome Sandstone and by Mowla Sandstone in McLARTY HILLS. We do not recognise the Jowlaenga Formation (Brunnschweiler, 1957) as a valid unit - this unit was originally defined to lie between the Broome Sandstone and Jarlemai Siltstone. This is discussed in Appendix I.

The contact between Broome Sandstone and Jarlemai Siltstone has not been seen in outcrop. We consider that the Broome Sandstone is a shallow-water marine deposit, laid down as the sea which deposited the Jarlemai Siltstone regressed. A conformable relationship is suggested.

Most fossil determinations (from outcrop and drilling) from the Jarlemai Siltstone indicate a late Oxfordian to Kimmeridgian age, but the Broome Sandstone has been tentatively dated as Neocomian (Playford & others, 1975). However, as we now identify most outcrops of the 'Jowlaenga Formation' with the Broome Sandstone, the Broome Sandstone may extend down into the Late Jurassic (Skwarko, 1970, dated the 'Jowlaenga Formation' as latest Jurassic). In the same general area, there is good evidence that the Jarlemai Siltstone extends up into the Tithonian (Langey Crossing area on DERBY - Barry Ingram, GSWA, written communication, 1978 - see also Crowe & others, 1978), and a date of uppermost Jurassic or basal Cretaceous has been determined for the Jarlemai Siltstone in WAPET Parda 1 (WAPET, 1965a). Hence the possibility of conformity with the Broome Sandstone is not ruled out by dating.

It is probable that the Jarlemai Siltstone/Broome Sandstone boundary is time transgressive. It seems that the area of the Fitzroy Trough (see Structural Geology) was a negative feature in the study area at this time, and deposition of Jarlemai Siltstone may have continued in this area after the sea had shallowed sufficiently to deposit Broome Sandstone in areas further to the south.

Callawa Formation (Table 16)

The Callawa Formation crops out along the southwestern margin of the Canning Basin. It is characterised by poorly sorted sandstone, with conglomerate beds (Fig. 7), and is strongly cross-bedded (Fig. 8). Cross-beds sets are usually trough-shaped and have been laid down by unidirectional currents. Fine sandstone and siltstone suspension deposits are present in places, and are in places bioturbated. Large trace fossils up to 40 cm high and 10 cm wide are in places associated with the suspension deposits. The conglomerate content of the formation generally decreases away from the edge of the basin. Traves & others (1956) suggest that pebbles were eroded from what is now the Paterson Formation, and redeposited nearby as Callawa Formation. Our fieldwork shows that conglomerate is most common in YARRIE, where Paterson

Formation has been eroded, and we see no evidence to disprove Traves & others' suggestion.

We consider the Callawa Formation to be a continental deposit, fluvial near the basin margin, and possibly deltaic further to the northeast where it passes laterally into the Broome Sandstone, though we have seen no evidence in outcrop for deltaic deposits.

The Callawa Formation probably disconformably or unconformably overlies the Jarlemai Siltstone, and is disconformably overlain by the Parda Formation. It also appears to pass laterally into the Broome Sandstone and Frezier Sandstone, which underlie and overlie the Parda Formation. These paradoxical relationships can be explained if the Callawa Formation is regarded as a marginal continental deposit of the Canning Basin, with deposition more or less continuous from Broome Sandstone to Frezier Sandstone times. This explanation requires the disconformity between the Parda Formation and Callawa Formation to represent only a very short time gap during which the very top of the Callawa Formation at that time was reworked by the transgressing Parda Formation sea.

Mowla Sandstone (Table 17)

We have recognised several outcrops of the Mowla Sandstone in McLARTY HILLS. It conformably overlies the Jarlemai Siltstone, and consists of scattered hill-cappings of ferruginised, medium to very coarse, poorly sorted sandstone, with pebbles, granules, and clay-pellet conglomerate. Bedding is partly obscured by the ferruginisation, but large-scale cross-bedding and ripple marks are common. It is interpreted as a deltaic to fluvial deposit, representing a regressional sequence after deposition of the fine-grained marine Jarlemai Siltstone. Further west from McLARTY HILLS, the Jarlemai Siltstone is overlain by the marine Broome Sandstone, and we conclude that the Mowla Sandstone may be a continental equivalent to the Broome Sandstone in the area. We also consider that the Mowla Sandstone may be equivalent to, or possibly even once continuous with, the Frezier Sandstone which occurs to the south, as each unit represents the final phase of deposition after the Jurassic-Cretaceous transgression.

Broome Sandstone (Table 18)

The Broome Sandstone is considered to be a shallow-marine sequence deposited as the Jurassic-Cretaceous sea regressed from the Canning Basin. It consists of fine to medium sandstone, with interbedded mudstone, and minor conglomerate; most outcrops (on BROOME, PENDER and LA GRANGE) show strong cross-bedding, scour and fill structures (Fig. 9), ripple marks and bioturbation,

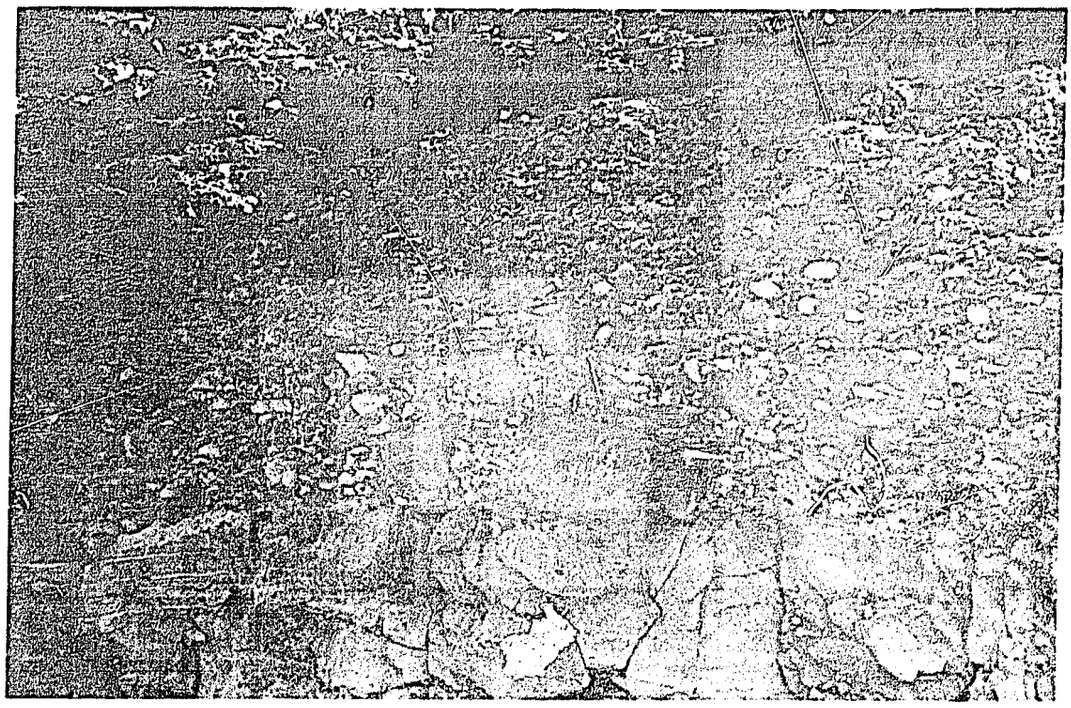


Fig. 7. Conglomerate bed in Callawa Formation.
Shay Gap mine road, YARRIE. (BMR M/2185-9).

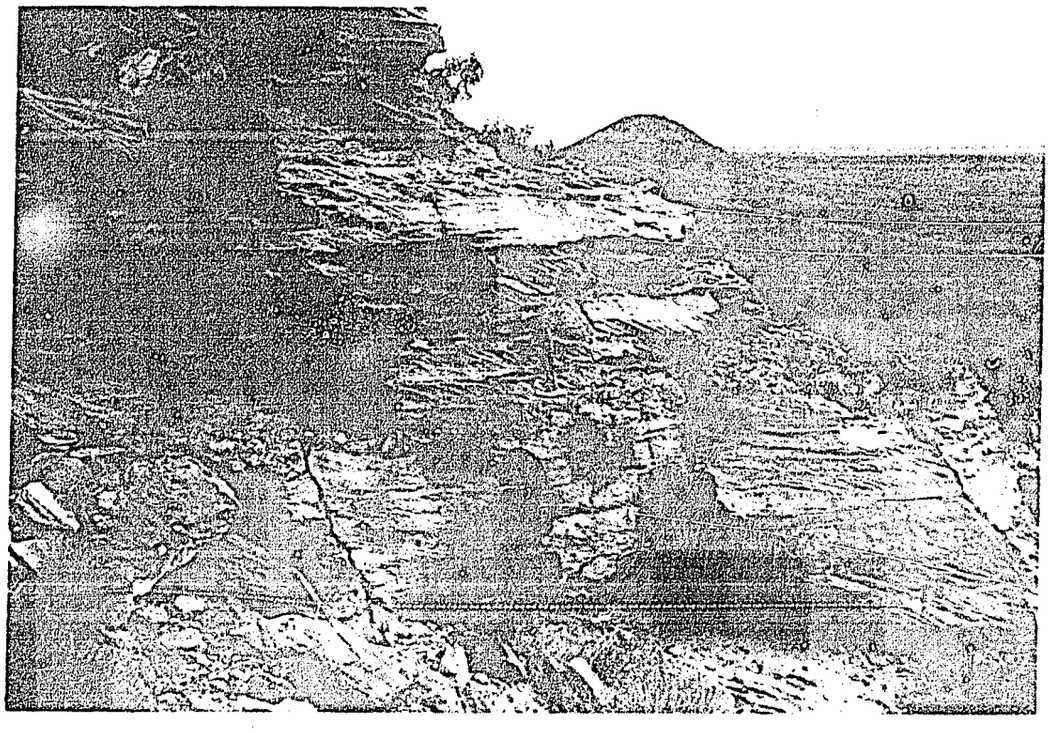


Fig. 8. Cross-bedded coarse sandstone and conglomerate in the Callawa Formation, eastern PORT HEDLAND. (BMR M/2185-6).

Table 17

Unit	Map Symbol	Defined by
Mowla Sandstone	JKo	Brunnschweiler (1954) and Guppy & others (1958).

Distribution

Scattered outcrops confined to northeastern McLARTY HILLS; not recognised in the subsurface.

Lithology

Coarse to very coarse sandstone; pebbly in places, granule and clay pellet conglomerate; cross-bedded, ripple marked.

Facies Variation

None observed

Thickness

No section measured, but no more than 10 m exposed in the area.

Type Section Locality

Near Mowla Bluff (MOUNT ANDERSON: Lat. 18°49'20"S, Long. 123°38'50"E).

Age and Criteria

Tithonian to Aptian on the basis that it overlies and interfingers with the Jarlemai Siltstone in MOUNT ANDERSON (the top of the Jarlemai Siltstone is probably Tithonian in this area), and that it appears to be equivalent to the Aptian Frezier Sandstone.

Fossils

Plant fossils in MOUNT ANDERSON.

Relationships

Overlies and interfingers with Jarlemai Siltstone in MOUNT ANDERSON. Contact with Jarlemai Siltstone not seen in the area. May be equivalent to Frezier Sandstone.

Subdivisions

Nature of Exposure

Ferruginised cappings on hills of Jarlemai Siltstone.

Remarks

Table 18

Unit	Map Symbol	Defined by
Broome Sandstone	Kb	REEVES (1951)

Distribution

Crops out from Cape Leveque to MANDORA, and eastwards to the western part of McLARTY HILLS; identified in most of the petroleum exploration wells in the area.

Lithology

Sandstone, fine to medium; mudstone; minor conglomerate. Strongly cross-bedded and ripple marked; bioturbated in places.

Facies Variation

Massive mudstone and sandy mudstone at Cape Borda considered to be part of the Broome Sandstone.

Thickness

Ranges in thickness from 56 m in WAPET Thangoo 1 (Appendix 2,A6) to 274 m in WAPET Tappers Inlet (Appendix 2,A16) 1; 12 m exposed at type section. Pinches out within 5 km outside northeast corner of study area.

Type Section Locality

Gantheaume Point (LA GRANGE: Lat. 17°58'30"S, Long. 122°10'30"E).

Age and Criteria

Latest Jurassic to Aptian. It contains a Neocomian microflora and Early Cretaceous plant and shelly fossils, and interfingers with or disconformably overlain by the overlying Aptian Melligo Sandstone.

Fossils

Microflora, plant fossils, bivalves, dinosaur footprints.

Relationships

Conformably overlies the Jarlemai Siltstone, interfingers with the overlying Melligo Sandstone, disconformably overlain by the Parda Formation and Frezier Sandstone, grades laterally into the Callawa Formation.

Subdivisions

Nature of Exposure

Good exposure in coastal cliffs. Rare inland exposures in small hills and washaways.

Remarks

Includes the Leveque Sandstone of Brunnschweiler (1957), and part of Jowlaenga Formation of Brunnschweiler (1957).

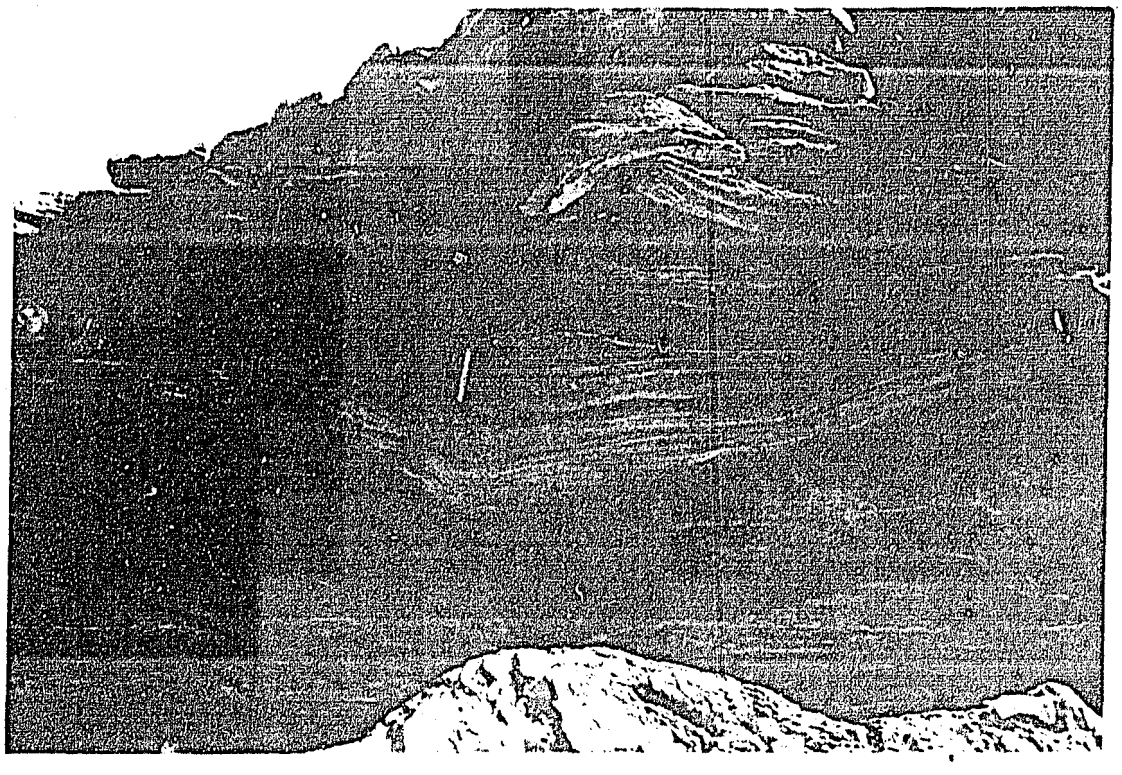


Fig. 9. Scour and fill structures in the Broome Sandstone near Broome town jetty, LA GRANGE (BMR M/2185-19).

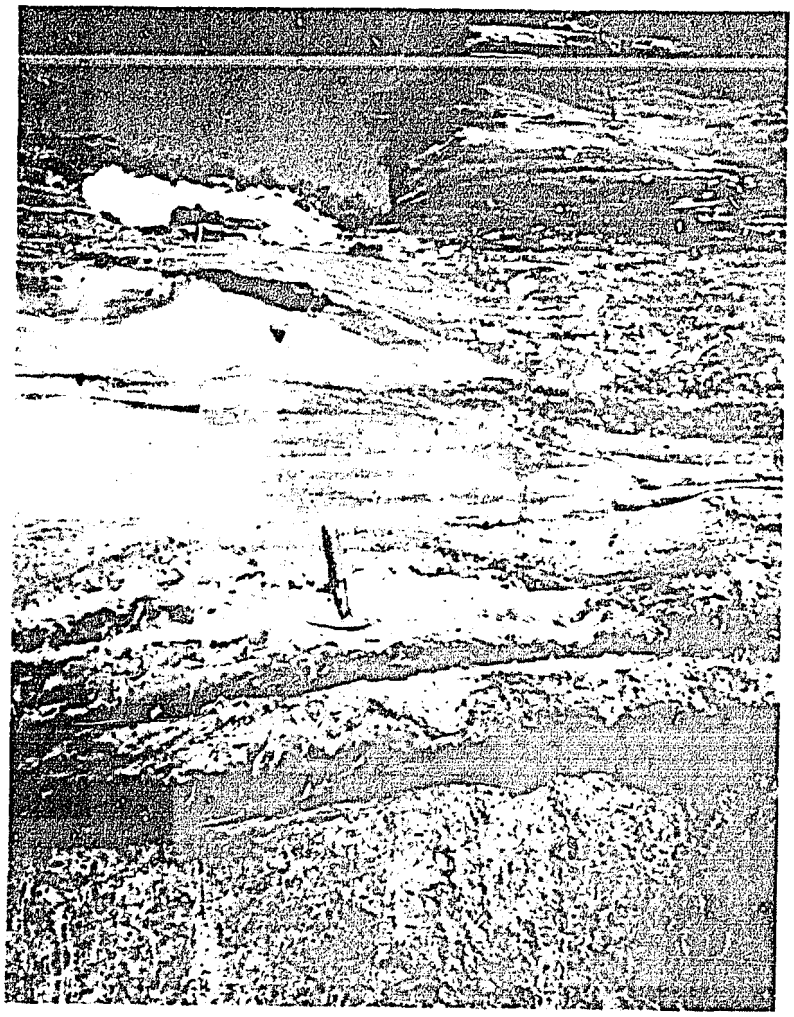


Fig. 10. Bioturbated poorly sorted medium sandstone of the Broome Sandstone disconformably overlain by flat bedded and low angle cross-bedded fine sandstone and granule conglomerate of the Melligo Sandstone, Perpendicular Head area, PENDER (BMR 2220)



Fig. 11. Silicified flat-bedded sandstone of the Melligo Sandstone, Nellie Point, YAMPI (BMR M/2185-20).

consistent with deposition by alternating direction (tidal) currents, and periods of slack water. Outcrops along the west coast of the Dampier Peninsula (originally assigned to the 'Jowlaenga Formation' by Brunnschweiler, 1957) are strongly bioturbated. Fossils in the Broome Sandstone, including those of plants, and dinosaur footprints (at Gantheaume Point on BROOME), indicate nearshore deposition; the sedimentary structures in the unit show that it is not a continental deposit.

The Broome Sandstone passes gradationally up into and interfingers with, and is in places disconformably overlain (Fig. 10) by, the Melligo Sandstone, and probably passes laterally into the continental Callawa Formation in the MUNRO-MANDORA area; there are no outcrops in this area of these units, so the nature of the transition is not known.

We consider that the coarse sandstone of the 'Leveque Sandstone' of Brunnschweiler (1957) is part of the Broome Sandstone, as it has lithologies and sedimentary structures similar to other outcrops of Broome Sandstone, and it is not mappable as a unit away from its type section, which is only 9 m thick.

Melligo Sandstone (Table 19)

The Melligo Sandstone was originally defined and mapped in the Dampier Peninsula, where the formation is a distinctive flat-bedded to low-angle cross-bedded, thin-bedded, well-sorted sandstone which shows parting lineation and is usually silicified (Fig. 11). Heavy-mineral-rich laminae are present in places. It overlies what was originally mapped as 'Jowlaenga Formation'. Our mapping shows that it overlies the Broome Sandstone, and that the boundary is conformable (interfingering and gradational) and, in places, disconformable (Fig. 10). Brunnschweiler (1957) states that it is completely silicified, but our mapping shows that this is not always true.

As well as recognising the Melligo Sandstone where mapped by Brunnschweiler in PENDER and YAMPI, we have recognised it in LA GRANGE (Cape Gourdon area) and PENDER (Perpendicular Head area). At these localities, the unit is not silicified, and it conformably and disconformably overlies the Broome Sandstone; it has the same sedimentary structures as outcrops in the type area and is also well sorted. It is thin (only a few metres) at these localities, but is still recognisable as a separate sedimentary unit.

We interpret the Melligo Sandstone to be a beach deposit bordering the regressing sea in which the Broome Sandstone was deposited.

It contains the key Aptian fossil Fissilunula clarkei in the Dampier Peninsula, but no fossils were found in the unit in LA GRANGE. We consider that it may be a time-transgressive unit.

Parda Formation (Table 20)

The Pards Formation has its type section at Parda Hill in LA GRANGE. This was visited in 1977, but no outcrop attributable to the Parda Formation was found. Most of the hill is covered with scree of fragments of silicified, fine to medium, poorly sorted sandstone, which crops out at the very top of the hill, and rare fragments of very thin-bedded, fissile, way bedded, very fine sandstone and silty mudstone. However, at Stoney Hill, 2 km to the northeast, an outcrop of Parda Formation was found about 4 m below the crest of the hill, which is again capped by silicified sandstone (identified as Frezier Sandstone - see below). The outcrop consists of thin-bedded, interbedded, very fine sandstone and silty mudstone, similar to the rare fragments of fine-grained scree at Parda Hill.

Although this lithology is very similar to that of the Jarlemai Siltstone in McLARTY HILLS, WAPET Parda 1 (WAPET, 1965a), 2 km east of Parda Hill, confirmed that the Jarlemai Siltstone is at depth at this locality, and is separated from the Parda Formation by the Broome Sandstone. The sandstone overlying the Parda Formation as hill cappings in this area is identified as Frezier Sandstone.

The sequence consisting of mudstone overlain by sandstone (as seen at Stoney Hill), which is stratigraphically well above the Jarlemai Siltstone, can be correlated in outcrop south into northwest ANKETELL, where the mudstone overlies sandstone interpreted either as Callawa Formation or its equivalent, the Broome Sandstone; the sequence of mudstone overlying Callawa Formation can be correlated from ANKETELL across YARRIE into the very east of PORT HEDLAND. GSWA groundwater drilling in PORT HEDLAND and YARRIE shows that the mudstone outcrops in that area are separated from the Jarlemai Siltstone by the Callawa Formation: hence we have no doubts in identifying the mudstone as Parda Formation.

Outcrops of mudstone in the Cape Gourdon area on LA GRANGE can also be identified as Parda Formation. Here, the mudstone is overlain by Frezier Sandstone (contact not seen) and disconformably overlies a sequence interpreted to be Broome Sandstone overlain by Melligo Sandstone. An outcrop at Cape Gourdon (Figs. 12 & 13) shows suspension deposits of the Parda Formation filling a channel about 10-15 m wide and 5 m deep cut into the Melligo Sandstone. The long axis of the channel is orientated slightly west of north, and the floor dips to the north. Hence, the Parda Formation disconformably overlies the Melligo Sandstone at this locality. Two kilometres northeast of this outcrop, the Melligo Sandstone is overlain by the Frezier Sandstone; the Parda Formation is absent - either not deposited here, or eroded before the Frezier Sandstone was deposited.

Table 19

Unit	Map Symbol	Defined by
Melligo Sandstone	Km	Brunnschweiler (1957) McWhae & others (1958).

Distribution

Northern part of Dampier Peninsula (PENDER, YAMPI); present in places along coast as far south as Gourdon Bay (LA GRANGE). The unit has not been recognised in any petroleum exploration wells.

Lithology

Fine to medium well-sorted quartz sandstone; commonly silicified; rich in heavy minerals in places; rare pebbles. Planar bedded to very low angle cross-bedded.

Facies Variation

None observed.

Thickness

No section measured; ranges from 2 to 20 m.

Type Section Locality

Type area at Melligo Creek (PENDER: Lat. 16°34'S, Long. 122°56'E)

Age and Criteria

Aptian; contains key Aptian fossil Fissilunula clarkei.

Fossils

Bivalves and belemnites described by Brunnschweiler (1957) and Skwarko (1970).

Relationships

Brunnschweiler (1957) reports the basal contact to be erosional but at Dampier Hill on DERBY, and One Arm Point (YAMPI), the Melligo Sandstone interfingers with the underlying Broome Sandstone. The Parda Formation disconformably overlies the Melligo Sandstone, apparently with little time break.

Subdivisions

Nature of Exposure

Silicified hill cappings inland.

Remarks

Identification based on good sorting and planar bedding.

Table 20

Unit	Map Symbol	Defined by
Parda Formation	Kp	Lindner & Drew in McWhae & others (1958)

Distribution

Crops out along the coast near Gourdon Bay (LA GRANGE), and as small hills in southern LA GRANGE, western MUNRO, western ANKETELL and northern YARRIE

Lithology

Mudstone, fine sandstone, thin bedded, wavy bedding.

Facies Variation

None observed.

Thickness

No section measured; ranges in thickness from 1 to 30 m.

Type Section Locality

Parda Hill (LA GRANGE: Lat. 18°56'10"S, Long 121°59'20"E).

Age and Criteria

Aptian (?) as it underlies the Aptian (?) Frezier Sandstone, and overlies the Aptian Melligo Sandstone and Neocomian to Aptian Broome Sandstone.

Fossils

Rare indeterminate bivalves found at Mt Phire.

Relationships

Disconformably (?) overlain by the Frezier Sandstone; disconformably overlies the Melligo Sandstone, Broome Sandstone, and Callawa Formation.

Subdivisions

Nature of Exposure

Well exposed in small hills and mesas.

Remarks

Exposures often capped by pisolitic laterite formed in situ from the Parda Formation.

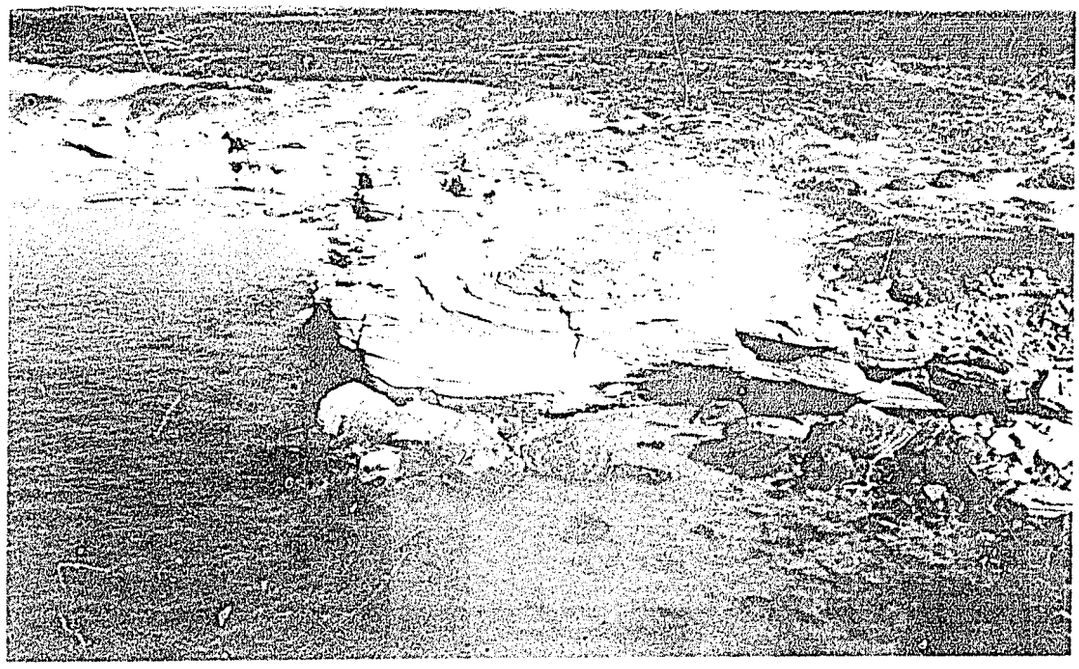


Fig. 12. Interbedded mudstone and rippled very fine sandstone of the Broome Sandstone, gradationally overlain by flat-bedded fine sandstone of the Melligo Sandstone, disconformably overlain by suspension deposits of the Parda Formation, occupying a 5 m deep channel cut into Melligo Sandstone. Cape Gourdon, LA GRANGE (BMR M/2184-12).

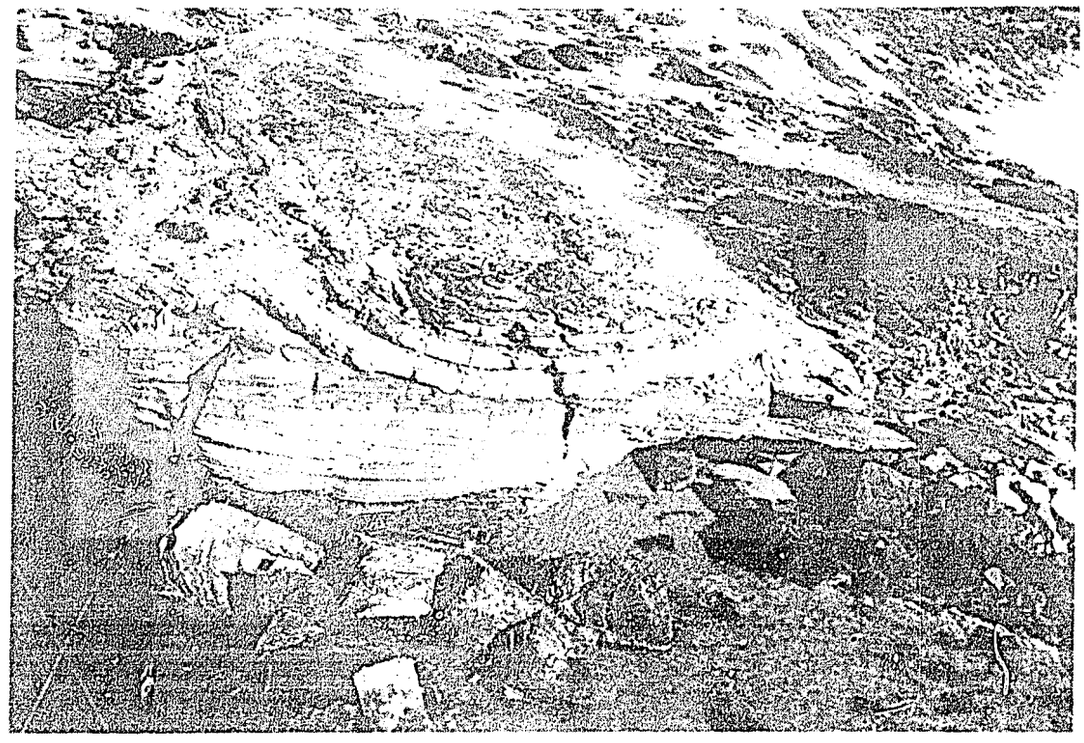


Fig. 13. Closer view of channel infill of Parda Formation shown in Plate 6. (BMR M/2184-11).

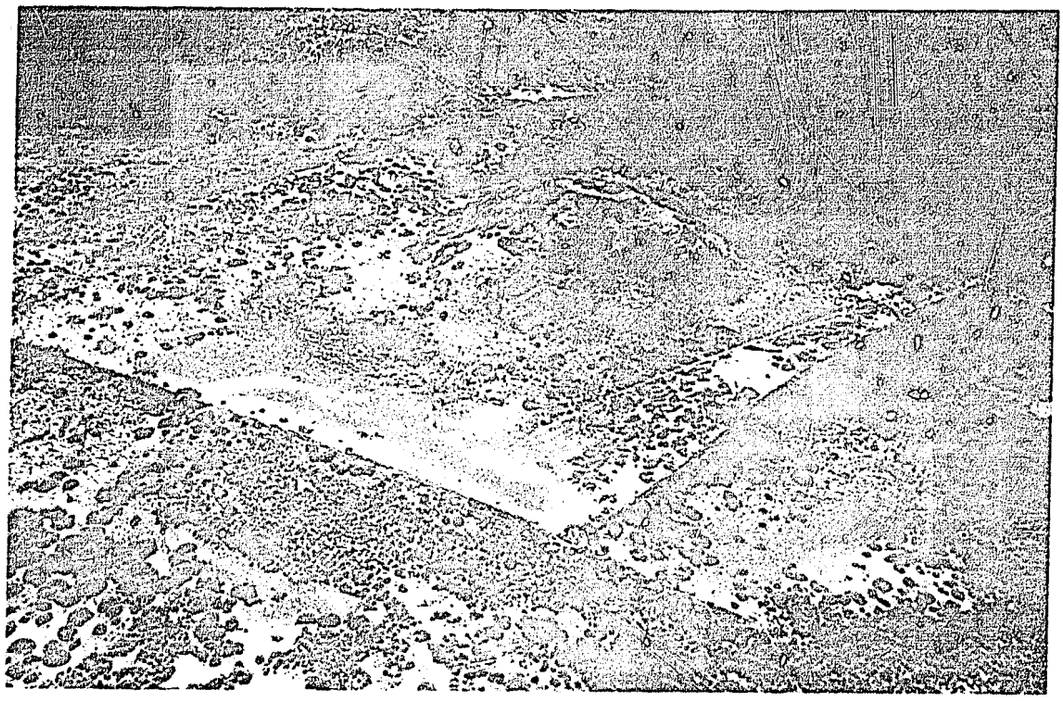


Fig. 14. Joints in Parda Formation in MUNRO. Hill is capped with Frezier Sandstone. (BMR M/2184-25).

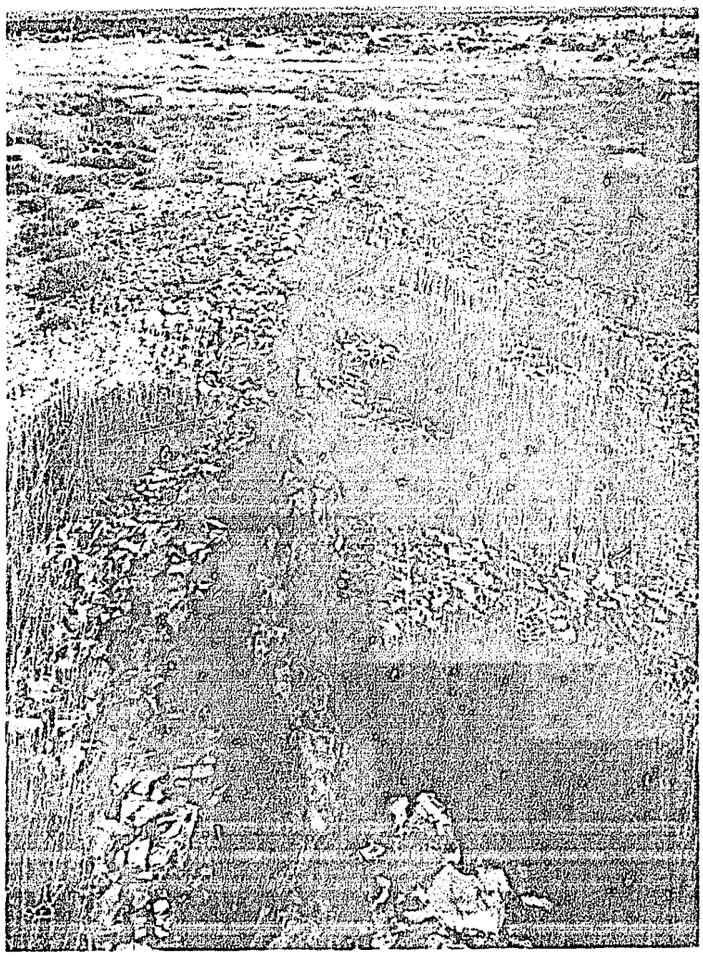


Fig. 15. Closeup of joint shown in Fig. 14 (above), showing joint infilling of fine sandstone (core), and ferruginous mudstone. (BMR M/2184-23).

In YARRIE, the Parda Formation disconformably overlies the Callawa Formation.

About 20 km south of WAPET Willara 1, prominent joints occur in the Parda Formation (Fig. 14). These joints have a core of fine sandstone, sandwiched between hard ferruginous mudstone (Fig. 15).

The Parda Formation is a suspension deposit, laid down in quiet water conditions. The regressive sequence, from Jarlemai Siltstone (in the subsurface) through the shallow-marine Broome Sandstone and the beach deposits of the Melligo Sandstone on LA GRANGE, indicates that the Parda Formation could be a lagoonal deposit, laid down behind (and hence over) beach deposits of the Melligo Sandstone. However, in YARRIE and PORT HEDLAND, it overlies the continental Callawa Formation. The extent and uniformity of the Parda Formation suggest it is a marine or lagoonal deposit, although only rare fossils have been found in it (at Mount Phire on MUNRO - unidentifiable bivalves).

We conclude that the Parda Formation represents a marine transgression which occurred only in the southwestern Canning Basin; this transgression took place, possibly owing to local downwarping of the southwestern Canning Basin, probably at a time when the sea was regressing from the area further to the north.

The age of the Parda Formation is probably Aptian, as it underlies the Frezier Sandstone which has tentatively been dated as Aptian, and overlies the Melligo Sandstone which in the Dampier Peninsula is definitely Aptian. However, the Melligo Sandstone could be older in the LA GRANGE area, and hence the Parda Formation could also be older.

Frezier Sandstone (Table 21)

The exposures of Frezier Sandstone, as mapped by Veevers & Wells (1961), are confined mainly to the coastline between Cape Villaret and Cape Frezier (LA GRANGE). It was also identified by those authors in the interval 40.8 to 182.6 m (134 to 599 ft) in WAPET Samphire Marsh 1 and 30.5 to 105.5 m (100-346 ft) in BMR Wallal 4 & 4A. These intervals have now been reassigned to the Broome Sandstone (Gorter & others, 1979).

Mapping during the 1977 field season has extended the term Frezier Sandstone to cover numerous outcrops on MUNRO, ANKETELL, and JOANNA SPRING where it has been identified in outcrop and by its black tone on the aerial photographs. In places, outcrops of Frezier Sandstone form anastomosing low ridges (Fig. 16). The Emeriau Sandstone (Brunnschweiler, 1957) defined from Pender Bay, occupies the same stratigraphic position as, and is lithologically similar to, the Frezier Sandstone.

The poorly sorted nature of the rock and the presence of abundant large-scale trough cross-bedding with basal conglomerate lenses and associated current ripple marks suggest deposition in a fluviatile environment, probably in channels.

The overall coarsening upwards of the sequence in the southern part of the area suggests a deltaic environment. This is supported by the repetition of the cycles at Karrobridal Hill. The textural and compositional immaturity of the rock indicates that it was originally laid down by currents, but the lack of current-generated structures in the rock and presence of bioturbation suggest that it has been reworked. Where vertical burrows only are present the reworking may be due to pedogenic processes. This unit is probably considered to be a basinward equivalent facies of the Callawa Formation, which has had its original structures destroyed by pedogenic processes.

In summary, we believe that the Frezier Sandstone in the southern part of the area was deposited by a delta which debouched into the shallow sea or lagoon in which the Parda Formation was formerly deposited.

Emeriau Sandstone (Table 22)

Exposures of this sandstone unit are confined to BROOME and PENDER. The Emeriau Sandstone defined from Pender Bay occupies the same stratigraphic position as, and is lithologically similar to, the Frezier Sandstone. The large distance between the exposures of Frezier Sandstone and the Emeriau Sandstone is probably due to erosion in the Roebuck Bay area rather than non-deposition in that area.

Brunnschweiler (1957) dated the Emeriau Sandstone as Tertiary from general considerations, and equated it with the Pender Bay Conglomerate. However, in our opinion the Pender Bay Conglomerate cannot be equated with the Emeriau Sandstone because the latter is a lithified rock unit, whereas the Pender Bay Conglomerate is not only an unconsolidated regolith but also contains reworked boulders of Emeriau Sandstone. Therefore, we consider it to be of Cretaceous age.

The poor sorting and the cross-bedding of the rock indicate that the Emeriau Sandstone was probably laid down in a fluvial environment.

Anketell Sandstone (Table 23)

The common occurrence of the trace fossil Rhizocorallium is consistent with a shallow-marine to intertidal environment (Veevers, 1962). The small scour-and-fill structures and the bioturbated zones are features of shallow-water sediments deposited in a tidal zone.

The thin sequence of mudstone and fine sandstone suggests a calm sea possibly a relatively low-lying landmass which contributed fine clastic detritus during this phase of deposition. The coarse clastic phase may represent deposition in channels.

Table 21

Unit	Map Symbol	Defined by
Frezier Sandstone	Kf	Lindner & Drew (in McWhae & others, 1958, p. 108).

Distribution

The unit crops out widely as isolated hills in southern LA GRANGE, MUNRO, ANKETELL, western JOANNA SPRING, and southwest McLARTY HILLS.

Lithology

Consists of poorly sorted medium-fine grained quartz wacke ranging up to very coarse and granular quartz wacke with angular grains; granular and pebble conglomerate; very poorly bedded and very ferruginized; large scale trough and planar crossbedding with sets containing granular conglomerate bases; minor bioturbated mudstone beds. At Karrobridal Hill (MUNRO), below this cross-bedded unit, is a poorly to moderately sorted fine to medium-grained quartz wacke-quartz arenite, intensively bioturbated. In areas where no bioturbation is present, this sequence is yellow-brown, laminated to thin-bedded with some ripple-marks, and numerous vertical burrows (1 cm x 6 cm). In some outcrops, the unit is a feldspathic wacke. On ANKETELL and southern MUNRO, this non-ferruginized finer grained facies in interbedded with the mudstone sequence of Parda Formation.

Facies Variation

A lower, fine-grained, burrowed facies and an upper coarse-grained crossbedded facies are known. The fine-grained facies is more common in the southern part of the area, and is not recognised in coastal outcrops.

Thickness

About 15 m is exposed.

Type Section Locality

Cape Frezier (LA GRANGE: Lat. 18°52'09"S, Long. 121°36'18"E).

Age and Criteria

Early Cretaceous (possibly Aptian) based on rare fossils (Dickins in Veevers & Wells, 1961), and on the age of the underlying Broome Sandstone.

Fossils

Rare bivalve Pseudavicula papyracea collected by Veevers & Wells (1961) near the La Grange Telegraph Station. Additional fossils found in 1977 on MUNRO and JOANNA SPRING but no identification of them was possible.

Relationships

The lower boundary with the Parda Formation is thought to be iscon-formable. It also rests disconformably on the Melligo Sandstone near Cape Gourdon (LA GRANGE). On southern ANKETELL, it grades vertically and laterally into the Callawa Formation. The unit is disconformably overlain by Anketell Sandstone on ANKETELL and JOANNA SPRING. In the north, it is overlain by Quaternary deposits.

Subdivisions

Upper coarse-grained, cross-bedded and conglomeratic quartz wacke and arenite.

Lower fine to medium grained planar-bedded, burrowed quartz wacke with minor feldspathic wacke.

Nature of Exposure

Forms small, black hills with scree slopes.

Remarks

See text regarding nomenclature.

Table 22

Unit	Map Symbol	Defined by
Emeriau Sandstone	Ke	Brunnschweiler (1957)

Distribution

The unit is confined to hills in northern BROOME at Carnot Peak, and Kings Peak, and on the coast at Emeriau Point on PENDER.

Lithology

Consists of poorly sorted, medium-grained quartz sandstone and minor conglomerate with matrix of iron oxides; cross-bedded.

Facies Variation

-

Thickness

About 4 m exposed at type section; about 30 m at Carnot Peak.

Type Section Locality

Emeriau Point (PENDER: Lat. 16°46'S, Long. 122°34'E).

Age and Criteria

Cretaceous; overlies Early Cretaceous Broome Sandstone and lithologically similar to Frezier Sandstone.

Fossils

None.

Relationships

It rests disconformably on Broome Sandstone at Emeriau Point; its top is eroded.

Subdivisions

None.

Nature of Exposure

Forms conical hills which are black on the aerial photos.

Remarks

-

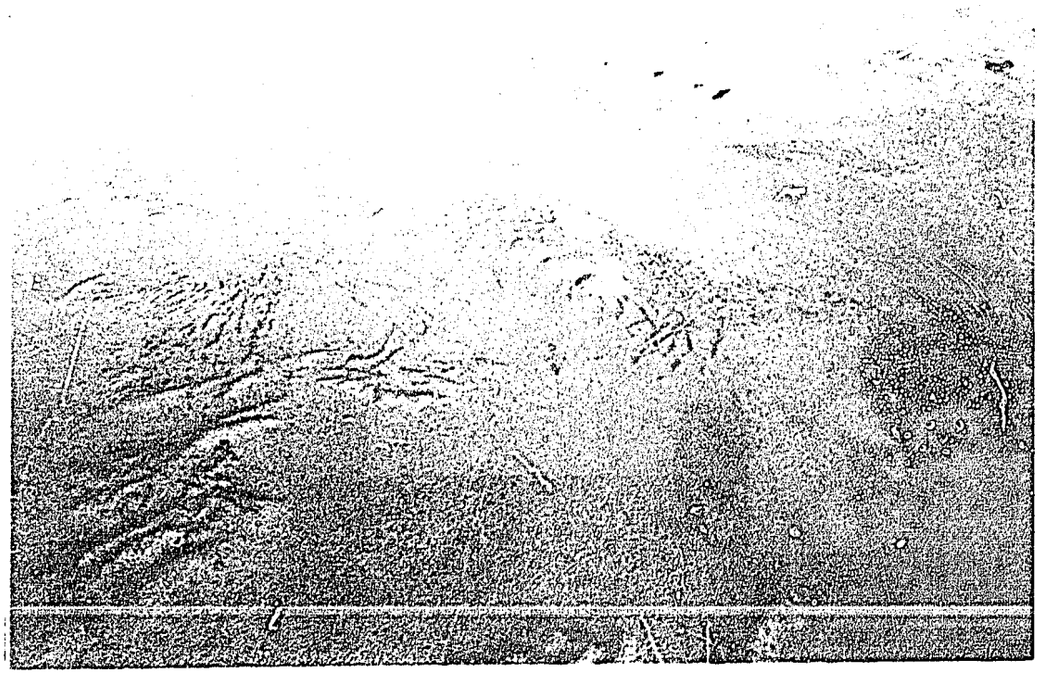


Fig. 16. Anastomosing ridges (of uncertain origin) of Frezier Sandstone, disconformably (?) overlain by Anketell Sandstone low hills, (right centre), northeastern ANKETELL. (BMR M/2184-31).

Table 23

Unit	Map Symbol	Defined by
Anketell Sandstone	Ka	Traves & others (1956)

Distribution

Occurs on the surface in central ANKETELL, in southern and eastern JOANNA SPRING, and northern PATERSON RANGE.

Lithology

Fine sandstone and mudstone interbedded with coarse-grained quartz-wacke and minor granule conglomerate. The coarser grained units form large lenticular units or beds which are poorly sorted and thin-bedded. The finer sediments are laminated to thin-bedded. The contacts between the coarse and fine parts are sharp, although some scour-and-fill structures are present. Bioturbation is common in places.

Facies Variation

None observed.

Thickness

No complete section measured; probably no thicker than 50 m.

Type Section Locality

A hill 25.7 km east of Lake Auld. (TABLETOP: Lat. 22°08'S, Long. 120°20'E)

Age and Criteria

Foraminifera indicate an Early Cretaceous age (Traves & others, 1956). In the west, it is younger than Frezier Sandstone (which, by superposition, is Aptian), but to the east it may be as young as the Bejah Claystone, but no older than the Samuel Formation (Towner & others, 1976).

Fossils

Rare indeterminate brachiopod ? found during present survey. Trace fossil, Rhizocorallium, abundant in the unit. Wood fragments are also common. Arenaceous foraminifera occur (Crespin in Traves & others, 1956).

Relationships

Disconformable on Frezier Sandstone and Callawa Formation; unconformable on Paterson Formation. Top is eroded.

Subdivisions

Nature of Exposure

Exposed in mesas along edge of an eroded plateau, and as isolated hills.

Remarks

The exposures on MUNRO identified by Veevers & Wells (1961) are now mapped as Parda Formation.

Table 24

Unit	Map Symbol	Defined by
Lake George Beds	KTg	Crowe & Towner (1976b)

Distribution

Occur in two small areas in western JOANNA SPRING.

Lithology

Composed of fine to coarse grained quartz wacke and granule conglomerate, poorly sorted. Strongly silicified, hexagonal pipe-like structures developed. It is massive and unbedded.

Facies Variation

None observed.

Thickness

About 2 m thick in western JOANNA SPRING.

Type Section Locality

8 km southeast of Helen Hill (TABLETOP: Lat. 22°50'00"S, Long. 123°42'55"E).

Age and Criteria

Probably Cretaceous to Early Tertiary on the basis that it overlies Early Cretaceous rocks.

Fossils

No age-diagnostic fossils are known.

Relationships

Overlies Anketell Sandstone unconformably ? To the south of area, the contacts are locally gradational (Towner & others, 1976). Is capped by laterite.

Subdivisions

None.

Nature of Exposure

Forms low isolated, silicified rises.

Remarks

In summary, the Anketell Sandstone was probably deposited in a nearshore environment.

CRETACEOUS TO TERTIARY

Lake George Beds (Table 24)

The poor exposure of the Lake George Beds in the area does not allow an interpretation of the depositional environment to be made. However, Towner & others (1976) believe that, farther to the south, the unit may have been deposited as an alluvial overbank deposit which subsequently has been deeply weathered and which may have been partially reworked in a soil profile.

TERTIARY(?)

Borda Sandstone (Table 25)

The Borda Sandstone is only known to crop out at Cape Borda, on PENDER. Brunnschweiler (1957) states that it overlies the 'Pender Bay Conglomerate', but our observations show that at Cape Borda a sequence of poorly sorted consolidated sandstone and minor mudstone, passing down into a basal pebble conglomerate (ferruginous sandstone clasts), disconformably overlies massive mudstone and sandy mudstone. The upper unit is the Borda Sandstone, and the lower is tentatively identified as part of the Broome Sandstone.

We consider the disconformity to represent a major time break, as the Emeriau Sandstone is missing, and the pebbles in the basal conglomerate of the Borda Sandstone are identified as being derived from the Emeriau Sandstone. Hence we have given the Borda Sandstone a Tertiary(?) age.

Little can be said on the origin of the Borda Sandstone. It may be a local continental deposit, laid down in a valley in the Cape Borda area.

CAINOZOIC

Oakover Beds (Table 26)

The Oakover Beds were originally defined by Maitland (1904) and referred to as 'Beds' by Traves & others (1956), McWhae & others (1958), and Playford & others (1975). Noldart & Wyatt (1962) use 'Formation' but no grounds for upgrading the unit were given. Hence, the name Oakover Beds is used in this Record.

Outcrops of the unit cover a large part of the floor of the Oakover and Nullagine River Valleys (YARRIE and NULLAGINE).

On NULLAGINE, Noldart & Wyatt (1962) have stated that 'a thin bed of ferruginous pisolite ironstone gravel often containing limonitic concretions occurs at the base of the beds in several localities and may represent the basal member of the formation. The gravel is similar in all respects to the ferruginous pisolitic ironstone deposits forming higher level capping in other localities, and is probably related to the deposition of those beds.'

The Oakover Beds were probably deposited in a lacustrine environment, the lake being formed by post-Cretaceous blockage of the Oakover River. The fine-grained sediments deposited were rich in calcium and magnesium. The climatic conditions that were prevalent at that time were such that evaporation greatly exceeded precipitation and this resulted in a thin zone of caliche forming at the top of the sequence due to calcification of the carbonate-rich sediments. Deep weathering has resulted in the upper part of the profile becoming chalcedonic.

In summary, the Oakover Beds were laid down in a lacustrine environment under continental conditions.

Poondano Formation (Table 27)

The Poondano Formation consists of pisolitic limonite and goethite deposits preserved as hill-cappings overlying Callawa Formation and older rocks along what are thought to be remnants of Tertiary drainage channels. Fragments of wood are locally abundant in the formation. De la Hunty (1962) showed that these deposits are sufficiently rich in iron to be considered as a source of iron ore.

Harms & Morgan (1964) consider the Poondano Formation to be equivalent to pisolitic limonite deposits several hundred kilometres to the southwest in the Robe River-Duck Creek-Beasley River areas, and consider the iron ore to be of chemical-sedimentary origin, most of it being deposited from solution in choked river valleys or by pene-contemporaneous erosion of this material and nearby re-deposition. However, MacLeod (1966) favours an origin by replacement and desilicification by iron-rich solutions of jaspilite detritus in river channels.

Veevers & Wells (1961) favoured a Mesozoic age for the Poondano Formation, Traves & others (1957) and McWhae & others (1958) a Tertiary age, while Playford & others (1975) believe it to be Cainozoic, perhaps late Tertiary or Pleistocene. Overall, its position in the landscape and its stratigraphic position point to a Tertiary age.

Table 25

Unit	Map Symbol	Defined by
Borda Sandstone	Tb	Brunnschweiler (1957)

Distribution
Cape Borda (PENDER) only.

Lithology
Poorly sorted, poorly consolidated sandstone, minor mudstone, basal conglomerate.

Facies Variation
None observed.

Thickness
5m

Type Section Locality
Cape Borda (PENDER: Lat. 16°41'06'S, Long. 122°44'42"E).

Age and Criteria
Tertiary (?), as it contains clasts of the Cretaceous Emeriau Sandstone.

Fossils
None.

Relationships
Disconformably overlies Broome Sandstone (major time break). Top eroded.

Subdivisions
None.

Nature of Exposure
Good exposure at Cape Borda.

Remarks
Local continental (valley fill?) deposit.

Unit	Map Symbol	Defined by
Oakover Beds	To	Maitland (1904) Noldart & Wyatt (1962)

Distribution

Outcrops along the centre of the Oakover River Valley (YARRIE and NULLAGINE). Large expanses of calcrete which are possibly part of the Oakover Beds crop out at the same level as the sand plain east of Isabella Range (YARRIE), which is at the same level as the mesa tops in the Oakover Valley.

Lithology

Calcareous sandstone containing limestone breccia and silica nodules, with ferruginous concretions and pisolitic ironstone (Traves & others 1956); capped by white to brown, vuggy, horizontally banded, silicified limestone, chalcedony and common opal.

Facies Variation

None observed.

Thickness

No section measured; ranges from 5 to 30 m thick (McWhae & others, 1958; Playford & others, 1975).

Type Section Locality

None defined - type area is Oakover River Valley YARRIE.

Age and Criteria

Probably Late Tertiary - the presence of reworked pisolitic ironstone indicates a post-laterite formation age (the lateritic deposits of Western Australia are generally considered to be of Oligocene-Miocene age).

Fossils

Undiagnostic ostracods are recorded from the formation (Lloyd, 1963).

Relationships

Overlies unconformably the Proterozoic Carawine Do[illegible]tes and the Permian Paterson Formation. The top of Oakover Beds is ero[illegible].

Subdivisions

None attempted.

Nature of Exposure

Forms flat-topped ridges. The upper silicified part is well exposed, but the underlying sediments are very soft and weather easily.

Remarks

Table 27

Unit	Map Symbol	Defined by
Poondano Formation	Tp	Lindner & Drew in McWhae & others (1958)

Distribution
Western PORT HEDLAND

Lithology
Pisolitic limonite and goethite.

Facies Variation
None observed.

Thickness
8 m

Type Section Locality
No type section. "Type locality" is Poondano Well area, PORT HEDLAND.

Age and Criteria
Tertiary - unconformably overlies Callawa Formation, but is strongly eroded.

Fossils
Petrified wood.

Relationships
Unconformably overlies Callawa Formation and Precambrian rocks.

Subdivisions
None

Nature of Exposure
Ridge cappings.

Remarks
Probably a chemical-sedimentary deposit.

Table 28

Unit	Map Symbol	Defined by
Bossut Formation	Qcb	Lindner in WAPET (1961a)

Distribution

The unit crops out discontinuously along all the coastline in the study area. In the subsurface it occurs in WAPET Samphire Marsh 1, BMR Wallal 4, WAPET Chirup 1. The unit may extend seawards.

Lithology

Composed of fine to coarse-grained quartz calcarenite, oolite, and calcilutite. Large scale trough crossbedding and minor planar crossbedding is common.

Facies Variation

Includes aeolian dune, beach ridge, and marginal marine deposits.

Thickness

Maximum measured thickness is 33m in WAPET Samphire Marsh 1 (Appendix 2,A4).

Type Section Locality

Coastal area near Wallal Station (Traves & others, 1956, p.33).

Age and Criteria

No age determinations have been made of fauna within the unit. As the formation overlies lateritized Aptian sediments and is itself unlateritized, the age is probably Quaternary, as it is still being deposited in places.

Fossils

The formation contains a varied fauna of fragmented and complete forams, and molluscs which in places are so plentiful as to form coquinite (Veevers & Wells, 1961; Henderson & others, 1963).

Relationships

In WAPET Samphire Marsh 1, Chirup 1, & BMR Wallal 4, the formation overlies Broome Sandstone; the unit is overlain by Quaternary sands and surficial deposits.

Subdivisions

None attempted.

Nature of Exposure

Well cemented rocks form coastal cliffs and reefs.

Remarks

The Poondano Formation was originally defined to include 'unsorted silty kaolinitic quartz sandstone' which underlies the limonite in some deposits. However, this sandstone was identified as Callawa Formation during the 1977 field mapping program. Hence it is proposed that the term Poondano Formation be used only for the pisclitic limonite deposits.

Bossut Formation (Table 28)

The name Bossut Formation was first used by Traves & others (1956, p. 33) for sand that has been 'washed into low irregular coastal dunes that have been cemented with lime to form a 'Coastal Limestone' composed of quartz and fragmentary marine shells.' It was formally defined by Lindner in WAPET (1961a).

According to Lindner, the formation is a shore-line deposit and includes lithified dunes and beach and offshore bar deposits. It underlies Holocene silt and sand of the tidal flats, and fills in valleys and irregularities eroded in the pre-Pleistocene topography. It is believed to underlie the samphire-covered salt marsh.

The use of the term Bossut Formation has been expanded in this report to cover the units 'Chimney Rock Oolite' and 'North Head Limestone' (nomenclature of Brunnschweiler, 1957). These latter units are considered to be local facies of the Bossut Formation.

Extensive beach ridges occur along the coast line from just north of Broome (BROOME) to Cape Keraudren (PORT HEDLAND). They are patchily developed on PENDER. From the aerial photographs, these ridges can be divided into a well defined group near the coast and more subdued ridges inland. These beach ridges have also been included in the Bossut Formation.

The older group are low, rounded ridges partly covered by shrubs and vegetation. The younger group, best developed along Eighty Mile Beach, have well-defined ridge crests, and have a cover of small shrubs and grass and lack deflation features. Some appear to be still forming. The beach ridges range in height from 2 to 5 m above sea level. The intervening swales are covered with grass and some contain small claypans. The ridges are composed of quartzose sand, calcarenite, or oolite and in places have an abundance of shells. Large-scale crossbedding is present.

The Bossut Formation is considered to be a local equivalent of the Tamala Limestone (formerly Coastal Limestone) of the Perth and Carnarvon Basins.

From the lithological description and the abundant presence of marine shells, the Bossut Formation is considered to have been deposited in and adjacent to a shallow sea which covered a narrow strip along the present coastline.

Alluvium (Qa)

Surface deposits of alluvium composed of sand, silt, and gravel occupy a small area as there are only a few creeks and streams present. In the central part of the area, namely MUNRO, McLARTY HILLS, JOANNA SPRING, and ANKETELL, alluvium is confined mainly to small washout fans where small creeks drain breakways, and to small claypans.

On PORT HEDLAND, this unit forms the extensive plains of the De Grey River, and fills creek channels on the eastern side of Throssell Range (PATERSON RANGE).

In the north of the area, narrow strips of alluvium occur along the small creeks which drain into Cygnet, Pender, and Beagle Bays (PENDER); a broad area of alluvium occurs in the vicinity of Beagle Bay Mission; narrow areas occur along Deep Creek, Fraser River, and Baskerville Creek and its tributaries (BROOME).

On LA GRANGE, small patches of alluvium are present near La Grange Aboriginal Mission, near Thangoo Homestead, and near the northern boundary of that Sheet area. An extensive area of alluvium occurs surrounding a large claypan in southern central MANDORA; areas too small to map at the 1:250 000 scale are present in the extensive supratidal flats.

A Quaternary age is assigned to these deposits on the basis of superposition because they are still being formed at present.

Alluvial black soil suspension deposits (Qb) of clay and silt occur near intermittent watercourses. These deposits often have heave (gilgai) structures.

Calcrete (Czk)

The use of the term calcrete for the accumulations of carbonate in soils and near-surface rocks follows the terminology of Goudie (1972) who defined it as follows: 'calcrete is a term for terrestrial materials composed dominantly but not exclusively of calcium carbonate which occurs in states ranging from powdery and nodular to highly indurated, and involves the cementation of, accumulation in, and/or replacement of, greater or lesser quantities of soil, rock or weathered material primarily within the vadose zone.'

Calcrete crops out at the level of the plain over about 15 percent of PATERSON RANGE and there are minor exposures on YARRIE, PORT HEDLAND, MANDORA, ANKETELL, and JOANNA SPRING. Its distribution on PATERSON RANGE follows the low-lying country around Lake Waukarlycarly and Lake Dora, a palaeodrainage that connects the two lakes, and another drainage between Throssell and Paterson Ranges.

The calcrete consists of homogenous and earthy, or rubbly, nodular, massive, friable to highly indurated limestone, partly replaced by veins of chalcedony. Brecciation, probably caused by solution and/or dessication, is a common feature. Clastic material occurs both scattered and in some places concentrated in beds and lenses. Cavities are common in the valley calcrete, and the hummocky surfaces of the calcrete outcrops in places show karst features such as sink holes. In thin section, calcrete is seen to consist of angular fragments of calcareous mudstone and interstitial quartz grains cemented by calcite (Chin & Hickman, 1977).

The thickness of the unit is difficult to estimate because its base is rarely exposed, but in many places, particularly in valleys, it may exceed 5 m.

Calcrete deposits of fluvial origin lie unconformably on Palaeozoic and Precambrian rock units.

Calcrete can form under semi-arid to arid conditions, and some is pedogenic, particularly where overlying Ca-rich bedrock. The calcrete in the trunk valleys of relict drainage systems however, such as in the western Canning Basin, probably derived its carbonate from run-off and groundwater and ultimately from Ca-bearing bedrock and rainwater. Sanders & Hartley (1971) concluded that most of the valley calcrete formed by precipitation of $CaCO_3$ from carbonate-saturated groundwater. The $CaCO_3$ cements, partly or wholly replaces, and also pushes apart the colluvial/alluvial sediments in which it is precipitated.

Lake deposits (Ql)

Most of the lake deposits occur in the southern and the central part of the area. They form the surface of Lake Waukarlycarly, Lake Dora, and other small saline pans in the vicinity of these two lakes on PATERSON RANGE, the numerous small claypans on southwest McLARTY HILLS, in central MUNRO around Munda Claypan and Cudalgarra Claypan, and a large claypan north of Radi Hills on MANDORA.

The deposits are clay and silt, with lesser amounts of sand and gravel made up of laterite and bedrock fragments. Sorting is mostly poor. The surfaces of the claypans exhibit dessication cracks. The salt lakes are mostly covered with a thin salt crust. Authigenic gypsum is present in the salt lakes.

The lake deposits disconformably to unconformably overlie duricrust and bedrock. Laterally, the deposits grade into alluvial valley-fill sediments. Gypsiferous dune deposits, derived from surficial lake sediments, fringe some of the salt lakes.

The thickness of these deposits cannot be accurately estimated but they may be in the order of several tens of metres.

A Quaternary age is assigned to these deposits on the basis of superposition and because they are still being formed at present.

Supratidal deposits (Qcs)

The supratidal zone is defined by Lucia (1972, p. 160) as '..... that area of tidal flat sedimentation out of reach of the daily tide. Its elevation could be higher or lower than the mean-high tide mark. This environment is covered only by spring or storm tides, and lies exposed subaerially for long periods of time.'

Supratidal flats are extensive in the western part of MANDORA adjacent to the prominent line of coastal dunes, in the Admiral Bay and La Grange Bay regions (LA GRANGE), and at Carnot Bay (BROOME). They also comprise the Roebuck Plains area in northern LA GRANGE and southern BROOME.

The flats may merge landward with sediments of Qz, or are fringed by low 'cliffs' of aeolian sands. The supratidal flats are bounded seawards by zones of mangroves, particularly around Roebuck Bay. Along Eighty Mile Beach, mangroves are absent, and the flats are bounded by the coastal dunes of the Bossut Formation.

Spring tides flood the flats around Carnot Bay and Roebuck Bay. Along Eighty Mile Beach, tidal flooding is infrequent because of the high and extensive coastal dunes. After heavy rains during the wet season the supratidal flats are often covered by standing water. The flats are covered by grasses and samphire, and small patches of woodland.

The supratidal sediment is characteristically grey mud, which is darker in colour where wood, roots of dead grass, and other plant litter have been incorporated, particularly at the landward edge of the zone. The mud is commonly laminated, although in places the laminations have been by the activity of animals particularly crabs and gastropods. Minor amounts of coarse particles may be present, especially near the landward side, where quartz sand grains, pebbles, and laterite nodules are washed onto the flats during the wet season. During strong winds, a blanket of blown sand or small sand drifts may accumulate. Wind ripples commonly form, but are easily destroyed again. After flooding, salt crusts develop on the surface, from evaporation.

Intertidal deposits (Qci)

Mangrove Swamps. A band of mangroves up to 0.5 km wide lines the eastern shore of Roebuck Bay. It lies seawards of the supratidal flats and landward of the intertidal mud flats. Mangroves are also present around Carnot Bay and along the coast on PENDER and occur in small patches in some small

estuaries.

Landward growth of mangroves is limited by the dryness and high salt content of the supratidal environment (Coleman & others, 1966).

Mud is the characteristic deposit of this environment although some sand may be present. Crabs and other burrowers are very active. The mangrove roots are an effective sediment trap.

Intertidal mud flats. These vary in width, depending on the tidal range, which can vary from 2-3 m to 10-15 m; e.g. in Roebuck Bay the tidal range is 10 m, and the intertidal zone up to 1.5 km wide. The intertidal flats contain numerous erosion gullies which branch repeatedly towards their landward ends.

Laterite (Czl)

Nearly all the outcropping Mesozoic and older rocks in the Canning Basin have been deeply lateritised and are now capped by a duricrust of laterite. The upper part of the laterite profile consists of a thin, loose to poorly-consolidated sandy layer containing ironstone pisoliths (Czs). This is underlain by the 'laterite' - a hard, strongly cemented ironstone generally exhibiting a combination of pisolitic, nodular, and vesicular textures and, up to 3 m thick. Below this is a soft mottled zone, commonly several metres thick. This grades downwards into the 'pallid' zone which consists of soft decomposed kaolinitic material. Beneath the mottled zone is a basal leached kaolinized zone in which some primary sedimentary features can be recognised.

Some samples of the hard ironstone layer were collected for palaeomagnetic data, but the results were not available at the time of writing.

Although the laterite is best developed on the clayey Cretaceous Anketell Sandstone, it is present throughout the area. The thickest laterite is estimated to exceed 10 m, though no sections were measured; the total weathered profile may exceed 30 m as indicated by seismic results.

The youngest unit deeply lateritised is the Cretaceous to Tertiary Lake George Beds.

The lateritic duricrust in the Great Sandy Desert and the Gibson Desert probably formed at the same time as the relict palaeodrainages which are considered to be late Tertiary (mid-Miocene?) (Van de Graaff & others, 1977). However, as younger laterites are known in Western Australia, we prefer to map the unit as Cainozoic in age.

Aeolian sand (Qz)

Aeolian sand is abundant and occurs predominantly in the central and eastern parts of the area. It is virtually absent on PENDER and BROOME.

The sand occurs mainly as longitudinal west to west-northwest trending seif dunes, but there are some small sand plains that lack dunes. The sand is quartzose, fine to medium-grained, and red-brown to yellow, and contains minor reddish brown silt. The red colour is due to a thin coating of earthy hematite (Folk, 1976). The sand is well-sorted, the bedding is thin, and planar cross bedding occurs throughout.

The height of sand dunes varies from 3 to 20 m, whereas in the small plains the sand may attain a thickness of 5 m. The sand dunes are mainly fixed by vegetation, and significant sand movement occurs only after the vegetation has been burnt off.

The interdune sand deposits contain more carbonaceous material and are usually darker.

Crowe (1975) has described the formation and distribution of the sand dunes in the southern part of the Great Sandy Desert, and has shown that dense sand dune patterns correspond with depressions. All of Crowe's (1975) three types of sand dunes occur: simple longitudinal, chain longitudinal, and net-like dunes.

The sand overlies Palaeozoic, Mesozoic, and some Cainozoic units.

There is no direct evidence for the age of the aeolian sand except that it post-dates the formation of the duricrust (pre mid-Miocene?). The formation of an extensive sand blanket would have coincided with a change to a more arid climate, from the humid condition prevailing during the formation of the relict drainage system and the duricrust. Bowler (1976) records a number of well documented periods characterised by marked reductions in precipitation which could have initiated phases of dune building.

The numerous parallel longitudinal dunes were probably caused by unidirectional wind systems which induce helicoidal flow at the ground surface, thus heaping the dunes into elongated ridges (Bagnold, 1941; Wilson, 1973; Folk, 1971a, b). Today's prevailing wind direction corresponds with the general direction of the longitudinal dunes, thus suggesting no change in the wind regime since the dunes were formed.

Most of the sand in the Canning Basin has probably been derived virtually in situ from erosion and retreat of ferruginous sandstone breakaways, and from the redistribution of soil that was originally present at the top of the laterite profile.

STRUCTURAL GEOLOGY

The broad structure of the Canning Basin in and adjacent to the study area is shown in Figure 17. Depth to basement contours are approximate only and mainly based on geophysical measurements (pers. comm., BMR Basin Study Group).

Almost all structures in the basin in the study area are concealed beneath the almost undeformed Mesozoic rocks, and have to be deduced from geophysics, and from the stratigraphy in petroleum exploration wells. The magnetic and gravity surveys have delineated the gross structure of the basin, and the seismic work has provided more detailed information (generally of poor quality) on local structures.

Before the Devonian, the Canning Basin was essentially a shallow regional downwarp with little local basement relief (see Webby, 1978). In the Devonian, major faulting and downwarping created areas with different basement morphologies and depths. These basement features are preserved today and form the basis of the structural elements of the Canning Basin described below.

Seismic work (see Previous Investigations) shows that the Ordovician to Carboniferous rocks were in places faulted and folded, with considerable structural relief, in Devonian and Carboniferous times. Further deformation in Early Jurassic? times folded and faulted Permian rocks. Most local structures as mapped out by seismic methods are quite dissimilar at different horizons., or may only exist at one particular horizon. No attempt has been made to show such details in Figure 17.

Fitzroy Trough and margins

In the north of the study area is the Lennard Shelf, a shallow basement feature overlain by a basin sequence generally less than 1000 m thick. This grades into the Pender Terrace, also a shallow basement feature where, in the study area, the basement slopes more steeply to the south-southwest than beneath the shelf. The southern margin of the Pender Terrace is marked by the Pinnacle Fault System, a major growth fault system. Throw is down to the south, and movement probably started in Devonian times. Movement since the Jurassic has probably been negligible.

South of the Pinnacle Fault System is the Fitzroy Trough, a term applied both to the basement feature and the contained rocks. There are no seismic data on basement depths in the area of the present study, but poor-quality seismic information in DERBY suggests a maximum depth to basement of about 10 km.

The trough probably originated in the Middle Devonian, with maximum subsidence in the late Devonian and Carboniferous. Gewerkschaft Elwerath

Yulleroo 1 penetrated 3714 m of Carboniferous and Late Devonian rocks before bottoming in Late Devonian rocks. Rocks of this age are generally thin or absent outside the trough.

Several west-trending folds in Permian rocks are exposed to the east, outside the study area, but any structures in the study area are masked by younger, flat-lying rocks; limited seismic data, however, suggest that there are several west-northwest-trending folds in Permian and older rocks. Folds in Permian rocks in the trough were probably formed in the Early Jurassic. Rattigan (1967) and Smith (1968) proposed that compression between the Kimberley Block to the north and the Canning Basin caused right-lateral wrench movement in the Fitzroy Trough at that time. The strata were deformed into an en-echelon series of folds.

The Late Jurassic to Early Cretaceous Jarlemai Siltstone is thicker in the Fitzroy Trough than in the areas to the north and south (259 m in WAPET Barlee 1 in the trough, 89 m in WAPET Roebuck Bay 1 to the south, 74 m in WAPET Tappers Inlet 1 to the north), and a similar but not so marked thickening is present in the Jurassic Wallal Sandstone. This indicates that this part of the trough may still have been downwarping at this time. Further to the southeast, in MOUNT ANDERSON and DERBY, the Fitzroy Trough remained a land area during the Jurassic and Early Cretaceous (Crowe & others, 1978).

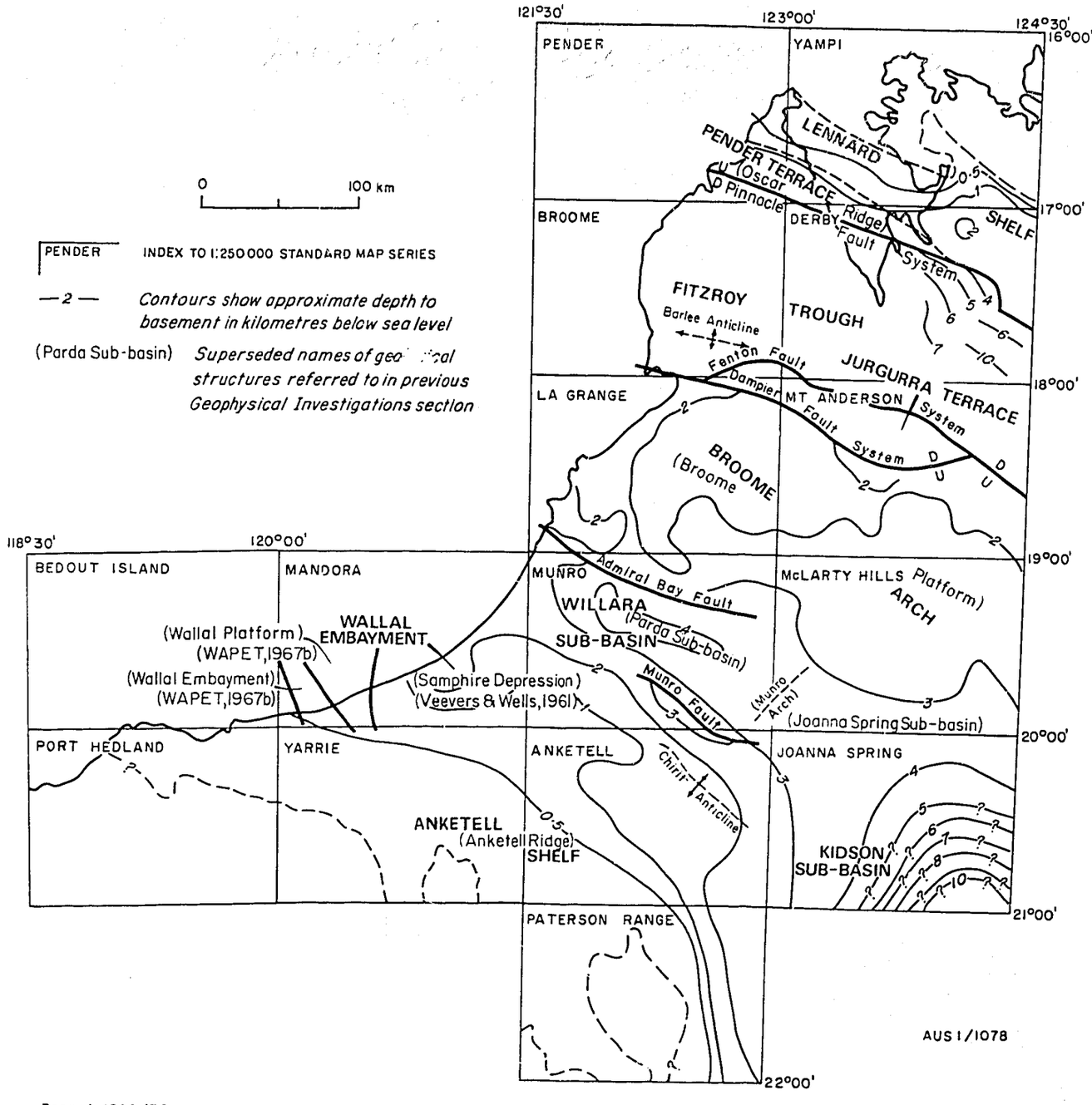
The southern boundary of the Fitzroy Trough is marked by the Fenton Fault System, which became active in Devonian times. It has a throw of at least 4000 m down to the north. The last major movement on the fault was probably in the Early Jurassic.

The Jurgurra Terrace is a basement feature of intermediate depth lying to the southwest of the trough between the Fenton Fault System and the Dampier Fault System farther southwest. Depths to basement range from about 2500 m to 4500 m.

The Dampier Fault System is interpreted from geophysical evidence - it lacks surface expression. Faulting is probably normal with a displacement of up to 3000 m, mainly pre-Permian.

Broome Arch

Southwest of the terrace and the trough is another basement feature, the Broome Arch ('Broome Swell' of Veevers & Wells, 1961; 'Broome Platform' of Koop, 1966a), where the basin sequence is 1500 m to 3000 m thick.



Record 1980/30

Fig. 17 Canning E[illegible]res

Willara and Kidson Sub-basins, Wallal and Samphire Embayments, Anketell Shelf

Lying to the southwest of the Broome Arch are two contiguous deep depressions, the Kidson Sub-basin and the Willara Sub-basin. The Kidson Sub-basin (Koop, 1966b), which occurs in JOANNA SPRING and parts of ANKETELL and McLARTY HILLS, has been interpreted from aeromagnetic data (WAPET, 1963a; Darby & Fraser, 1979). Information from boreholes in it indicates a thickening of the pre-Mesozoic sedimentary rocks to the south and southeast and this is confirmed by seismic evidence (French Petroleum, 1967). The maximum estimated depth for this portion of the Kidson Sub-basin may be as much as 10 000 m in southeast JOANNA SPRING.

The Willara Sub-basin is separated from the Broome Arch by the Admiral Bay Fault, which is a combined fault-hinge line with a throw of less than 2000m. The maximum estimated depth of the Willara Sub-basin is in the order of 4500 m.

The Willara and Kidson Sub-basins are bounded to the southwest by the Anketell Shelf, an area of shallow basement.

The Samphire Embayment (formerly Samphire Depression, Veevers & Wells, 1961) is a basement depression that lies between BMR 4A Wallal and WAPET Samphire Marsh No. 1 bores. Both these wells are located near aeromagnetic anomalies that indicated relatively shallow basement, and consequently the intervening Samphire Embayment may encompass deeper basement. The embayment is bounded on its southwestern margin by a northwest-trending fault which affected the pre-Permian rocks. The embayment underlies and contains nearly 2000 m of Mesozoic, Permian and Ordovician rocks.

The Wallal Embayment (WAPET, 1967b) is a small structural feature occurring to the southwest of the Samphire Embayment. It is controlled on its northeast flank by a small fault and on its southwest flank by definite section thinning towards the southwest. The embayment contains at least 760 m of Mesozoic and upper Palaeozoic sediments which were intersected in WAPET Chirup No. 1 (WAPET, 1968b).

GEOLOGICAL HISTORY

The geological history of the study area is summarised in Table 29 and Figures 18-34.

ECONOMIC GEOLOGY

PETROLEUM

Since drilling for petroleum exploration began in 1919, 96 wells have been drilled in the Canning basin, 20 of which occur in the area of this report. Only one well, Gewerkschaft Elwerath Yulleroo 1 has recovered hydrocarbons on test. A number of other wells have recorded minor oil and gas shows (Table 2).

As large regions in the central and southern parts of this report area are still relatively unexplored, Smith (1977) suggests that high-quality seismic coverage is required, followed by several stratigraphic wells to improve knowledge of the area's geological history and its hydrocarbon potential. However, Burne & Kanstler (1977) are of the opinion that the petroleum potential is low because many of the promising structures or areas have already been tested.

The lack of commercial success, although partly attributable to unsuitable reservoir and entrapment situations, is also thought to be related to the nature of potential source rocks and their level of maturation (Burne & others, 1979).

Burne & Kanstler (1977) concluded that sediments which now lie at depth where present temperatures are between 50° and 70°C are the most likely to have generated hydrocarbons. They also showed that much of the area has a geothermal gradient ranging between 20° and 30°C/km, similar to the normal worldwide gradient range of 18° - 29°C/km (Klemme, 1975). There are, however, two areas with gradients of 40-46°C/km. One of these areas is related to elevated basement (Broome Arch) where the higher gradient appears to result from the relatively shallow depth to basement. The other high, associated with the Willara Sub-basin, according to Burne & Kantsler ..... 'partly reflects the thick Ordovician sequences of marine sediments which are assumed to have only low to moderate thermal conductivities ... and ... (is affected by) the proximity of the fault systems along the southern flank of the Broome Arch by a build up of shear stresses or by convection of hot brines along the faults.'

Within the area of this report, the strata which are at a level suitable for the generation and preservation of liquid hydrocarbons include the Ordovician rocks of the Lennard Shelf (PENDER) and the Broome Arch, Early Devonian rocks in the Willara Sub-basin and Kidson Sub-basin, and Upper Carboniferous and Permian sediments in the Fitzroy Trough. Away from the Fitzroy Trough, Permian rocks are considered not to have reached the oil generative stage. The onshore Jurassic-Cretaceous sequence appears not to have attained optimum temperature for oil generation, except possibly in the Barlee Anticline region (BROOME).

Later, Burne & others (1979) attempted to explain the poor exploration record of the area and assess its hydrocarbon potential by examining the source rock potential; to do this they analysed the total organic carbon and determined the amount of and nature of the extractable organic matter present in some of the Palaeozoic lithologies.

Their results reinforced the conclusions of Burne & Kanstler. They concluded that :-

(i) good source lithologies exist at suitable levels of organic metamorphism, but are not at optimum positions in the sequence to enable migration into best known reservoir lithologies;

TABLE 29 - GEOLOGICAL HISTORY

AGE	EVENTS IN SEQUENCE	REMARKS
Ordovician to Early Carboniferous	Erosion of Precambrian rocks and deposition of Ordovician to Early Carboniferous sediments in the Canning Basin	
	Faulting) Uplift)	Formation of Fitzroy Trough, Broome Arch, Willara and Kidson Sub-basins (Fig. 18).
Late Carboniferous to Early Permian	Glaciation of adjacent Precambrian highlands.	Formation of valleys and striated pavements in Precambrian rocks.
	Marine deposition of sand in the north; lacustrine then fluvial deposition of silt and sand in the south.	Deposition of Betty Formation in the north, and Paterson Formation in the south; unconformable on earlier sediments; under a cold climate (Fig. 19).
Early Permian	Marine deposition of mud and fine sand over the whole area during a period of higher sea level.	Deposition of Winifred Formation. Warmer climate indicated by shelly fossils, bryozoans, and forams (Fig. 20).
	Marine deposition of sand and mud with striated pebbles	Deposition of Carolyn Formation initially under cold climate which later became warmer (Fig. 21).
	Regression; folding, faulting and erosion; probably penecontemporaneously.	Faulting and folding in Fitzroy Trough; development of unconformity between Poole Sandstone and Carolyn Formation.
	Marine transgression; deposition of lime and silt.	Nura Nura Member with fossils indicating warm climate.

TABLE 29 (cont'd)

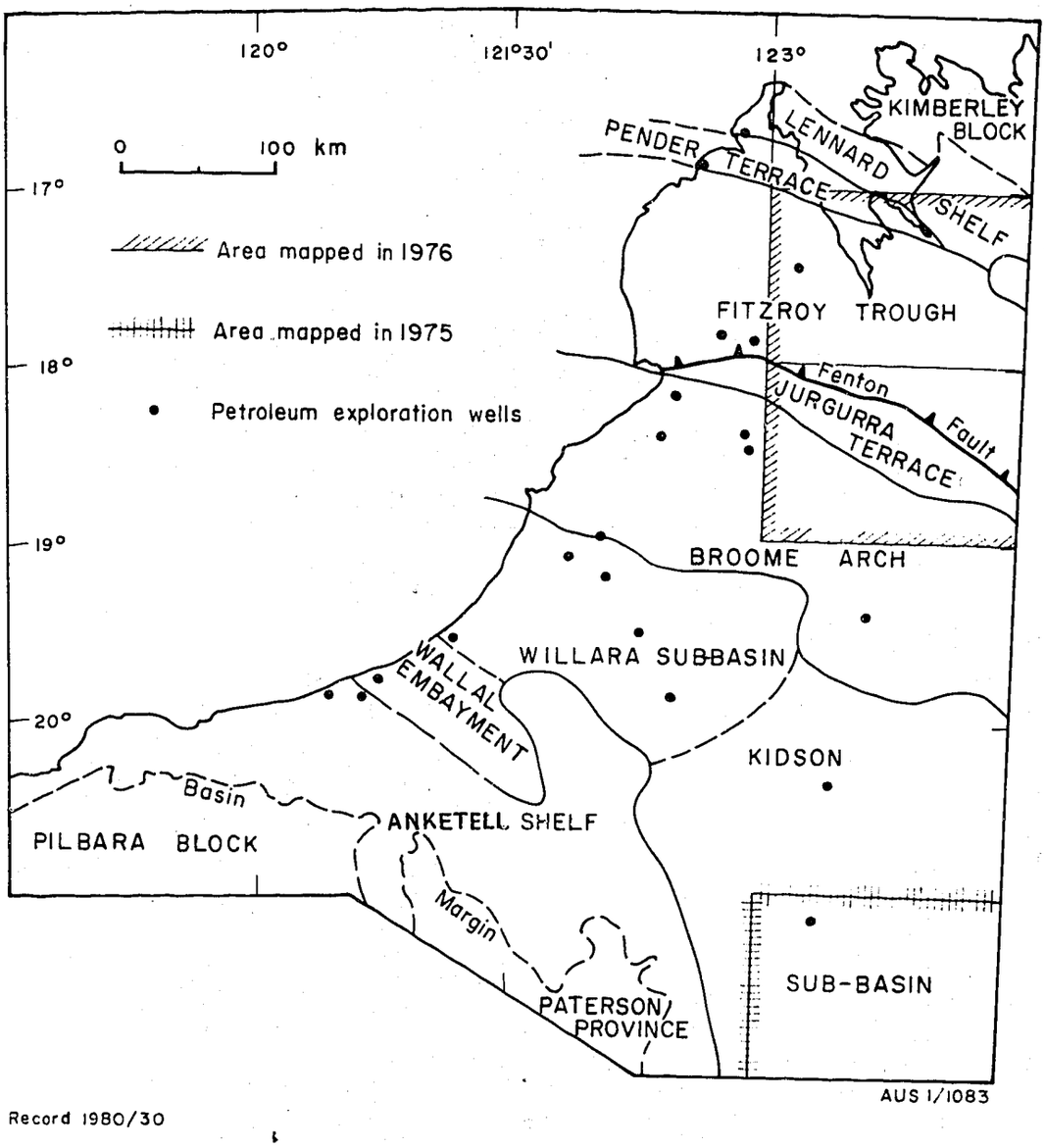
AGE	EVENTS IN SEQUENCE	REMARKS
Early Permian (contd)	Deposition of fine sand in shallow water except in extreme north and south of area.	Poole Sandstone, may be under lagoonal conditions (Fig. 22).
	Sea level rise; deposition of mud	Noonkanbah Formation; open marine conditions indicated by fossils (Fig. 23).
Early to Late Permian	Regression; deposition of fine sand and some mud in shallow marine water except on the Broome Arch, Willara Sub-basin.	Triwhite Sandstone in the south; basal Liveringa Group in the north (Fig. 24).
Late Permian	Marine transgression in the Fitzroy Trough and Wallal and Samphire Embayments; deposition of sand and mud.	Chirup Formation in swamp or marshy environment on MANDORA; upper Liveringa Group in the north in open marine to lagoonal conditions (Fig. 25).
	Regression, erosion.	Unconformity between Liveringa Group and Blina Shale.
Early Triassic	Marine transgression into Fitzroy Trough and Samphire Embayment; deposition of mud in broad tidal flat environment	Blina Shale (Fig. 26)
Early Triassic to Early Jurassic	Regression Tectonism	Movement along bounding faults of Fitzroy Trough producing E-W anticlines and faults.
	Erosion and weathering	Blina Shale and older rocks eroded. Development of unconformity beneath Wallal Sandstone.

TABLE 29 (contd)

AGE	EVENTS IN SEQUENCE		REMARKS
Late Jurassic (Tithonian) to Early Cretaceous (Aptian) (contd.)	Regression - continental deposition of sand and gravel	Regression - continental deposition of sand and gravel	Frezier Sandstone in south and central areas, Emeriau Sandstone in north (Fig. 33).
	Marine transgression from SE (Officer Basin) - deposition of silt and sand under nearshore marine conditions		Anketell Sandstone (Fig. 34) deposited unconformably over Frezier Sandstone
Late Cretaceous to Miocene (?)		Regression; deep chemical weathering and erosion.	Soils formed on Anketell Sandstone (Lake George Beds). Ferruginisation and lateritisation probably under high rainfall and subtropical temperatures.
		Development of drainage systems	Borda Sandstone probably deposits of one of these rivers; alluvia laid down.
Miocene (?) Pliocene		Change from humid to semi arid climate	'Fossilisation' of the early Tertiary landscape; induration of alluvium.
		Erosion and deposition	Detritus eroded from higher areas; choked rivers forming salt lakes, claypans; alluvial deposition continued.
		Lacustrine (?) carbonate deposition	Deposition of Oakover Beds in the Oakover Valley
Pleistocene		Weathering and erosion; deposition of aeolian sands	Arid conditions prevailed; orientation of tuning fork junctions of self dunes indicate prevailing easterly wind direction.
Late Pleistocene to Holocene		Transgression; deposit of calcarenite and calcilutite	Bossut Formation: inundation of coastal strip only; probably due to deglaciation
		Minor regression	Beach ridges (part of Bossut Formation) and supratidal environment developed.

TABLE 29 (contd)

AGE	EVENTS IN SEQUENCE		REMARKS
late Early (?) - Late Jurassic	Continental and shallow marine deposition of sand and gravel.		Wallal Sandstone (Fig. 27)
Late Jurassic (Oxfordian - Kimmeridgian)	Marine transgression from NW; deposition of sand and mud in shallow water		Alexander Formation (Fig. 28)
	Continued transgression; mud deposition in deeper water		Jarlemai Siltstone (Fig. 29)
	SOUTHWEST AND CENTRAL AREAS	NORTHERN AREA	
Late Jurassic (Tithonian) to Early Cretaceous (Aptian)	Possible uplift and erosion of SW basin margin		Possible erosion of Jarlemai Siltstone and Wallal Sandstone near basin margin.
	Alluvial deposition of sand, gravel and silt near SW basin margin; shallow marine deposition of sand and mud basinward; continental to deltaic deposition of sand and gravel in east	Shallow marine deposition of sand and mud	Callawa Formation (Fig. 30) deposited unconformably (?) over Jarlemai Siltstone and Wallal Sandstone along SW basin margin; Broome Sandstone (Fig. 30) conformably deposited over Jarlemai Siltstone basinward of Callawa Formation and in north; Mowla Sandstone (Fig. 30) deposited over Jarlemai Siltstone in east landward of Broome Sandstone.
	Regression - deposition of beach sands in NW	Regression - deposition of beach sands	Melligo Sandstone (Fig. 31) deposited over Broome Sandstone.
	Transgression - deposition of fine sand and mud in shallow marine environment		Parda Formation (Fig. 32) disconformably deposited over Broome and Melligo Sandstones and Callawa Formation.



Record 1980/30

Fig. 18 Base map for the Palaeogeographic maps (Figs. 19-34), showing area covered by this report, areas previously mapped in 1975 (Towner & others, 1975) and in 1976 (Crowe & others, 1978), and Structural Divisions (present day high and lows in the basements)

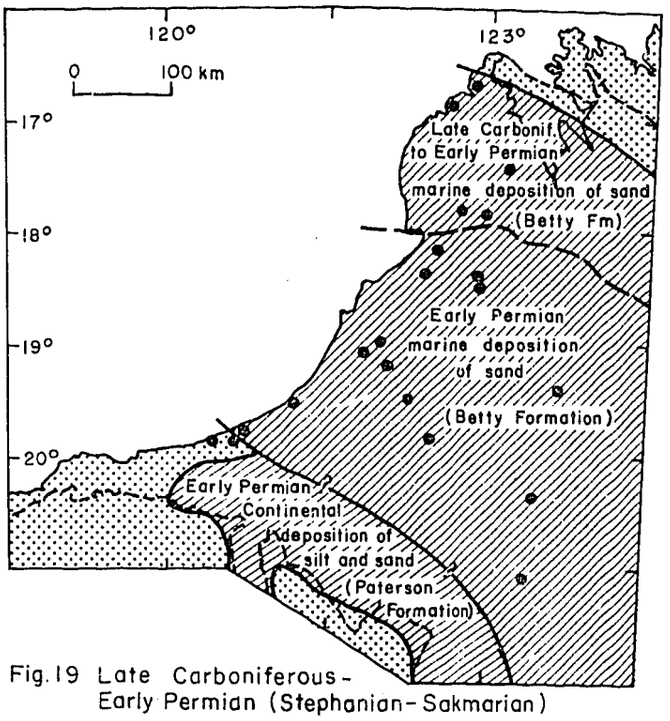


Fig. 19 Late Carboniferous - Early Permian (Stephanian - Sakmarian) palaeogeography

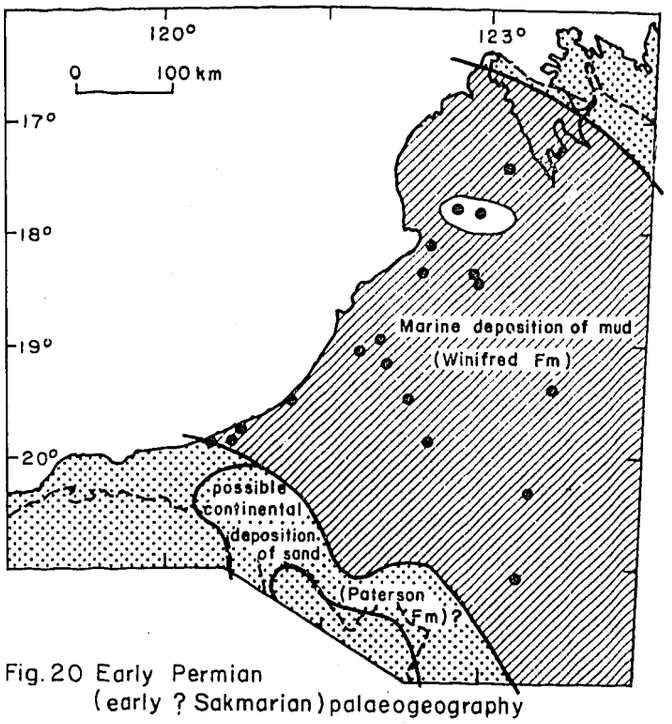


Fig. 20 Early Permian (early ? Sakmarian) palaeogeography

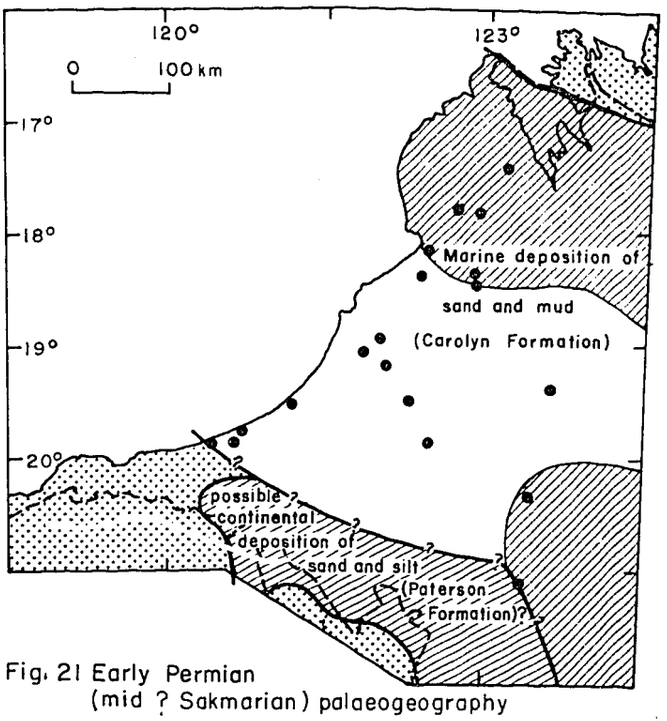


Fig. 21 Early Permian (mid ? Sakmarian) palaeogeography

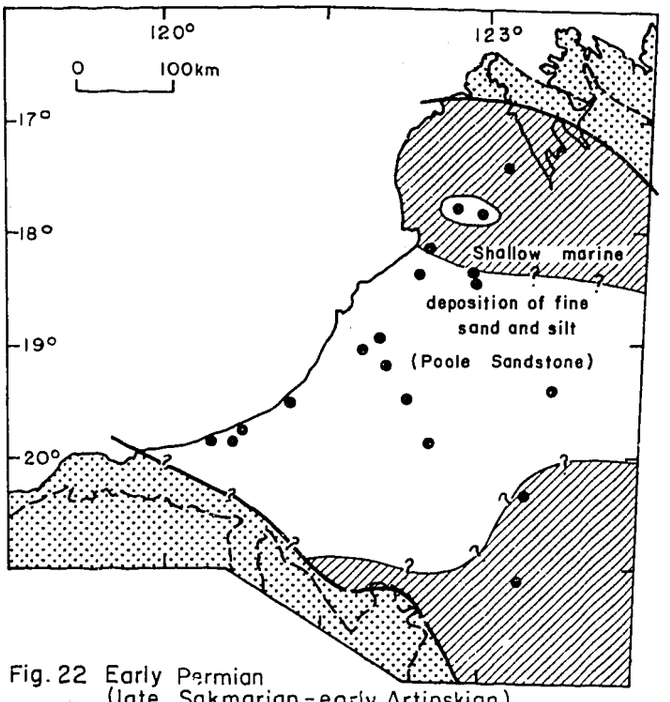


Fig. 22 Early Permian (late Sakmarian - early Artinskian) palaeogeography

AUS1/1084

Record 1980/30

- *Petroleum exploration well*
- *Land area of non-deposition*
- *Land area of deposition-rocks preserved*
- *Land area of deposition-rocks removed by later erosion*

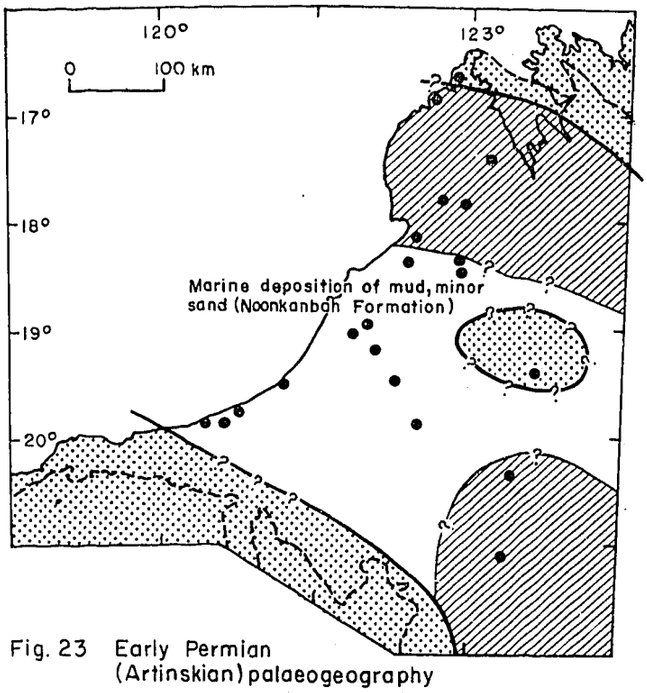


Fig. 23 Early Permian (Artinskian) palaeogeography

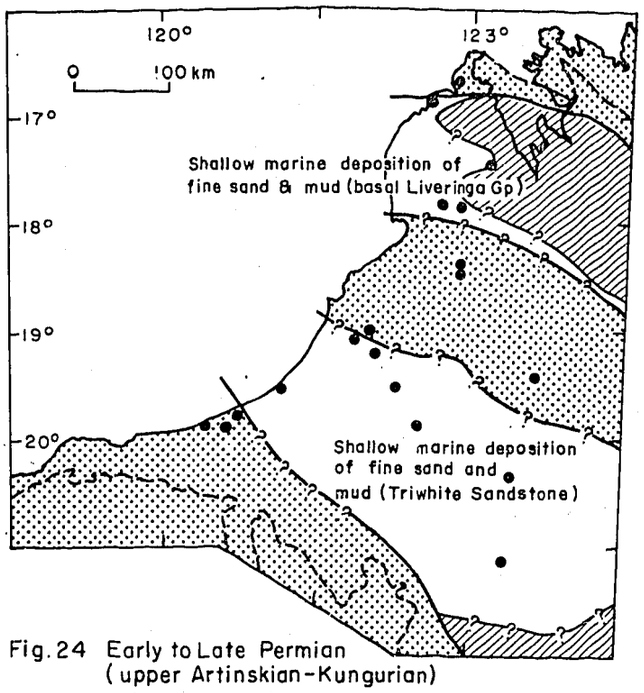


Fig. 24 Early to Late Permian (upper Artinskian–Kungurian) palaeogeography

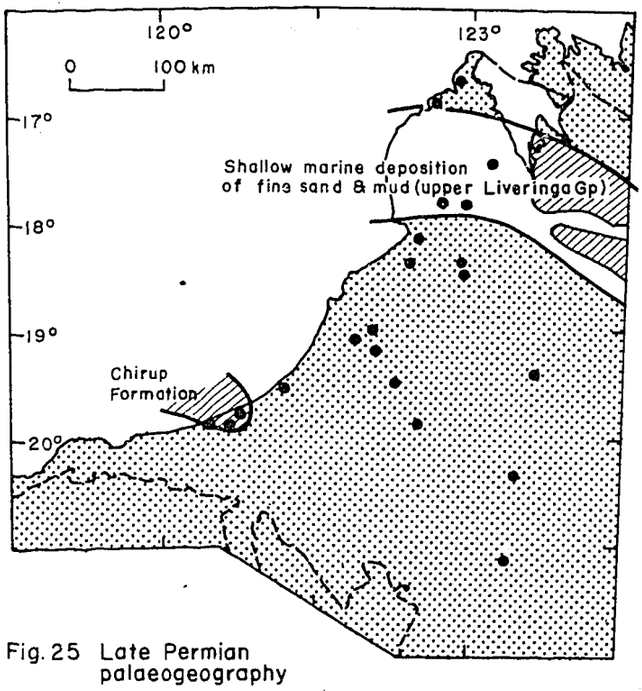


Fig. 25 Late Permian palaeogeography

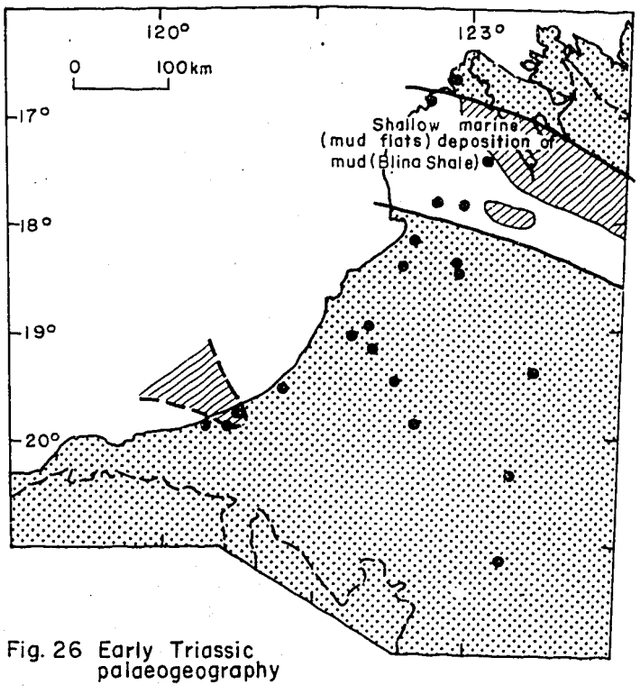


Fig. 26 Early Triassic palaeogeography

● *Petroleum exploration well*

Land area of non-deposition

Land area of deposition-rocks preserved

Land area of deposition-rocks removed by later erosion

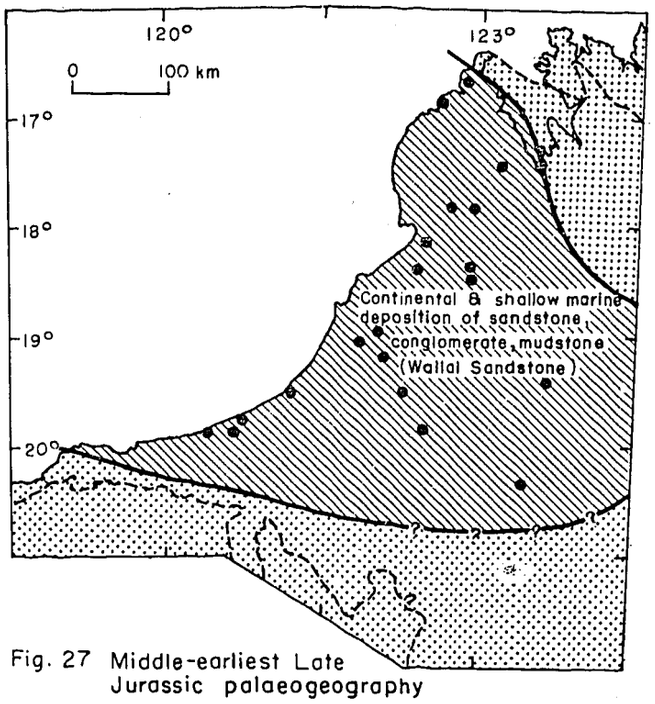


Fig. 27 Middle-earliest Late Jurassic palaeogeography

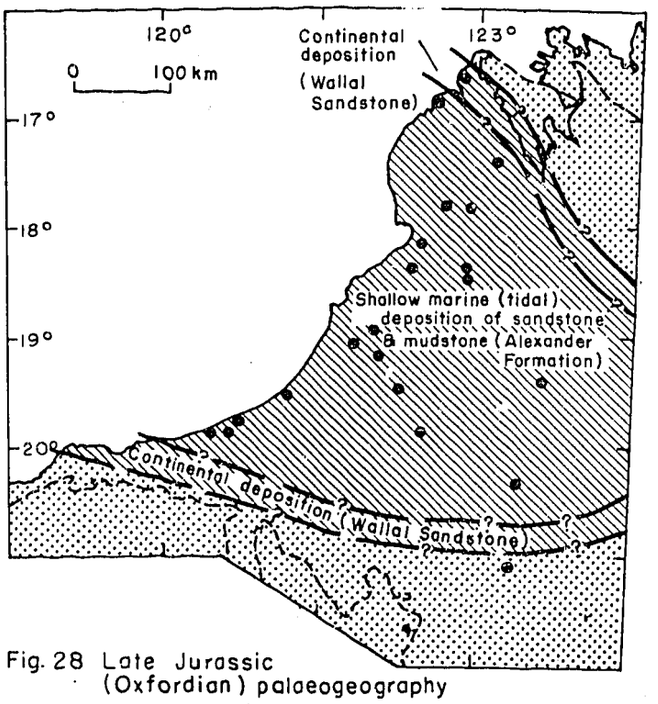


Fig. 28 Late Jurassic (Oxfordian) palaeogeography

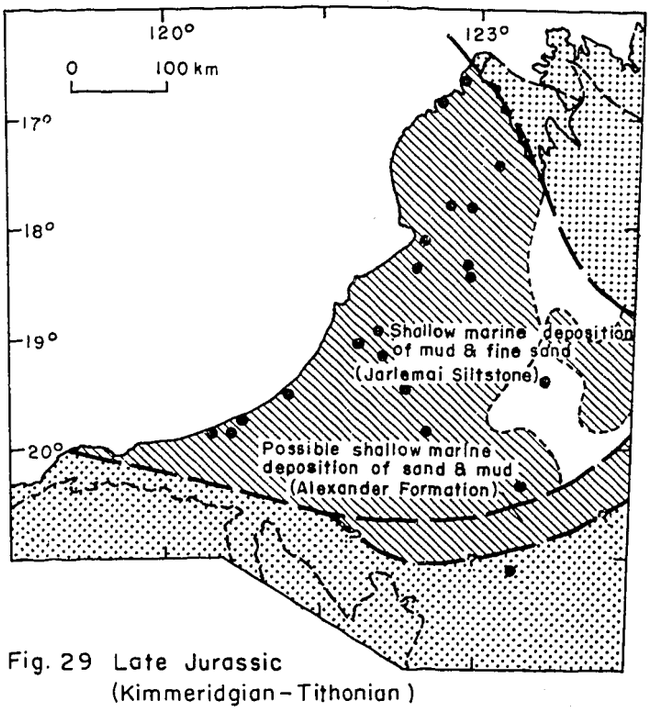


Fig. 29 Late Jurassic (Kimmeridgian–Tithonian)

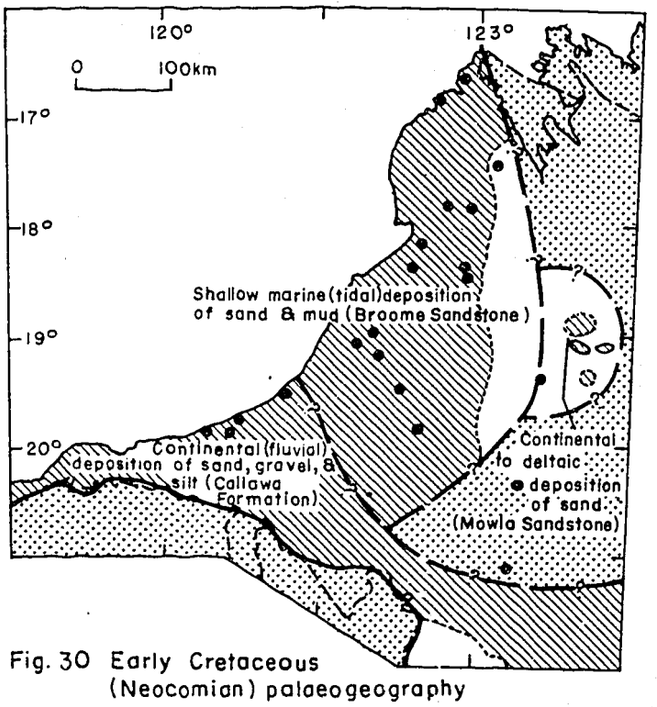


Fig. 30 Early Cretaceous (Neocomian) palaeogeography

Record 1980/30

AUS 1/1086

- *Petroleum exploration well*
- *Land area of non-deposition*
- *Land area of deposition-rocks preserved*
- *Land area of deposition-rocks removed by later erosion*

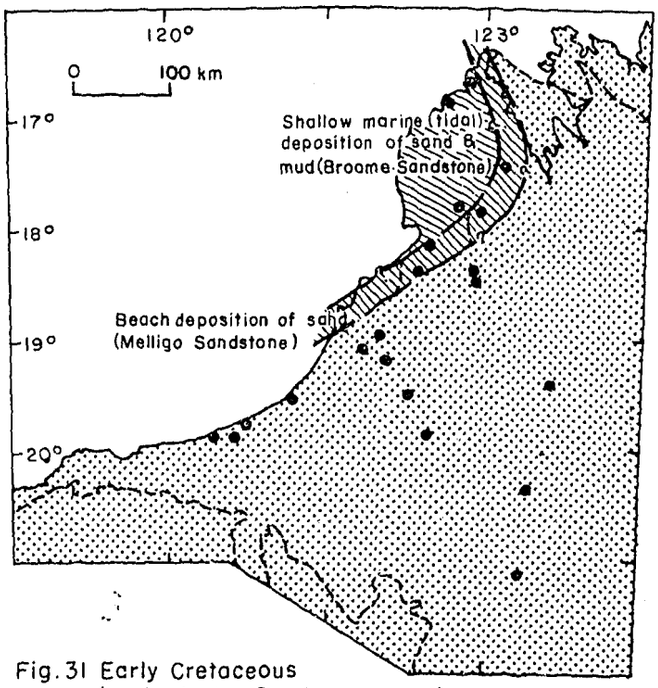


Fig. 31 Early Cretaceous (early Aptian ? palaeogeography

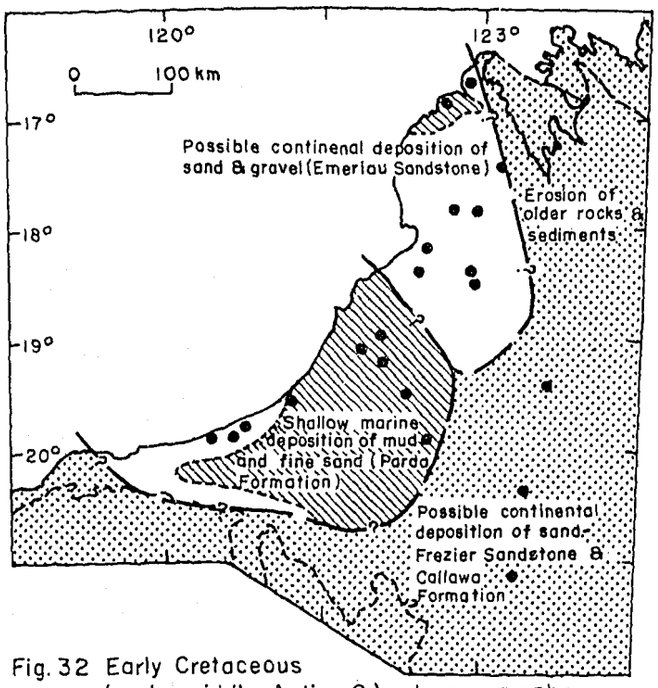


Fig. 32 Early Cretaceous (early-middle Aptian ?) palaeogeography

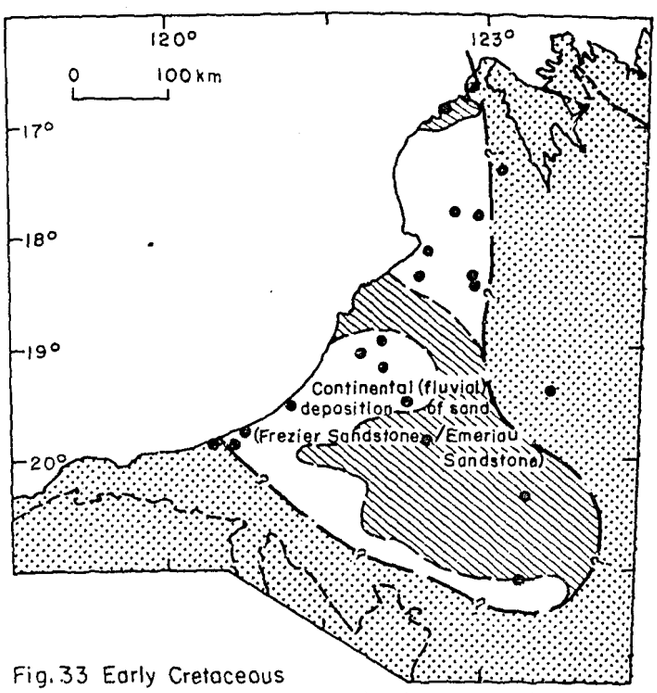


Fig. 33 Early Cretaceous (middle-late Aptian ?) paleogeography

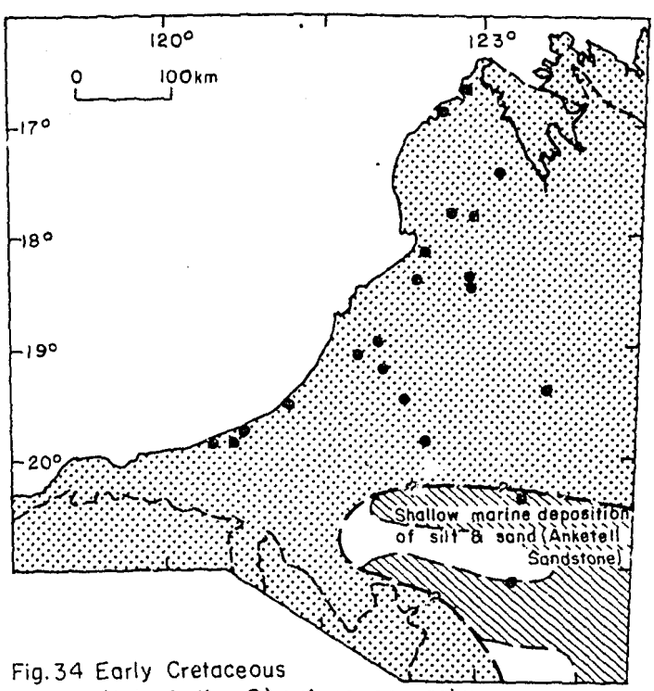


Fig. 34 Early Cretaceous (late Aptian ?) palaeogeography

- *Petroleum exploration well*
- *Land area of non-deposition*
- *Land area of deposition-rocks preserved*
- *Land area of deposition-rocks removed by later erosion*

(ii) the slow rate of burial of the sediments means that by the time maturation has occurred primary porosity has been lost in many potential reservoirs;

(iii) extensive periods of uplift, erosion, and groundwater flushing have also adversely affected prospectivity.

In the Kidson Sub-basin, the best potential reservoir lithology occurs in the Devonian Tandalgoo Red Beds, where porosities of up to 30 percent and permeabilities commonly up to several darcies have been determined (WAPET, 1966f). However, the formation has no source potential. The Ordovician succession in the Willara Sub-basin has a low organic carbon content and lacks suitable reservoir lithologies. Maturation and organic-content determinations indicate that the Ordovician shales on the Broome Arch have source potential, but they are a very tight sequence and lack a suitable seal in the overlying Permian formations. The Upper Devonian and Carboniferous sequences contains good source lithologies, but prospectivity is limited by poor porosity and the small thickness of potential reservoirs in the Fairfield Group, together with the lack of a seal above much of the overlying Anderson Formation.

Of the Permian units within the area, the Noonkanbah Formation is of particular interest, having a high organic content; it could act both as a source and as a seal for oil, but the best potential Permian reservoir occurs stratigraphically below this formation. The prospects of the Mesozoic rocks onshore is poor because of their thinness and shallow depth.

The sequence on the Anketell Shelf has no hydrocarbon potential.

Surface water

Apart from several springs in PORT HEDLAND, no permanent surface water exists in the area; rivers flow only in the wet season. The larger rivers such as the De Grey, Oakover, and Nullagine all have large semi-permanent pools during the dry season. Large pools not associated with any major stream include Christmas Pool which is situated in a gully at the base of the Paterson Range. It is a permanent rockhole filled by natural catchment from within the range, as well as by a soak fed by the percolation of waters through the glacial deposits of the Paterson Formation.

In the desert areas in the southern and central portions of the region small rockholes are located on mesas/buttes composed of Mesozoic rocks. These occur mainly in the lateritised Anketell Sandstone and are about 1 m deep and 0.5 m wide. All of those found during this survey were dry; following a period of heavy rainfall each could possibly contain a small supply of water, perhaps

up to 60 litres.

In southwest McLARTY HILLS, there is a small freshwater soak situated among bullrushes and acacias.

The large claypans on MANDORA, McLARTY HILLS, and PATERSON RANGE, including Lake Waukarlycarly, retain some water after heavy rain, but the water soon evaporates.

Traves & others (1956, p.42) mention that rainwater catchment tanks were placed along the Telegraph line between Callawa Homestead and La Grange Aboriginal Mission. These tanks have a 10-m-square galvanised iron catchment roof. They were in a state of disrepair when visited during the 1977 survey.

Groundwater

The area is prospective for groundwater. Stratigraphic and petroleum exploration wells, together with the associated seismic camp water bores, have produced potable water. However, the present distribution of wells in the area is not adequate for testing the potential resources. The coastal strip between Broome and Port Hedland, northwestern YARRIE, and the vicinity of Telfer township (PATERSON RANGE) are the only areas so far in which sub-artesian and artesian aquifers have been penetrated.

The only region where the groundwater has been adequately and systematically tested is in northeastern PORT HEDLAND and northwestern YARRIE. Here, the GSWA has investigated the groundwater potential available to meet the needs of future development of the Pilbara's natural resources. Drilling and pump tests at 25 boresites indicated the presence of two aquifer systems (Leech, 1974, 1979). An unconfined aquifer within the Callawa Formation and the Quaternary-Tertiary sequence has a variable salinity and supply, and can only be used for watering stock. A confined aquifer in the Wallal Sandstone has salinities ranging from 240 to 13 000 mg/l. It contains large volumes of domestic and industrial-quality groundwater. Shay Gap township obtains good-quality water (320 mg/l) from a borefield in this aquifer a few kilometres north of the town.

Company bores near the Telfer gold mine yield moderate to poor quality potable water (1500 mg/l), but better water has been obtained from test bores into quartzite in the Wilki Range (Chin & Hickman, 1977).

Reliable sources of water of variable quality and quantity can be expected at shallow depths in the calcrete bodies located in ancient drainage valleys and partly covered by aeolian sand. Small supplies of good quality are found in coastal dunes, but are only sufficient to supply station wells.

Table 10 in Veevers and Wells (1961, p.247) gives an indication of water supply from some bores in the west Canning Basin.

Heavy-mineral sands

Heavy-mineral concentrations occur in recent beach sands between Broome and Cape Leveque. These have been reported by Simpson (1951), Brunnschweiler (1952, 1957), Stillwell (1953), Wilson (1953), Wilkins (1953), and Farrand (1965). The results of these reports have been incorporated in Baxter (1977) and Gardiner (1977).

The heavy minerals present are opaques (mainly magnetite and magnetite-ilmenite compounds) with zircon, and some rutile, tourmaline, andalusite, kyanite, and staurolite.

Seven samples of beach sands containing heavy minerals were collected from the area between James Price Point and Coulomb Point (BROOME) during the 1977 field mapping. These samples were microscopically examined by J. Colwell (BMR), and the results are given in Table 29, along with three other analyses of heavy-mineral sands from the area that have been made available to the authors.

Greatest concentrations are in the James Price Point-Coulomb Point area. Between these points is a beach about 14 km long and 18-36 m wide, overlying a platform cut into Broome Sandstone, at the foot of a cliff 6-12 m high truncating Broome Sandstone and red soil. Drilling carried out by Enterprise Exploration in their lease area (Wilson, 1953; reported in Baxter, 1977) indicated 42 600 tonnes of mineral sands containing approximately 21 000 tonnes of heavy minerals. The principal concentrations, between 20% and 80%, occurred in sands generally thinner than 1.5 m.

Brunnschweiler (1952) suggested that the source of the heavy minerals could be either Mesozoic sandstones exposed in the Dampier Peninsula, or the Precambrian Pilbara Block, 400-600 km southwest. He remarked that the sandstones of the Dampier Peninsula were composed almost entirely of quartz in thin section, implying that they were unlikely to be the source. However, our 1977 mapping showed that the top of the Broome Sandstone at One Arm Point (YAMPI) and Perpendicular Point (PENDER) contains heavy-mineral grains, and that the Melligo Sandstone at Mount Jowlaenga contains up to an estimated 20% of opaque heavy-mineral grains. In addition, J. Colwell stresses that the grains in the heavy-mineral samples he examined are well to very well-rounded, and are most probably multicyclic (pers. comm., 1979). Hence it is quite possible that the heavy-mineral grains were derived from the top of the Broome Sandstone and the Melligo Sandstone, which were deposited in nearshore and beach environments conducive to the concentration of heavy minerals.

Iron Ore

At Poondano (PORT HEDLAND) Tertiary pisolitic goethite and limonite is present as mesa cappings of Poondano Formation (Tp). Composition ranges from

52.2 to 59.4% Fe (de la Hunty, 1962) with an estimated reserve of 2 347 000 tonnes. Phosphorus contents are low (0.02-0.05% P) and the ore can be upgraded by about 6.7% Fe on ignition. Similar deposits occur in three mesas west and southwest of the Ord Range (PORT HEDLAND) with reserves of 1 184 000 tonnes at an average of about 57% Fe (de la Hunty, 1962).

Phosphate

Freas & Zimmerman (1965) report phosphatic sideritic ironstone in the Jarlemai Siltstone, Alexander Formation, and Wallal Sandstone in petroleum exploration wells in the area. A 122-m interval (depth not specified by Freas & Zimmerman) of the Jarlemai Siltstone in WAPET Barlee 1 (WAPET, 1961c) contained an average of more than 1% P_2O_5; within this the interval 158-168 m averaged 5.7% P_2O_5 and 23.4% Fe_2O_3. The Jarlemai Siltstone in WAPET Thangoo 1 (WAPET, 1961b) between 137 and 152 m averaged 4.3% P_2O_5 and 45.8% Fe_2O_3, and in WAPET Samphire Marsh 1 (WAPET, 1961a) between 186 and 189 m assayed at 7.4% P_2O_5 and 32.2% Fe_2O_3. They considered that the Jurassic sequence is not favourable for economic phosphate occurrences, as clastic rocks predominate, and the phosphate present occurs in ironstones.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the many helpful field discussions that took place with Mr Bob Leech from the Hydrological Section of GSWA, concerning the interpretation of subsurface data in northern PORT HEDLAND and western YARRIE.

We also thank the station managers and people throughout the area who gave valuable guidance on positions and conditions of the tracks and some of the bores, or who gave assistance in other ways. We thank Glen Roberts for his assistance while he was under contract to delivery fuel from Port Hedland to Base Camp 2 (ANKETELL).

The Basin Study Group of BMR gave some assistance with the compilation of subsurface data.

The Royal Flying Doctor Service, Derby and Port Hedland transmitted radio messages for the field party.

Table 30 Heavy Mineral Analyses, Broome 1:250 000 Sheet area.

	1	2	3	4	5	6	7	8	9	10
% heavy mineral	0.3	0.3	0.5	92.9	45.9	59.5	67.9	96.8?	not known	68.5
opaques	59.0[a]	58.6[a]	79.9[a]	55.8[a]	62.5[a]	68.2[a]	70.7[a]	86.6[c]	47.8[e]	95.5[h]
zircon	33.6	31.5	10.8	36.3	7.2	1.3	7.8	11.4	32.0	2.3
rutile	2.7	1.9	1.5	1.9	2.0	1.0	0.6	1.7	21.9	0.7
brown tourmaline	2.0	4.7	4.5	3.0	20.7	22.6	14.6			)
blue-green tourmaline	0.7	1.4	1.2	0.5	1.6	1.9	0.3			) 1.5
andalusite	0.5	0	0.3	0.2	1.6	1.3	1.8			)
staurolite	1.1	1.4	1.5	1.4	3.3	2.2	3.0			
kyanite	0.2?	0	0	0.2	0.3	0	0			
others	0.2[b]	0.6[b]	0.3[b]	0.7[b]	1.0[b]	1.6[b]	1.2[b]	0.4[d]	7.8[f]	
	100.0	100.1	100.0	100.0	100.2	100.1	100.0	100.1	109.5[g]	100.0

a. unidentified opaques
b. unidentified non-opaque heavy mineral
c. magnetite-ilmenite compounds (68.2%) and magnetite (18.4%)
d. leucoxene, tourmaline, monazite, etc.
e. ilmenite (0.6%), unspecified (47.2%)
f. includes tourmaline, staurolite, kyanite, andalusite, quartz, green spinel, very rare garnet and cassiterite, and extremely rare monazite
g. opaques and rutile determined by reflection in polished briquette, zircon and others in Canada Balsam Mount. High total is a result of combining these two analyses.
h. magnetite

Sample localities

1. BMR 77062589 A - Coulomb Point. Top lamina from intertidal zone
2. BMR 77062589 B - Coulomb Point. Surface grab sample from aeolian dune
3. BMR 77062589 C - Coulomb Point. Grab sample from 1 m depth in intertidal zone
4. BMR 77062590 A - 0.4 km NE James Price Point. Top lamina from intertidal zone
5. BMR 77062590 B - 0.4 km NE James Price Point. Grab sample from 30 cm depth in intertidal zone
6. BMR 77062590 C - 0.4 km NE James Price Point. Top lamina from backshore zone
7. BMR 77062591 - 2.4 km NNE James Price Point. Surface grab sample from backshore zone
8. Brunnschweiler (1957) - About 8 km N James Price Point - "Surface sample"
9. Stilwell (1953) - 48-64 km N Broome. 6 to 9 m in a costean dug across the width of the beach
10. Broome town area. Sample collected by M. Condon (BMR) in 1954, BMR technical files (Broome E/51-6).

REFERENCES

ALLEN, J.R.L., 1965 - Fining-upward sequences in alluvial succession. Journal of Geology, 4, 229-46.

AUSTRALIAN BUREAU OF STATISTICS, 1978 - Year Book, Australia, published by Australian Bureau of Statistics.

BAGNOLD, R.A., 1941 - THE PHYSICS OF BLOWN SAND AND DESERT DUNES. Methuen & Co. Ltd., London.

BALME, B.E., 1967 - Palynological examination of samples from WAPET Blackstone No. 1. In WAPET (1967b).

BAXTER, J.L. 1977 - Heavy mineral sand deposits of Western Australia. Geological Survey of Western Australia, Mineral Resources, Bulletin 10.

BEARD, J.S., 1967 - Some vegetation types of tropical Australia. Journal of Ecology, 55, 271-80.

BEARD, J.S., 1969 - The natural regions of the deserts of Western Australian. Journal of Ecology, 57, 677-711.

BEARD, J.S., & WEBB, M.J., 1974 - Vegetation Survey of Western Australia - Sheet 2, Great Sandy Desert. University of Western Australia, Perth.

BIRD, E.C.F., 1960 - The formation of sand beach ridges. Australian Journal of Science, 22, 349-50.

BOWLER, J.M., 1976 - Aridity in Australia - age, origins and expression in aeolian landforms and sediments. Earth Science Review, 12, 279-310.

BREMNER, C. St. J., 1942 - Aerial reconnaissance of the south margin of Fitzroy Basin, western Australia. Caltex (Australia) Oil Development Pty. Ltd., Company Report (unpublished).

BRUNNSCHWEILER, R.O., 1952 - Note on heavy-mineral beach sands in Dampier Peninsula, Northwest Australia. Bureau of Mineral Resources Australia, Record 1952/78 (unpublished).

BRUNNSCHWEILER, R.O., 1954 - Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia. Journal of the Geological Society of Australia, 1, 35-54.

BRUNNSCHWEILER, R.O., 1957 - The geology of Dampier Peninsula, Western Australia. Bureau of Mineral Resources, Australia, Report 13.

BURBIDGE, N.T., 1944 - Ecological notes on the vegetation of the 80-mile beach. Journal of Proceedings of Royal Society of Western Australia, 28, 157-64.

BURNE, R.V., & KANTSLER, A.T., 1977 - Geothermal constraints on the hydrocarbon potential of the Canning Basin, Western Australia. BMR Journal of Australian Geology & Geophysics, 2(4), 271-288.

BURNE, R.V., GORTER, J.D. & SAXBY, J.D., 1979 - Source rocks and hydrocarbon potential of the Palaeozoic in the onshore Canning Basin, Western Australia. BMR Journal of Australian Geology & Geophysics, 4 (1979), 125-133.

CASEY, J.N., 1957 - Anketell, Western Australia - 4-mile Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes SF/51-2. 1st Edition.

CHIN, R.J., & HICKMAN, A.H., 1977 - Proterozoic geology of the Paterson Range, W.A. 1:250 000 Sheet. Geological Survey of Western Australia, Record 1977/11 (unpublished).

CLAPP, F.G., 1925 - A few observations on the geology and geography of the Northwest and Desert Basins, Western Australia. Proceedings of the Linnaean Society of New South Wales, 50(2), 47.

CLOUD, P.E., Jnr, 1955 - The physical limits of glauconite formation. Bulletin of American Association of Petroleum Geologists, 35, 384-92.

COLEMAN, P.J., 1957 - Permian Productacea of Western Australia. Bureau of Mineral Resources, Australia, Bulletin, 40.

COLEMAN, J.M., GAGLIANO, S.M., & SMITH, W.G., 1966 - Chemical and physical weathering in saline high tidal flats, northern Queensland. Bulletin of Geological Society of America, 77, 205-6.

COMPSTON, W., 1966 - The carbon isotopic compositions of certain marine invertebrates and coals from the Australian Permian. Geochemica et Cosmochimica Acta, 18, 1-22.

CRESPIN, I., 1958 - Permian Foraminifera of Australia. Bureau of Mineral Resources, Australia, Bulletin 48.

CROWE. R.W.A., 1975 - The classification, genesis, and evolution of sand dunes in the Great Sandy Desert. Geological Survey of Western Australia, Annual Report 1975.

CROWE, R.W.A., & TOWNER, R.R., 1976a - Permian depositional history of the Noonkanbah 1:250 000 Sheet area, W.A. Bureau of Mineral Resources, Australia, Record 1976/24 (unpublished).

CROWE, R.W.A., & TOWNER, R.R., 1976b - Definitions of some new and revised rock units in the Canning Basin. Geological Survey of Western Australia, Annual Report 1977.

CROWE, R.W.A., TOWNER, R.R., & GIBSON, D.L., 1978 - The Permian and Mesozoic geological history of the Derby and Mount Anderson 1:250 000 Sheet areas, Western Australia. Bureau of Mineral Resources, Australia, Record 1978/8 (unpublished).

DARBY, F., & FRASER, A.R., 1969 - Reconnaissance helicopter gravity survey, Canning Basin, W.A., 1968. Bureau of Mineral Resource, Australia, Record 1969/37 (unpublished).

DARBY, F., & VALE, K.R., 1969 - Progress on the reconnaissance gravity survey of Australia. Bureau of Mineral Resources, Australia, Record 1969/110 (unpublished).

de la HUNTY, L.E., 1962 - Report on some limonitic iron ore deposits in the vicinity of Port Hedland, Pilbara Goldfield, W.A., Geological Survey of Western Australia Annual Report, 1960, 15-21.

DICKINS, J.M., 1963 - Permian pelecypods and gastropods from Western Australia. Bureau of Mineral Resources, Australia, Bulletin 63.

DICKINS, J.M., 1978 - Climate of the Permian in Australia: the invertebrate faunas. Palaecgeography, Palaeoclimatology, Palaeoecology, 23, 33-46.

DICKINS, J.M., & THOMAS, G.A., 1955 - Permian fossiliferous rocks from near the southwest margin of the Canning Basin, Western Australia. Bureau of Mineral Resources, Australia, Record 1955/5 (unpublished).

DICKINS, J.M., TOWNER, R.R., & CROWE, R.W.A., 1978 - Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia. In Yuri A. Orlov Memorial Volume: Palaeontological Society of India.

DOLBY, J.H., & BALME, B.E., 1976 - Triassic palynology of the Carnarvon Basin of Western Australia. Review of Palaeobotany and Palynology, 22 (1976), 105-108.

DOOLEY, J.C., 1963 - Onslow/Derby regional gravity traverses, Western Australia 1953. Bureau of Mineral Resources, Australia, Record 1963/13 (unpublished).

EVANS, P.R., 1969 - Upper Carboniferous and Permian palynological stages and their distribution in eastern Australia. In GONDWANA STRATIGRAPHY. IUGS Symposium, Buenos Aires, October, 1967, UNESCO, 41-54.

FARRAND, M., 1965 - The heavy-mineral content of contemporary coastal sands from northwestern Australia. CSIRO Mineragraphic Investigations Report 911 (unpublished).

FEEKEN, E.H.J., FEEKEN, G.E.E., & SPATE, D.H.K., 1970 - THE DISCOVERY AND EXPLORATION OF AUSTRALIA. Sydney, Nelson.

FLAVELLE, A.J., 1974 - CANNING BASIN GRAVITY SURVEYS, 1953-1962. Bureau of Mineral Resources, Australia, Record 1974/161 (unpublished).

FLAVELLE, A.J., & GOODSPEED, M.J., 1962 - Fitzroy and Canning Basins reccnnaisance gravity surveys, Western Australia 1952-60. Bureau of Mineral Resources, Australia, Record 1962/105 (unpublished).

FOLK, R.L., 1971a - Longitudinal dunes of the northwestern edge of the Simpson Desert, Northern Territory, Australia. 1. Geomorphology and grainsize relationships. Sedimentology, 16, 5-55.

FOLK, R.L., 1971b - Genesis of longitudinal and Oghurd dunes elucidated by rolling upon grease. Bulletin of Geological Society of America, 82, 3461-68.

FOLK, R.L., 1976 - Reddening of desert sands: Simpson Desert, Northern Territory Australia. Journal of Sedimentary Petrology, 46(3), 604-615.

FRASER, A.R., 1974 - Reconnaissance helicopter gravity survey of the northwest of Western Australia, 1969. Bureau of Mineral Resources, Australia, Record 1974/27 (unpublished).

FRASER, A.R., 1976 - Gravity provinces and their nomenclature. BMR Journal of Australian Geology & Geophysics, 1 (1976), 350-352.

FREAS, D.H., & ZIMMERMAN, D.O., 1965 - Geological evaluation for phosphate exploration of the Canning, Ord River and Bonaparte Gulf Basins of Northwestern Australia. IMC Development Corporation, Report No. 7 (unpublished).

FRENCH PETROLEUM CO. (AUSTRALIA) PTY LTD, 1967a - Jamura helicopter and land gravity survey, final report. Bureau of Mineral Resources, Australia, file 67/4832.

FRENCH PETROLEUM CO. (AUSTRALIA) PTY LTD, 1967b - McLarty seismic and gravity survey, final report. Bureau of Mineral Resources, Australia file 67/11145.

GARDENER, C.A., 1942 - The vegetation of Western Australia with special reference to the climate and the soils. Journal of Royal Society of Western Australia, 28, 11-87.

GARDINER, J.E., 1977 - Heavy-mineral sand deposits along the coast of Western Australia. Bureau of Mineral Resources, Australia, Record 1977/34 (unpublished).

GELLATLY, D.C., & SOFOULIS, J., 1973 - Yampi, Western Australia, 1:250 000 Geological Series. Bureau of Mineral Resources Explanatory Notes, SE/51-3.

GELLATLY, D.C., SOFOULIS, J., DERRICK, G.M., & MORGAN, C.M., 1968 - The older Precambrian geology of the Lennard River 1:250 000 Sheet area, SE/51-8, Western Australia. Bureau of Mineral Resources, Australia, Record 1968/126 (unpublished).

GEWERKSCHAFT ELWERATH, 1966 - Reflection seismic and magnetometer survey, Lower Fitzroy Project. Bureau of Mineral Resources, Australia, file 66/11111 (unpublished).

GEWERKSCHAFT ELWERATH, 1967 - Yulleroo No. 1, well completion report. Bureau of Mineral Resources, Australia, file 67/4249 (unpublished).

GIBSON, D.L., & CROWE, R.W.A., in press. - Mount Anderson, W.A. - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes, SE/51-11.

GORTER, J.D., 1978 - Triassic environments in the Canning Basin, Western Australia. BMR Journal of Australian Geology & Geophysics, 3, 25-33.

GORTER, J.D., RASIDI, J.S., TUCKER, D.H., BURNE, R.V., PASSMORE, V.L., WALES, D.W., & FORMAN, D.J., 1979 - Petroleum Geology of the Canning Basin. Bureau of Mineral Resources, Australia, Record 1979/32 (unpublished).

GOUDIE, A.S., 1972 - On the definition of calcrete deposits. Zeitschrift Fur Geomorphologie, 16(4), 464-468.

GOUDIE, A.S., 1973 - DURICRUSTS IN TROPICAL AND SUBTROPICAL LANDSCAPE. Clarendon Press, Oxford.

GUPPY, D.J., & LINDNER, A.W., 1949 - Preliminary report on the geology of Dampier Land, Western Australia. Bureau of Mineral Resources, Australia, Record 1949/11 (unpublished).

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1952 - The stratigraphy of the Mesozoic and Permian sediments of the Desert Basin, Western Australia. XIXieme International Geological Congress (Gondwana symposium) Algeria, 1952, 101-114.

GUPPY, D.J., LINDNER, A.W., RATTIGAN, J.H., & CASEY, J.N., 1958 - The geology of the Fitzroy Basin, Western Australia. Bureau of Mineral Resources, Australia, Bulletin 36.

HARMS, J.E., & MORGAN, B.D., 1964 - Pisolitic limonite deposits in northwest Australia. Proceedings of the Australasian Institute of Mining & Metallurgy, 212, 91-124.

HENDERSON, S.D., CONDON, M.A., & BASTIAN, L.V., 1963 - Stratigraphic drilling, Canning Basin Western Australia. Bureau of Mineral Resources, Australia, Report 60.

HICKMAN, A.H., 1975 - Explanatory Notes on the Nullagine 1:250 000 Geological Sheet, W.A. Geological Survey of Western Australia, Record 1975/5 (unpublished).

HICKMAN, A.H., 1977 - Explanatory Notes on the Precambrian part of the Port Hedland-Bedout Island 1:250 000 Geological Sheets, W.A. Geological Survey of Western Australia, Record 1977/2 (unpublished).

HICKMAN, A.H., & CHIN, R.J., 1976 - Explanatory Notes on the Precambrian part of the Yarrie 1:250 000 Geological Sheet. Geological Survey of Western Australia, Record 1976/15 (unpublished).

HOWE, H.V., RUSSEL, R.J., McGUIRT, J.H., CRAFT, B.C., & STEPHENSON, M.B., 1935 - Reports on the Geology of Cameron and Vermilian Parishes. Geological Survey of Louisiana, Bulletin 6.

INGRAM, R.L., 1954 - Terminology for the thickness of stratification and parting units in sedimentary rocks. Bulletin of Geological Society of America, 65, 937-938.

JACKSON, M.J., & VAN DE GRAAFF, W.J.E. (in press) - Geology of the Officer Basin, Western Australia. Bureau of Mineral Resources, Australia, Bulletin 206.

KEMP, E., 1976 - Palynological observations in the Officer Basin, Western Australia. Bureau of Mineral Resources, Australia, Bulletin 160.

KLEMME, H.D., 1975 - Geothermal gradients, heat flow and hydrocarbon recovery. In FISCHER, A.G., & JUDSON, S., (Editors), - PETROLEUM AND GLOBAL TECTONICS, Princeton University Press, Princeton, 251-304.

KOOP, W.J., 1966a - Sahara No. 1 Well stratigraphic nomenclature. In WAPET, 1966d.

KOOP, W.J., 1966b - Recent contributions to Palaeozoic geology in the South Canning Basin, Western Australia. The APEA Journal, 105-109.

LUCIA, F.J., 1972 - Recognition of evaporite-carbonate shoreline sedimentation. In RIGBY, K.J., & HAMBLING, W.K. (Editors), Recognition of ancient sedimentary environments. Society of Economic Palaeontologists & Mineralogists, Special Publication, 16, 169-91.

MacLEOD, W.N., 1966 - The geology and iron deposits of the Hamersley Range area, Western Australia. Geological Survey of Western Australia, Bulletin 117.

MAITLAND, A.G., 1904 - Preliminary report on the geological features and mineral resources of the Pilbara Goldfields. Geological Survey of Western Australia, Bulletin 15.

McKEE, E.D., & WEIR, G.W., 1953 - Terminology for stratification and cross-stratification in sedimentary rocks. Bulletin of Geological Society of America, 64, 381-390.

McWHAE, J.R.H., PLAYFORD, P.E., LINDNER, W.A., GLENISTER, B.F., & BALME, B.E., 1958 - The stratigraphy of Western Australia. Journal of Geological Society of Australia, 1956, 4(2).

NOLDART, A.J., & WYATT, J.D., 1962 - The geology of portion of the Pilbara Goldfields covering the Marble Bar and Nullagine 4-mile map sheets. Geological Survey of Western Australia, Bulletin 115.

PLAYFORD, P.E., COPE, R.N., LOW. C.H., COCKBAIN, A.E., & LOWRY, D.C., 1975 - Geology of Western Australia. Geological Survey of Western Australia Memoir 2.

PORRENGA, D.H., 1967 - Glauconite and chamosite as depth indicators in the marine environment. Marine Geology, 5, 495-501.

POWELL, D.E., 1976 - The geological evolution of the continental margin of Northwest Australia. The APEA Journal, (1), 13-23.

PRICE, W.A., 1955 - Environment and formation of the chenier plain. Quaternaria 2, 75-86.

QUILTY, J.H., 1960 - Aeromagnetic reconnaissance survey, Canning Basin, Western Australia. Bureau of Mineral Resources, Australia, Record 1960/11 (unpublished).

RATTIGAN, J.H., 1967 - Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia. Proceedings of the Australasian Institute of Mining & Metallurgy, 223, 17-22.

RATTIGAN, J.H., & ELLIOTT, R.M.L., 1954 - Canning Basin, geological survey of the Fraser River area. West Australian Petroleum Pty Ltd, Company Report (unpublished).

REEVES, F., 1949 - Geology and oil prospects of the Desert Basin, Western Australia. Vacuum Oil Company Report (unpublished).

REEVES, F., 1951 - Australian oil possibilities. Bulletin of American Association of Petroleum Geologists, 35(12), 1479.

REINECK, H.E., & SINGH, I.B., 1973 - DEPOSITIONAL SEDIMENTARY ENVIRONMENTS WITH REFERENCE TO TERRIGENOUS CLASTICS. Springer-Verlag, Heidelburg.

REINECK, H.E., & WUNDERLICH, F., 1968 - Classification and origin of flaser and lenticular bedding. Sedimentology, 11, 99-104.

REYNOLDS, M.A., 1963 - The sedimentary basins of Australia and New Guinea. Bureau of Mineral Resources, Australia, Record 1963/159 (unpublished).

SANDERS, C.C., & HARTLEY, A.S., 1971 - Hydrogeological significance of calcrete deposits in Western Australia. Geological Survey of Western Australia, Annual Report, 1970, 23-27.

SARJEANT, W.A.S., 1974 - FOSSIL AND LIVING DINOFLAGELLATES. Academic Press, London.

SIMPSON, E.S., 1951 - Minerals of Western Australia, Volume II. Government Printer, Perth.

SKWARKO, S.K., 1970 - Aptian (Lower Cretaceous) 'Apiotrigonia' from the Melligo Quartzite, Dampier Peninsula, Western Australia. Bureau of Mineral Resources, Australia, Bulletin 108, 227-35.

SMITH, E.R., 1960 - Seismic reflection survey near La Grange, Kimberley Division, W.A. Bureau of Mineral Resources, Australia, Record 1960/49 (unpublished).

SMITH, E.R., 1961 - Broome seismic reflection survey, Western Australia 1954-55. Bureau of Mineral Resources, Australia, Record 1961/57 (unpublished).

SMITH, D.N., & WILLIAMS, F.B., 1956 - The geology of the northwest coast of Dampier Land. West Australian Petroleum Pty Ltd, Company Report (unpublished).

SMITH, J.G., 1968 - Tectonics of the Fitzroy Wrench trough, Western Australia. American Journal of Science, 266, 766-776.

SMITH, E.R., 1977 - Australia's onshore basins: their petroleum prospects and future exploration programmes. The APEA Journal, 17(2), 17-23.

SMITH, R.N., 1898 - The prospects of obtaining water between the Pilbara Goldfield and the Great Australian Desert. Geological Survey of Western Australia, Bulletin 24.

STEVENS, G.R., 1965 - The Jurassic and Cretaceous belemnites of New Zealand and a review of the Jurassic and Cretaceous belemnites of the Indo-Pacific region. New Zealand Geological Survey Palaeontology, Bulletin 36.

STEPHENS, C.G., 1971 - Laterite and silcrete in Australia. Geoderma, 5,5-51.

STILLWELL, F., 1953 - Beach sand concentrates from north of Broome, Western Australia. CSIRO Mineragraphic Investigations Report 529 (unpublished).

TALBOT, H.W.B., 1920 - Geology of North-west, North-east and Central Divisions. Geological Survey of Western Australia, Bulletin 83.

THOMAS, G.A., 1954 - Report on Permian brachiopods from the Fitzroy Basin, Western Australia. Bureau of Mineral Resources, Australia, Record 1954/9 (unpublished).

TODD, T.W., 1968 - Dynamic diversions: influence of longshore current - tidal flow interaction on chenier and barrier island plains. Journal of Sedimentary Petrology, 38(3), 734-746.

TOTAL EXPLORATION PTY LTD, 1968a - McLarty No. 1 well completion report. Bureau of Mineral Resources, Australia, file 68/2009 (unpublished).

TOTAL EXPLORATION PTY LTD, 1968b - Kemp Field No. 1 well completion report. Bureau of Mineral Resources, Australia, file 68/2048 (unpublished).

TOWNER, R.R., CROWE, R.W.A., & YEATES, A.N., 1976 - Notes on the geology of the southern part of the Canning Basin. Bureau of Mineral Resources, Australia, Record 1976/95 (unpublished).

TRAVES, D.M., CASEY, J.N., & WELLS, A.T., 1956 - The geology of the southwestern Canning Basin, Western Australia. Bureau of Mineral Resources, Australia, Report 29.

VALE, K.R., & WILLIAMS, L.W., 1955 - Preliminary seismic reflection investigations, Broome area, Kimberley Division, Western Australia. Bureau of Mineral Resources, Australia, Record 1955/112 (unpublished).

VALE, K.R., & SMITH, E.R., 1956 - Seismic reflection traverse west to Langeys Crossing, Kimberley Division, W.A. Bureau of Mineral Resources, Australia, Record 1956/112 (unpublished).

VAN DE GRAAFF, W.J.E., CROWE, R.W.A., BUNTING, J.A., & JACKSON, M.J., 1977 - Relict Early Cainozoic drainages in arid Western Australia. Zeitschrift geomorphology, 21(4), 379-400.

VEEVERS, J.J., 1962 - Rhizocorallium in the Lower Cretaceous rocks of northern Australia. Bureau of Mineral Resources, Australia, Bulletin 62.

VEEVERS, J.J., & WELLS, A.T., 1961 - The geology of the Canning Basin, Western Australia. Bureau of Mineral Resources, Australia, Bulletin 60.

WADE, A., 1936 - The geology of the West Kimberley District of Western Australia. Final report on concessions held by Freney Kimberley Oil Co., Perth (unpublished).

WADE, A., 1938 - The geological succession in the West Kimberley district of Western Australia. Australian Association for Advancement of Science, Report, 23, 93.

WARBURTON, P.E., 1875 - JOURNEY ACROSS THE WESTERN INTERIOR OF AUSTRALIA. London, Sampson, Low, Marston, Low and Searle.

WEBBY, B.D., 1978 - History of the Ordovician Continental Platform Shelf Margin of Australia. Journal of Geological Society of Australia, 25(1), 41-63.

WELLS, A.T., 1959a - Yarrie, Western Australia - 4-mile Geological Series. Bureau of Mineral Resources, Australia Explanatory Notes SF51-1, 1st Edition.

WELLS, A.T., 1959b - Paterson Range, Western Australia - 4-mile Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes SF51-6, 1st Edition.

WELLS, L.A., 1902 - Journey of Calvert Scientific Exploration 1896-97. Western Australian Parliamentary Paper 46.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1956a - Roebuck east refraction profile A. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1956b - Roebuck Bay No. 1 well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1957 - Wallal Core Hole No. 1 well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1959a - Goldwyer No. 1 well completion report. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1959b - Dampier Downs, Roebuck Bay East, and Townshend seismograph survey. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1960 - Broome Platform reflection (50), refraction (49), and McHugh (57) Projects. West Australian Petroleum Pty Ltd, Company Report (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1961a - Samphire Marsh No. 1 well completion report. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication No. 5.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1961b - Thangoo No. 1 and No. 1A well completion report. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication No. 14.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1961c - Barlee No. 1 well completion report. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication No. 16.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1963a - South Canning Basin aeromagnetic survey. Bureau of Mineral Resources, Australia, file 62/1728 (unpublished); also as Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication No. 72.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1963b - Sahara regional gravity survey, Canning Basin. Bureau of Mineral Resources, Australia file 63/1910 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1963c - Sahara seismic reconnaissance survey. Bureau of Mineral Resources, Australia file 63/1539 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1964 - Tandalgoo Nos. 1, 2, 3 stratigraphic wells. Company Reports (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1964a - Parda seismic survey. Bureau of Mineral Resources, Australia file 64/4524 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1964b - Barlee Gravity Survey, Western Australia, 1959. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Publication No. 38.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1964c - Joanna Springs gravity survey. Bureau of Mineral Resources, Australia file 63/1908 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1965a - Parda No. 1 well completion report. Bureau of Mineral Resources, Australia file 65/4137 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1965b - Willara No. 1 well completion report. Bureau of Mineral Resources, Australia file 65/4158 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1965c - Dampier land semi-detailed gravity. Bureau of Mineral Resources, Australia file 65/4816 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966a - Willara Hill reflection seismic ("Vibroseis") survey. Bureau of Mineral Resources, Australia file 66/11081 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966b - King Sound aeromagnetic survey. Bureau of Mineral Resources, Australia file 66/4623 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966c - Nita-Willara Seismic. Bureau of Mineral Resources, Australia file 66/11131 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966d - Sahara No. 1 well completion report. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts, Publication No. 80.

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966e - Dampierland Seismograph Survey. Bureau of Mineral Resources, Australia file 66/11099 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1966f - Kidson No. 1 well completion report. Bureau of Mineral Resources, Australia, file 65/4177 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1967a - Munro Arch gravity survey. Bureau of Mineral Resources, Australia file 67/4829 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1967b - Wallal marine seismic survey. Bureau of Mineral Resources, Australia file 67/11208 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1967c - Roebuck seismic survey. Bureau of Mineral Resources, Australia file 66/11115 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1968a - Willara Hill No. 1 well completion report. Bureau of Mineral Resources, Australia file 68/2044 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1968b - Chirup No. 1 well completion report. Bureau of Mineral Resources, Australia file 68/2045 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1968c - Baskerville seismic survey. Bureau of Mineral Resources, Australia file 68/3023 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1969a - Wallal aeromagnetic survey. Bureau of Mineral Resources, Australia file 69/3037 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1969b - Munro Arch seismic. Bureau of Mineral Resources, Australia file 69/3042 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1969c - Munro R-1 seismic. Bureau of Mineral Resources, Australia file 69/3081 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1969d - Bedout Marine Seismic. Bureau of Mineral Resources, Australia file 69/3013 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1970a - Pender seismic survey. Bureau of Mineral Resources, Australia file 70/817 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1970b - King Sound Marine seismic. Bureau of Mineral Resources, Australia file 70/218 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971a - Broome-Samphire seismic survey. Bureau of Mineral Resources, Australia file 70/857 (unpublished)

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971b - Anketell seismic survey. Bureau of Mineral Resources, Australia file 70/896 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971c - Munro detailed seismic survey. Bureau of Mineral Resources, Australia file 70/1000 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971d - Munro D-2 seismic survey. Bureau of Mineral Resources, Australia file 71/478 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971e - North Broome seismic survey. Bureau of Mineral Resources, Australia file 71/252 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971f - Tappers Inlet No. 1 well completion report. Bureau of Mineral Resources, Australia file 71/301 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1971g - Munda No. 1 well completion report. Bureau of Mineral Resoures, Australia file 71/475 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1972a - North Broome D-2 seismic survey. Bureau of Mineral Resources, Australia file 72/961 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1972b - Pender No. 1 well completion report. Bureau of Mineral Resources, Australia file 72/2000 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1972c - Munro No. 1 well completion report. Bureau of Mineral Resources, Australia file 72/846 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1972d - Lake Betty No. 1 well completion report. Bureau of Mineral Resources, Australia file 71/441 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1973a - Thangoo No. 2 well completion report. Bureau of Mineral Resources, Australia file 73/218 (unpublished).

WAPET (WEST AUSTRALIAN PETROLEUM PTY LTD), 1973b - Sahara II seismic survey. Bureau of Mineral Resources, Australia file 73/234 (unpublished).

WILKINS, H.Y., 1953 - Dampier Peninsula, North-West Australia, heavy-mineral beach sands. Geological Survey of Western Australia, Technical Files 66W/2 (unpublished).

WILSON, H.V., 1953 - Dampier Peninsula, North Western Australia, heavy-mineral sands. Australia, Enterprise Exploration Company Pty Ltd, Company Report (unpublished).

WILSON, I.G., 1972 - Aeolian bedforms - their developments and origin Sedimentology, 19, 173-211.

WILSON, I.G., 1973 - Ergs. Sedimentary Geology, 10(2), 77-106.

WILLIAMS, H., TURNER, F.J., & GILBERT, G.M., 1958 - PETROGRAPHY - an introduction to the study of rocks in thin sections. Freeman & Co., San Francisco.

WILLIAMS, I.R., BRAKEL, A.T., CHIN, R.J., & WILLIAMS, E.J., 1976 - The stratigraphy of the Eastern Bangemall Basin and the Paterson Province. Geological Survey of Western Australia, Annual Report, 1975.

WOOLNOUGH, W.G., 1927 - Presidential address. Part 1 - The chemical criteria of peneplanation; Part 2 - The duricrusts of Australia. Journal of the Royal Society, New South Wales, 61, 17-53.

YEATES, A.N., & CHIN, R.J., 1979 - Tabletop, W.A. 1:250 000 Geological series. Bureau of Mineral Resources, Australia, Explanatory Notes SF/51-11.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L., 1975a - New and Revised stratigraphic nomenclature, northeast Canning Basin, Western Australia. Geological Survey of Western Australia, Annual Report, 1974.

YEATES, A.N., CROWE, R.W.A., TOWNER, R.R., WYBORN, L.A.I., & PASSMORE, V.L., 1975b - Notes on the geology of the Gregory Sub-basin and adjacent areas of the Canning Basin, Western Australia. Bureau of Mineral Resources, Australia, Record 1975/77 (unpublished).

APPENDIX 1. The 'Jowlaenga Sandstone'

The term Jowlaenga Sandstone was defined by Brunnschweiler (1957) (amended by McWhae & others (1958) to Jowlaenga Formation) to cover outcrops of fine to medium grained sandstone, which he interpreted to be a nearshore deposit, and which cropped out in the Mount Jowlaenga area (BROOME), in places along the east coast of the Dampier Peninsula, and on Valentine Island (DERBY). Our mapping in 1976 and 1977 has shown that all outcrops previously identified by Brunnschweiler as Jowlaenga Formation can be assigned to other formations.

The type section of the Jowlaenga Formation at Mount Jowlaenga was visited in 1977. We identified all outcrops that we saw at Mount Jowlaenga as Melligo Sandstone. Outcrop is poor; Melligo Sandstone is present at the top of the mountain (silicified, well-sorted, well-rounded, fine quartz sandstone), and outcrops identifiable with the Melligo Sandstone are also present down to about two-thirds of the way down the mountain. A specimen of Fissilunula clarkei (identified by S. Skwarko, BMR), a key Aptian fossil in the Melligo Sandstone, was found well below the top of the mountain. However, there may be outcrops of a different lithology at a lower level, which we did not see.

At North Cliffs (DERBY), visited in 1977, the basal 30 m of the section which is exposed in a steep gully or landslide scar, consists of very fine-grained sandy mudstone, mainly bioturbated with some (planar) bedding which is then overlain by a few metres of cross-bedded fine-grained sandstone with interbedded mudstone. There is then 20 m without outcrop beneath a 15-m-high cliff of silicified Melligo Sandstone. This sequence was originally mapped by Brunnschweiler as Melligo Sandstone overlying Jowlaenga Formation; however, we identify the mudstone as Jarlemai Siltstone as it is very similar to Jarlemai Siltstone exposed at Mowla Bluff on MOUNT ANDERSON - (Crowe & others, 1978). The fine-grained sandstone could be Broome Sandstone, but there is insufficient exposure to confirm this.

At Valentine Island (DERBY), and 2 km south of Cunningham Point and at One Arm Point (YAMPI), rocks previously mapped as Jowlaenga Formation have been identified by us as Broome Sandstone. At these places, the supposed Jowlaenga Formation is fine-grained quartz sandstone, generally bioturbated, but with traces of planar bedding. This lithology grades up into the Melligo Sandstone at these localities.

We now consider the rocks at Dampier Hill and Mount Clarkson, mapped by Crowe & others (1978) as Jowlaenga Formation, to be Broome Sandstone. At Dampier Hill, the Broome Sandstone interfingers with the Melligo Sandstone.

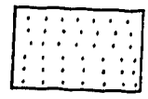
Rocks previously attributed to the Jowlaenga Formation and now identified as Broome Sandstone have been dated as latest Jurassic (Stevens, 1965; Skwarko, 1970); this implies that the Broome Sandstone may be as old as latest Jurassic, and the conformity of the Broome Sandstone with the Aptian Melligo Sandstone suggests that it extends up into the Aptian. Previously, the Broome Sandstone was considered to be Neocomian only (Playford & others, 1975).

APPENDIX 2

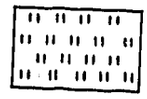
GRAPHIC LOGS OF PETROLEUM EXPLORATION WELLS

APPENDIX 2. Graphic logs of petroleum exploration wells (The locations of the wells are shown in Figure 1).

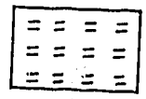
	Name	Latitudes	Longitudes	Principal Reference
1.	Roebuck Bay No. 1	18° 09' 30"S	122° 27' 30"E	WAPET (1956b)
2.	Wallal Core Hole No. 1	19° 51' 46"S	120° 37' 00"E	WAPET (1957)
3.	Wallal 4 & 4A	19° 44' 12"S	120° 44' 25"E	Henderson & others (1963)
4.	Samphire Marsh No. 1	19° 31' 08"S	121° 10' 51"E	WAPET (1961a)
5.	Goldwyer No. 1	18° 22' 47"S	122° 22' 58"E	WAPET (1959a)
6.	Thangoo No. 1	18° 22' 06"S	122° 53' 22"E	WAPET (1961b)
7.	Thangoo No. 1A	18° 21' 52"S	122° 53' 09'E	WAPET (1961b)
8.	Barlee No. 1	17° 48' 25"S	122° 42' 40"E	WAPET (1961c)
9.	Parda No. 1	18° 56' 08"S	122° 00' 34"E	WAPET (1965a)
10.	Willara No. 1	19° 10' 48"S	122° 04' 14"E	WAPET (1965b)
11.	Yulleroo No. 1	17° 51' 16"S	122° 54' 25"E	Gewerkschaft - Elwerath (1967)
12.	McLarty No. 1	19° 23' 45"S	123° 39' 30"E	Total (1968a)
13.	Kemp Field No. 1	20° 19' 10"S	123° 27' 58"E	Total (1968b)
14.	Willara Hill No. 1	19° 03' 31"S	121° 52' 45"E	WAPET (1968a)
15.	Chirup No. 1	19° 50' 54"S	120° 25' 57"E	WAPET (1968b)
16.	Tappers Inlet No. 1	16° 51' 38"S	122° 35' 22"E	WAPET (1971f)
17.	Munda No. 1	19° 28' 27"S	122° 17' 32"E	WAPET (1971g)
18.	Pender No. 1	16° 40' 48"S	122° 50' 06"E	WAPET (1972b)
19.	Munro No. 1	19° 51' 47"S	122° 28' 28"E	WAPET (1972c)
20.	Thangoo No. 2	18° 26' 32"S	122° 54' 33"E	WAPET (1973a)



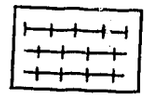
Sandstone



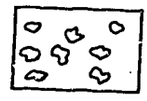
Siltstone



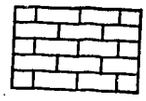
Claystone



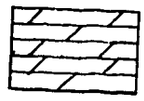
Mudstone



Conglomerate



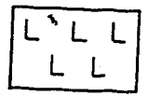
Limestone



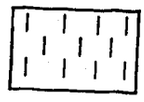
Dolomite



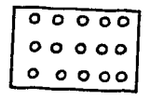
Shale



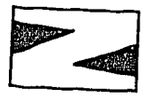
Salt



Calcarenite



Laterite



Coal

Record 1980/30

Fig. A Graphic Logs

W/A/370

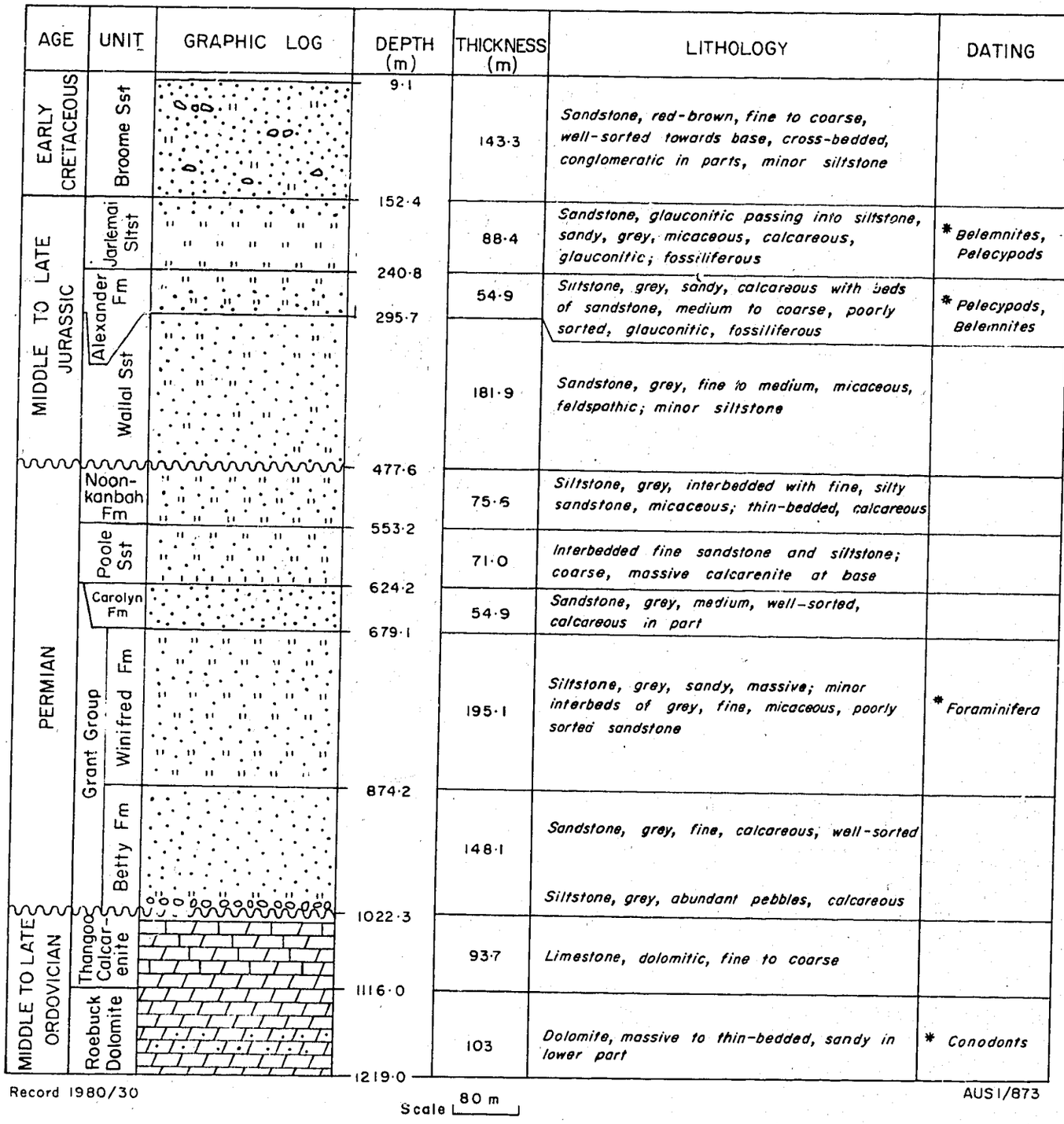


Fig.A 1 WAPET Roebuck Bay 1

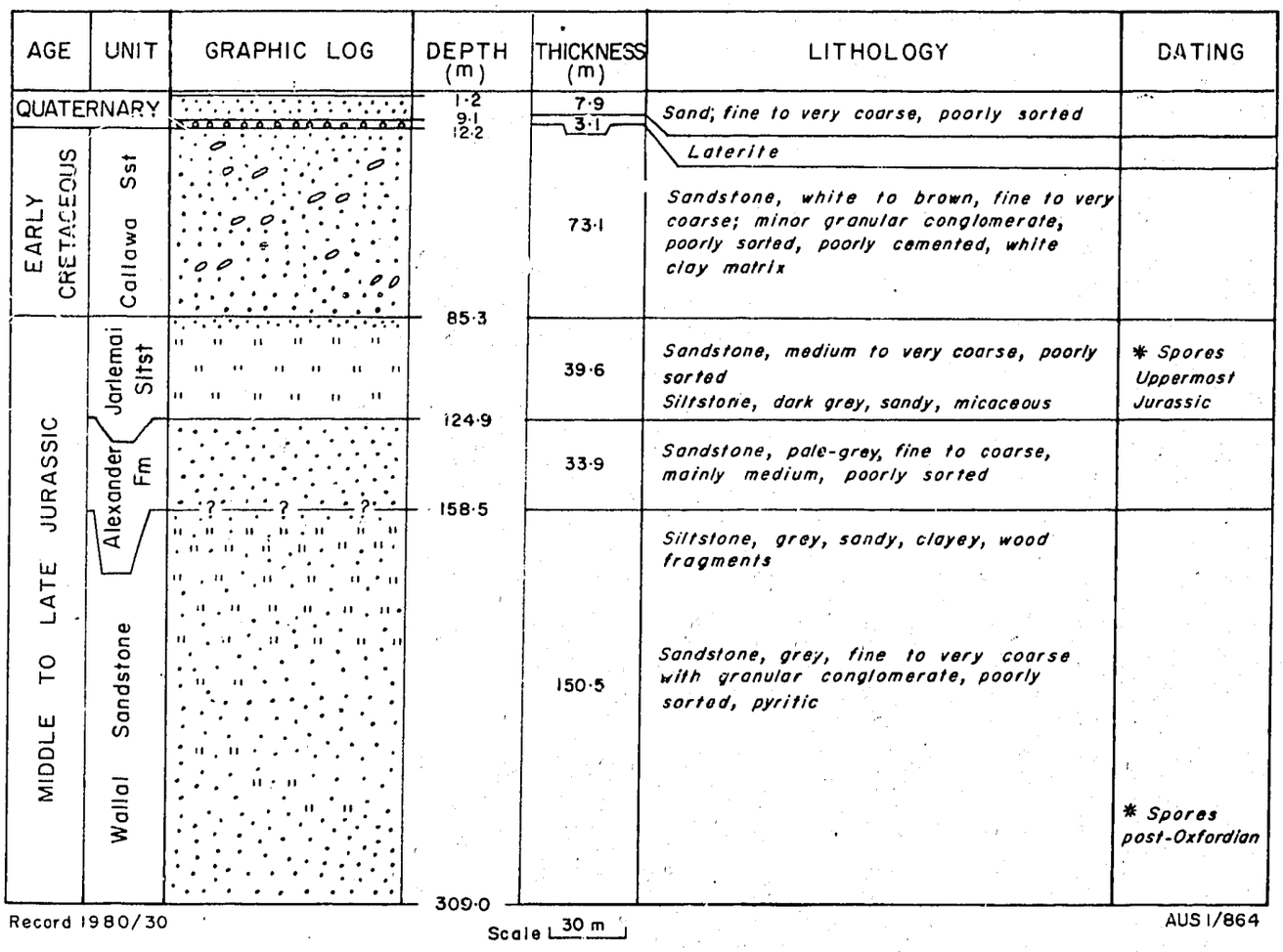


Fig. A 2 WAPET Wallal Core Hole 1

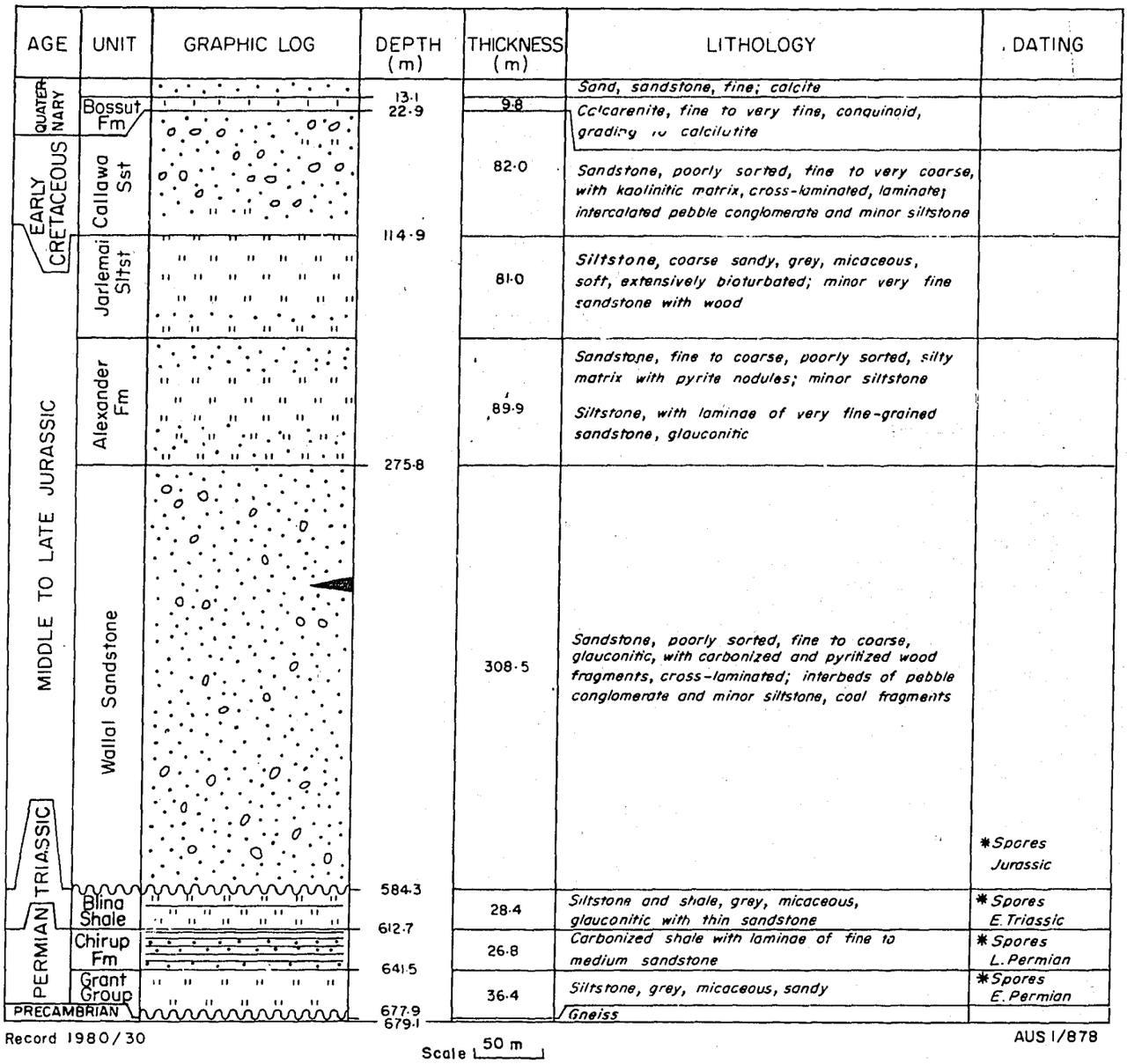


Fig. A 3 BMR Wallal 4 & 4A

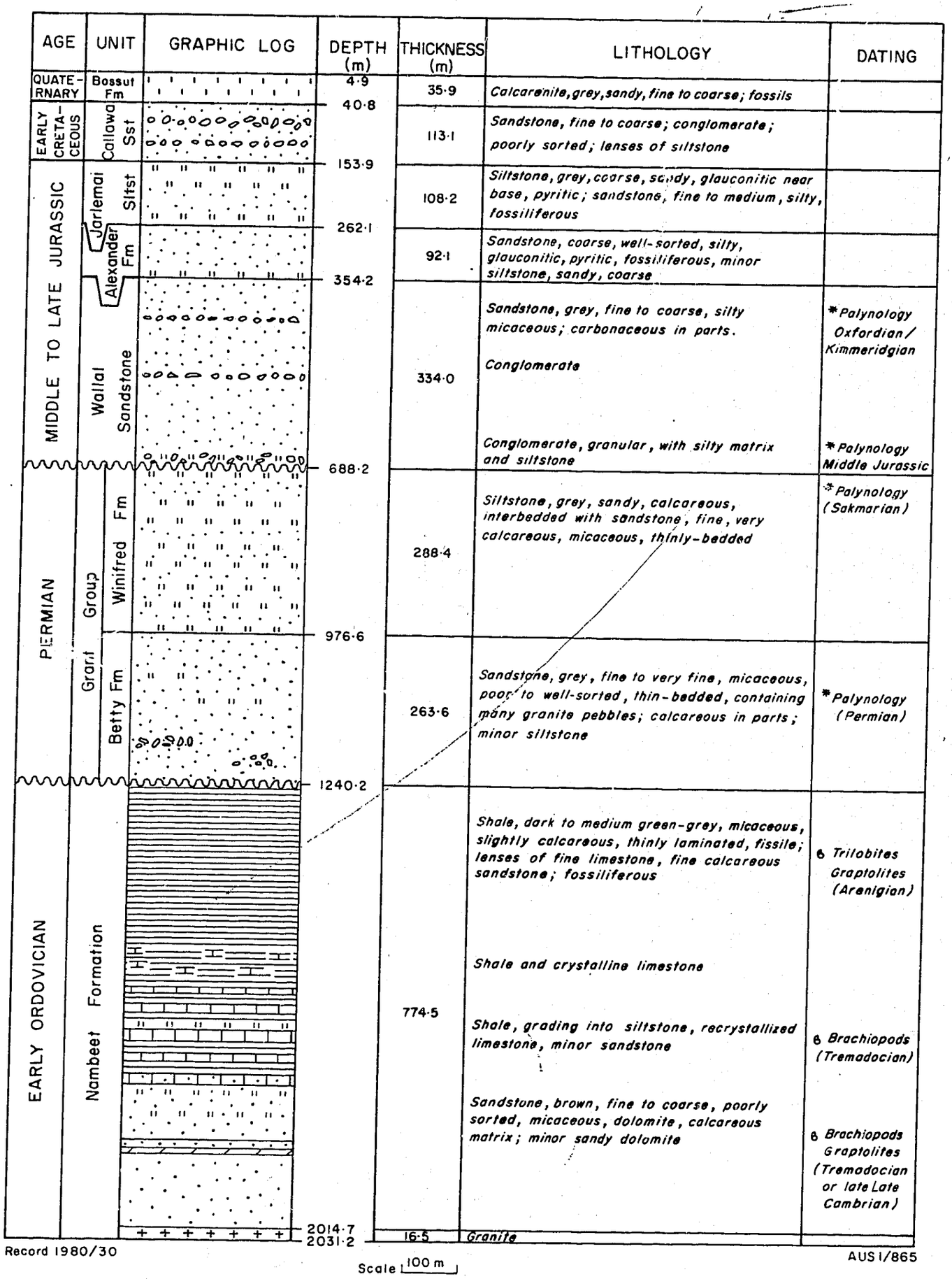


Fig. A 4 WAPET Samphire Marsh 1

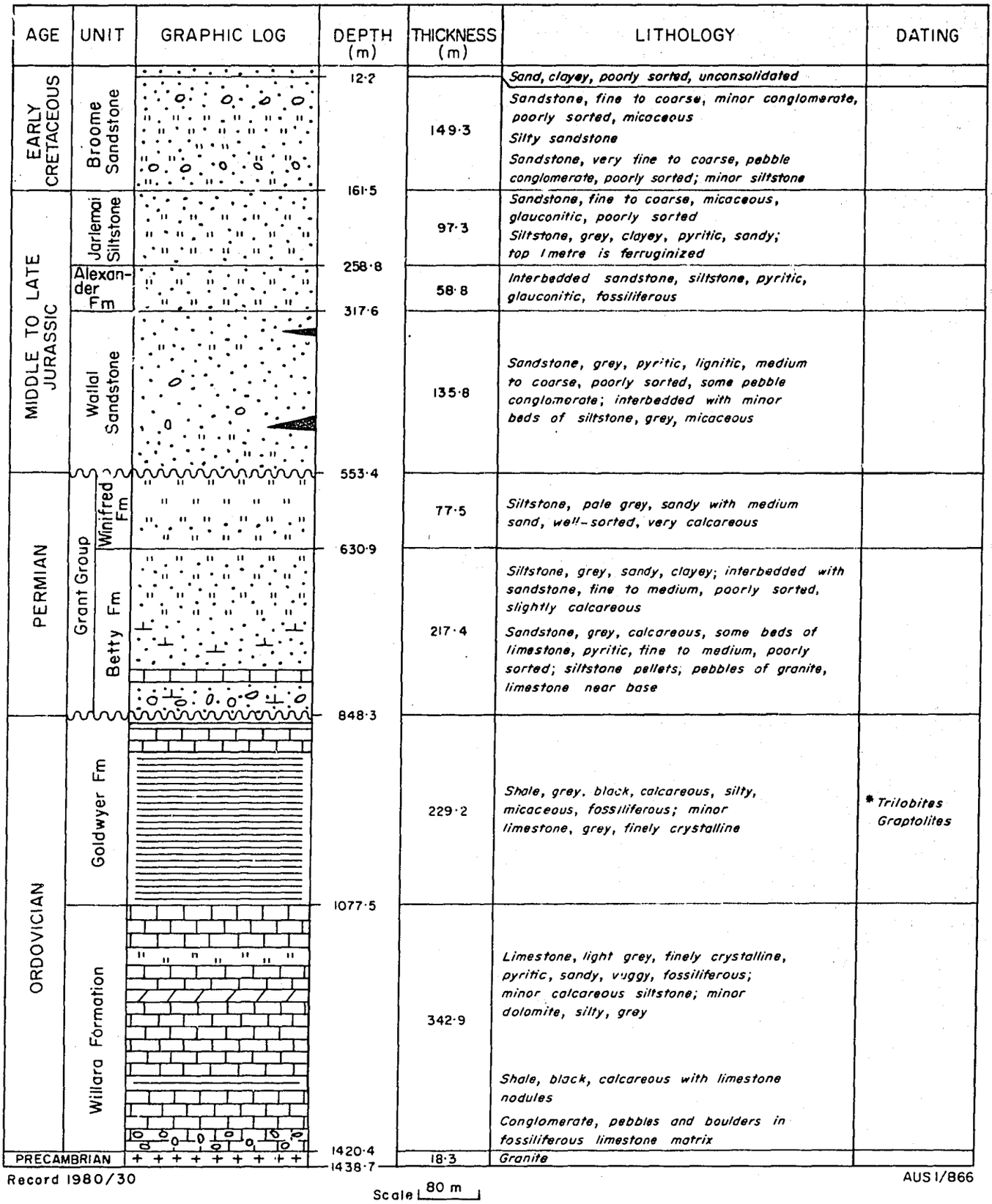


Fig. A 5 WAPET Goldwyer 1

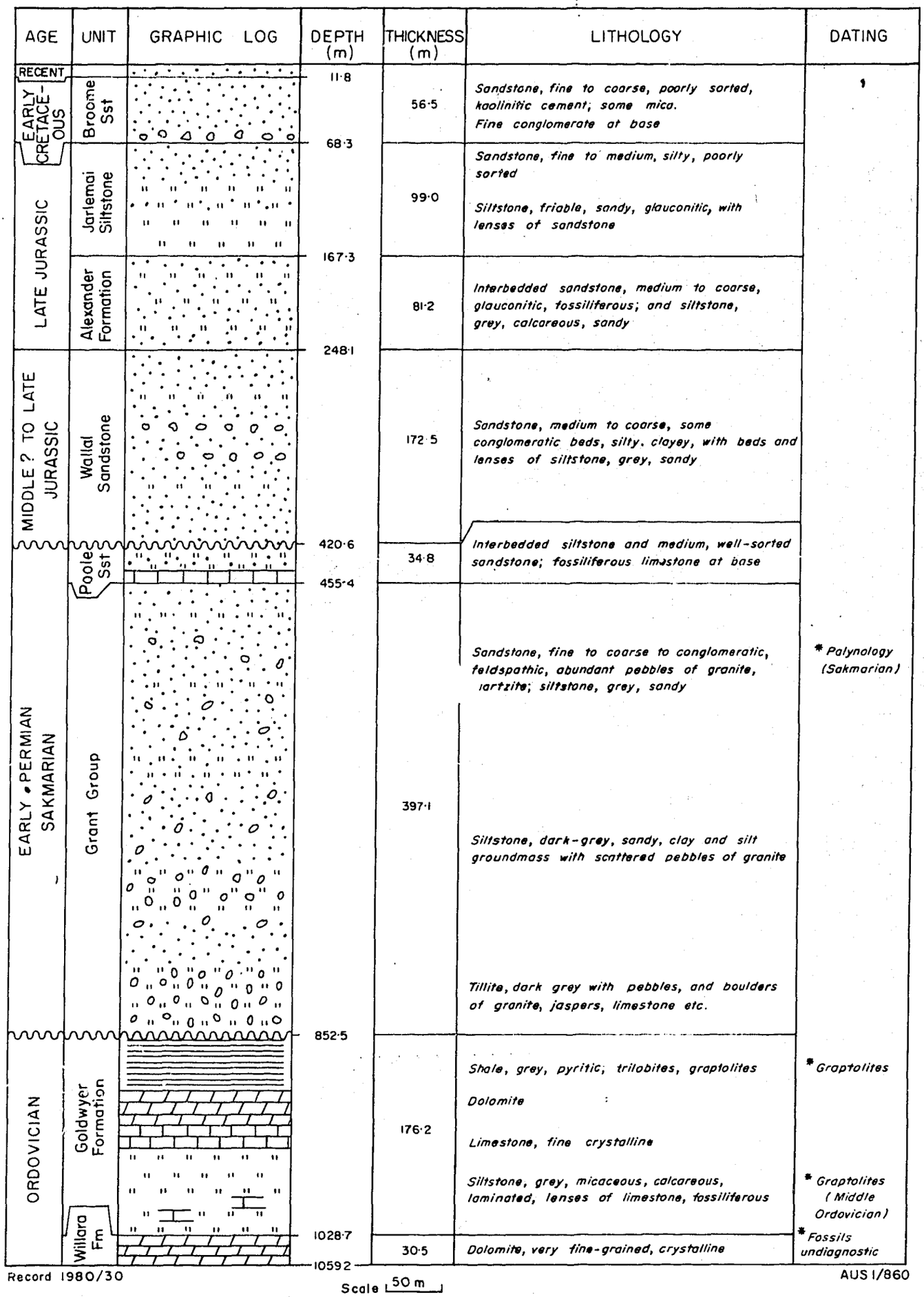


Fig. A 6 WAPET Thangoo 1

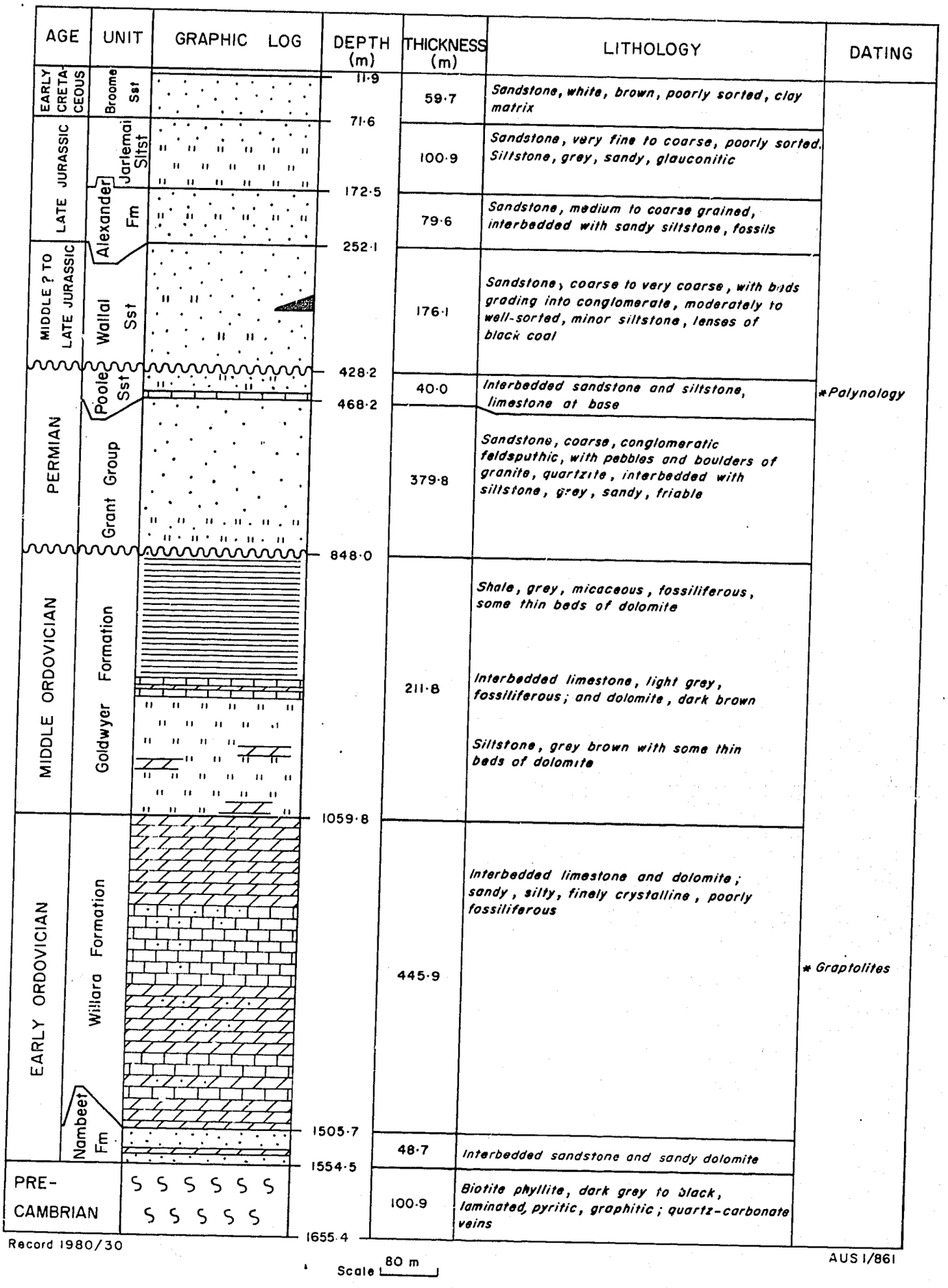


Fig. A 7 WAPET Thangoo 1A

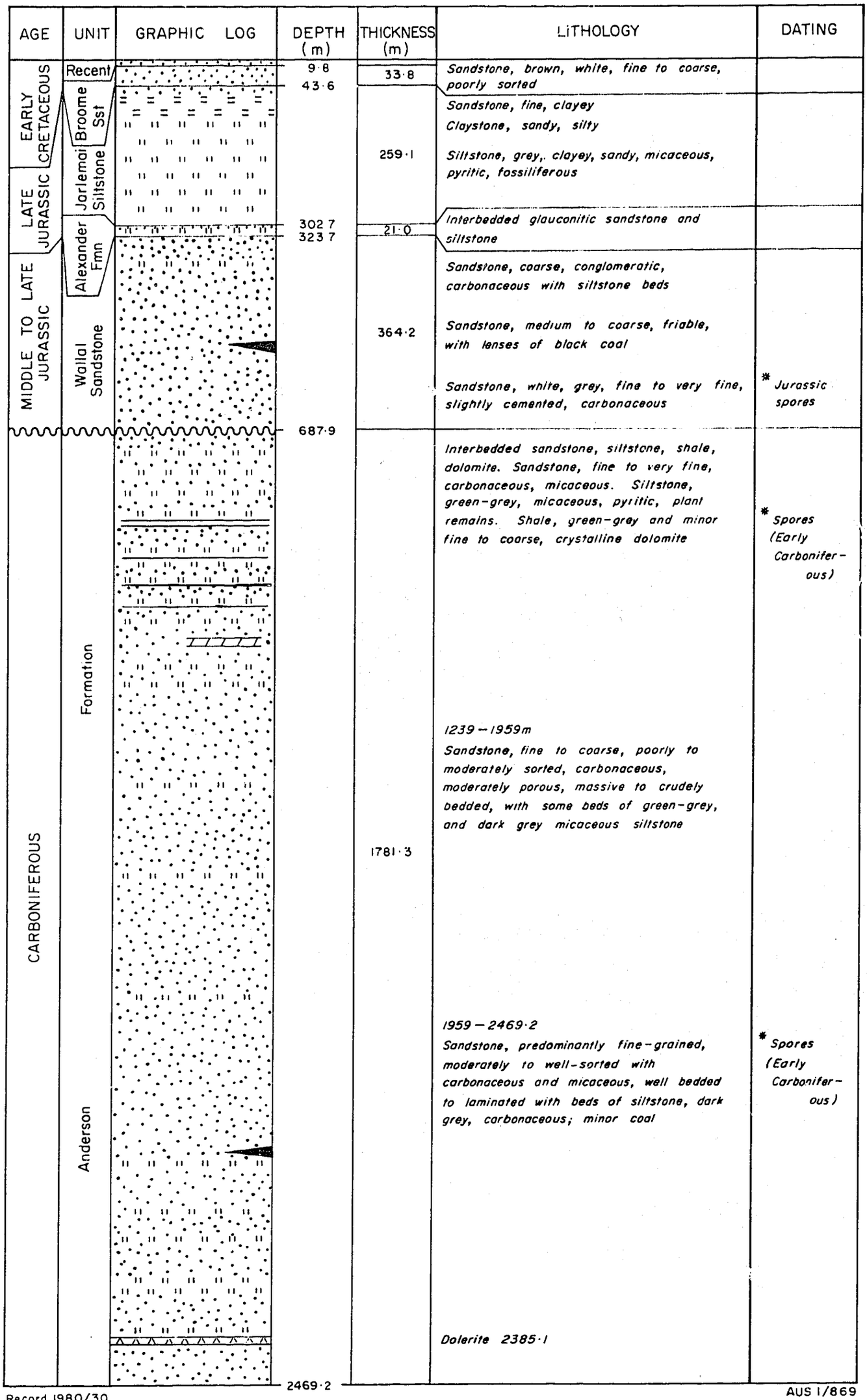


Fig.A 8 WAPET Barlee 1

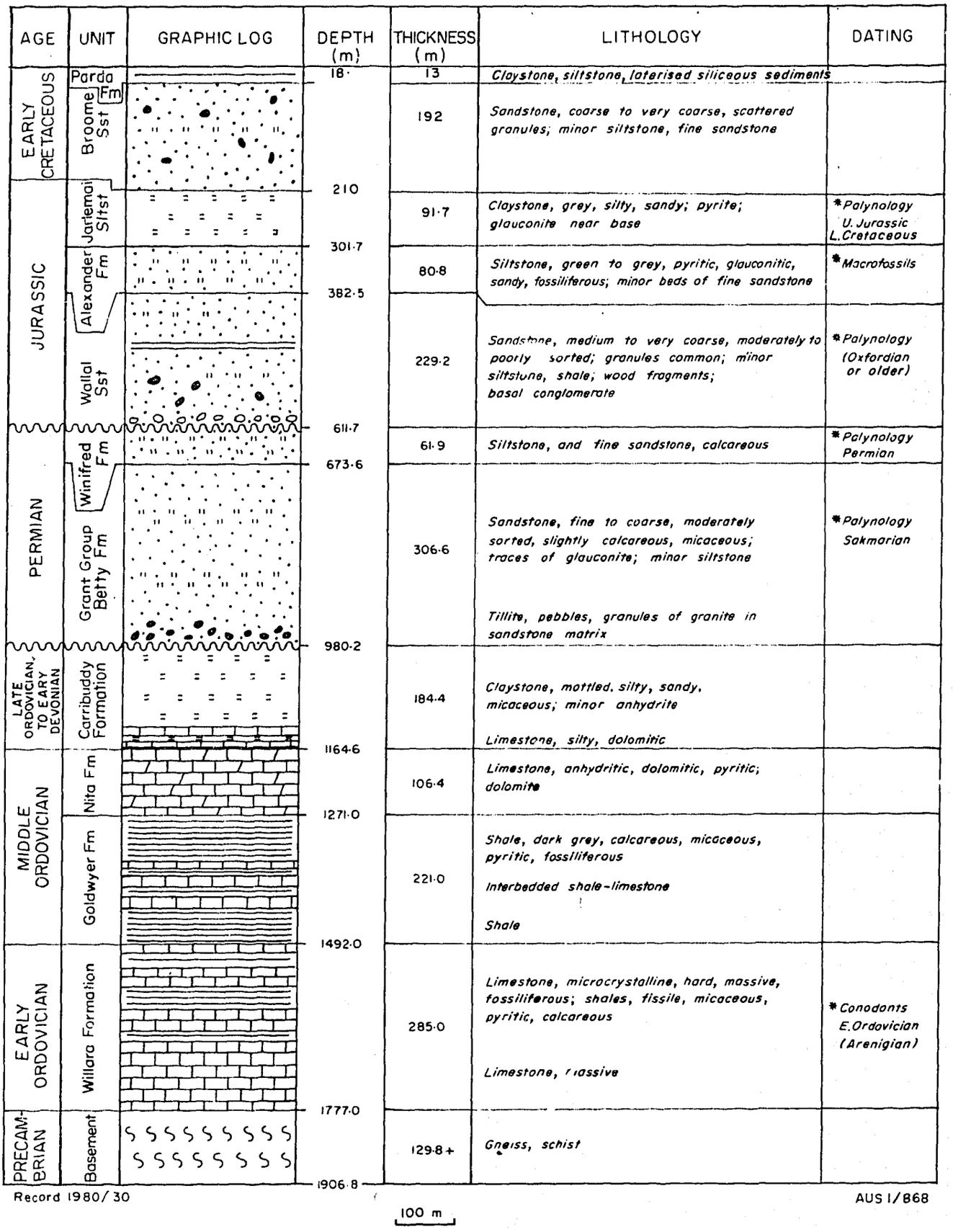


Fig. A 9 WAPET Parda 1

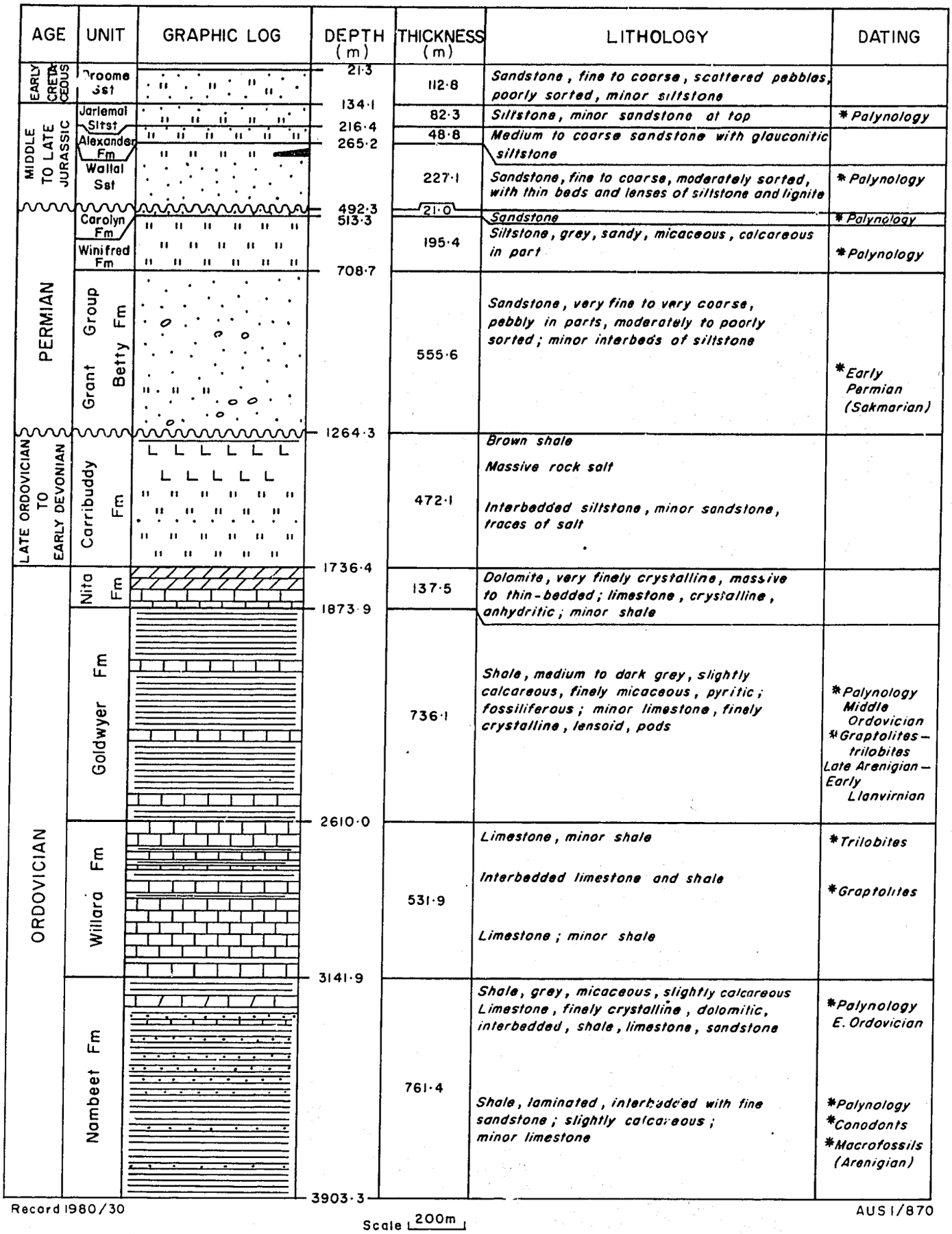


Fig. A 10 WAPET Willara 1

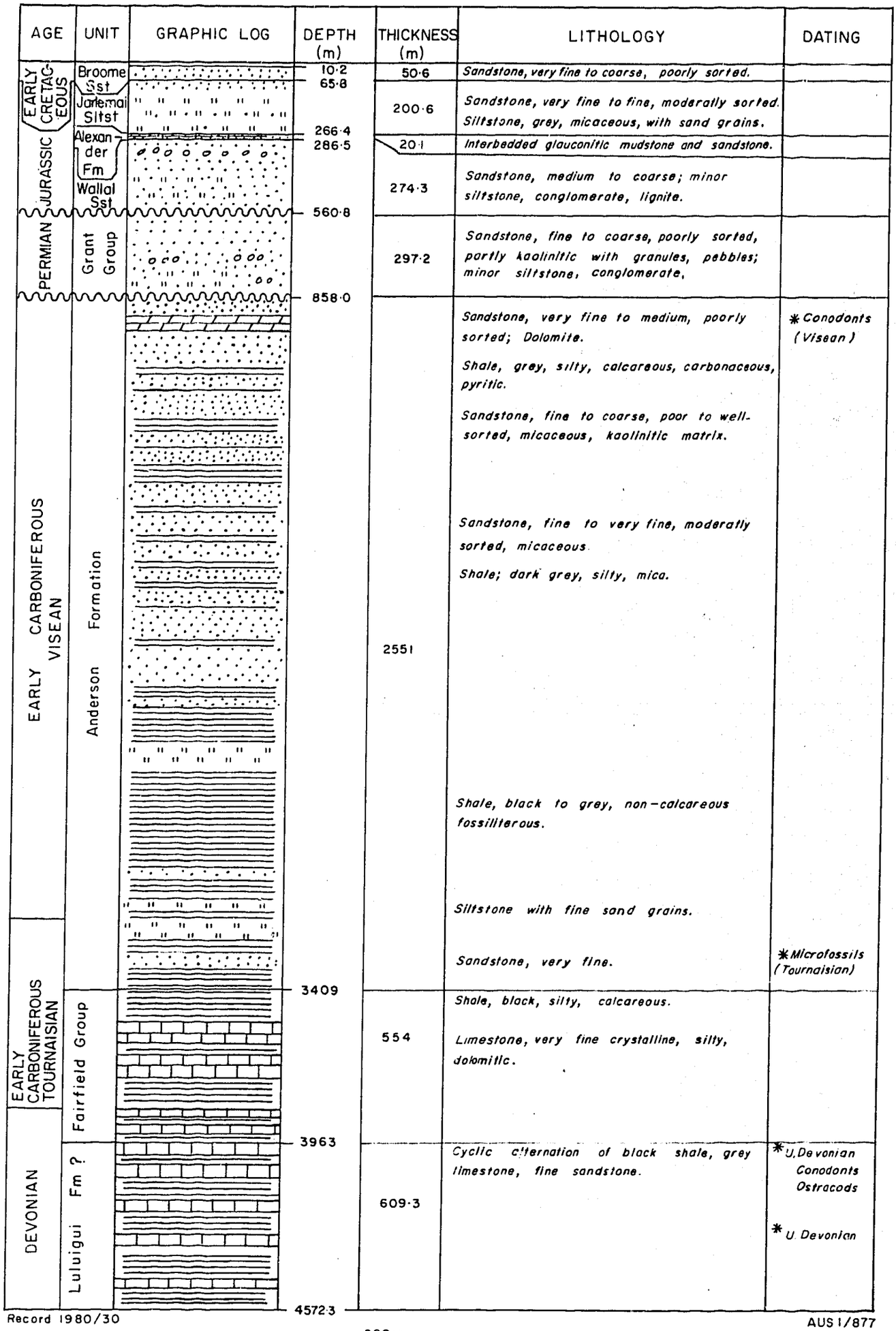


Fig. A II Gewerkschaft Elwerath Yulleroo 1

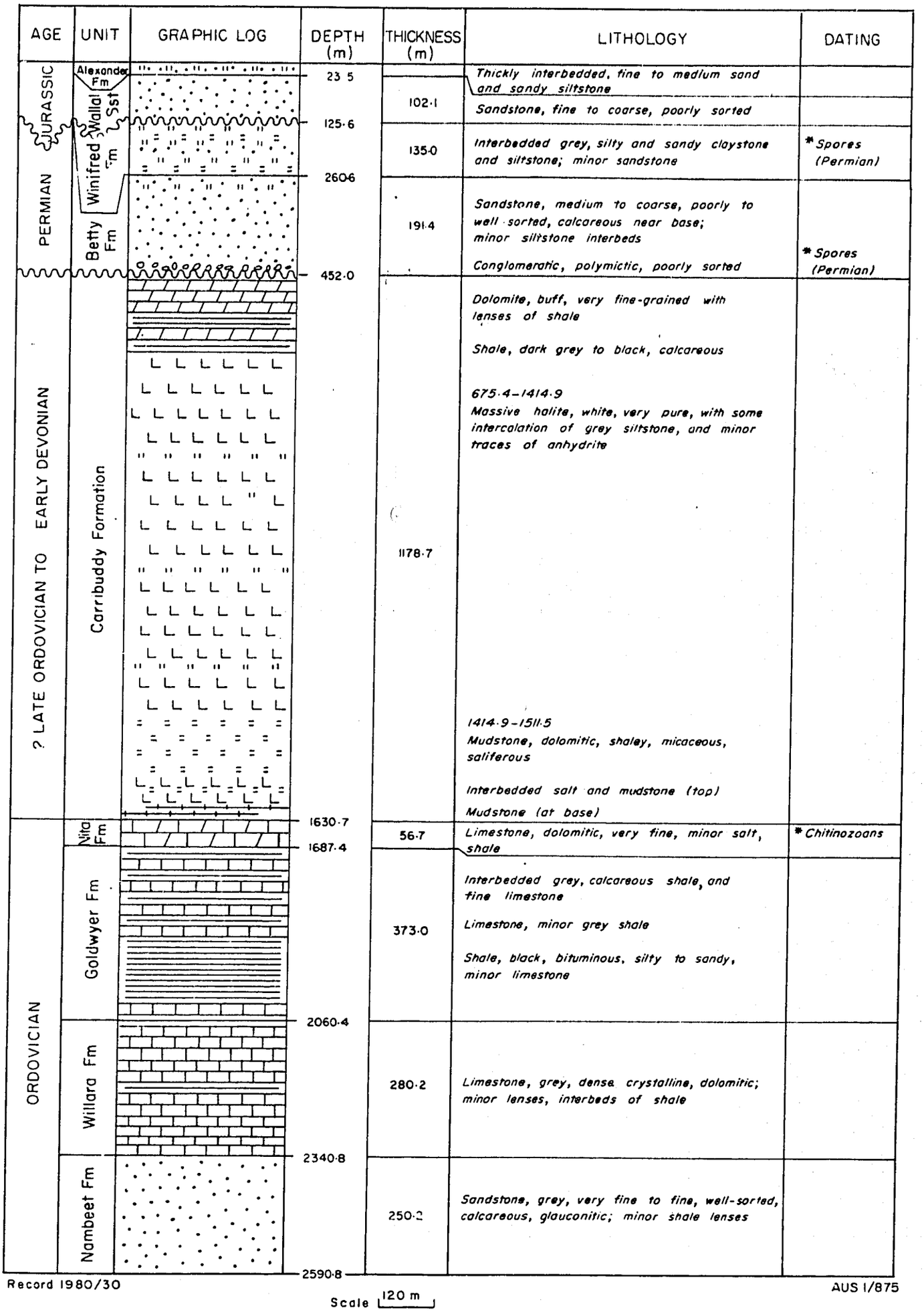


Fig. A 12 Total McLarty 1

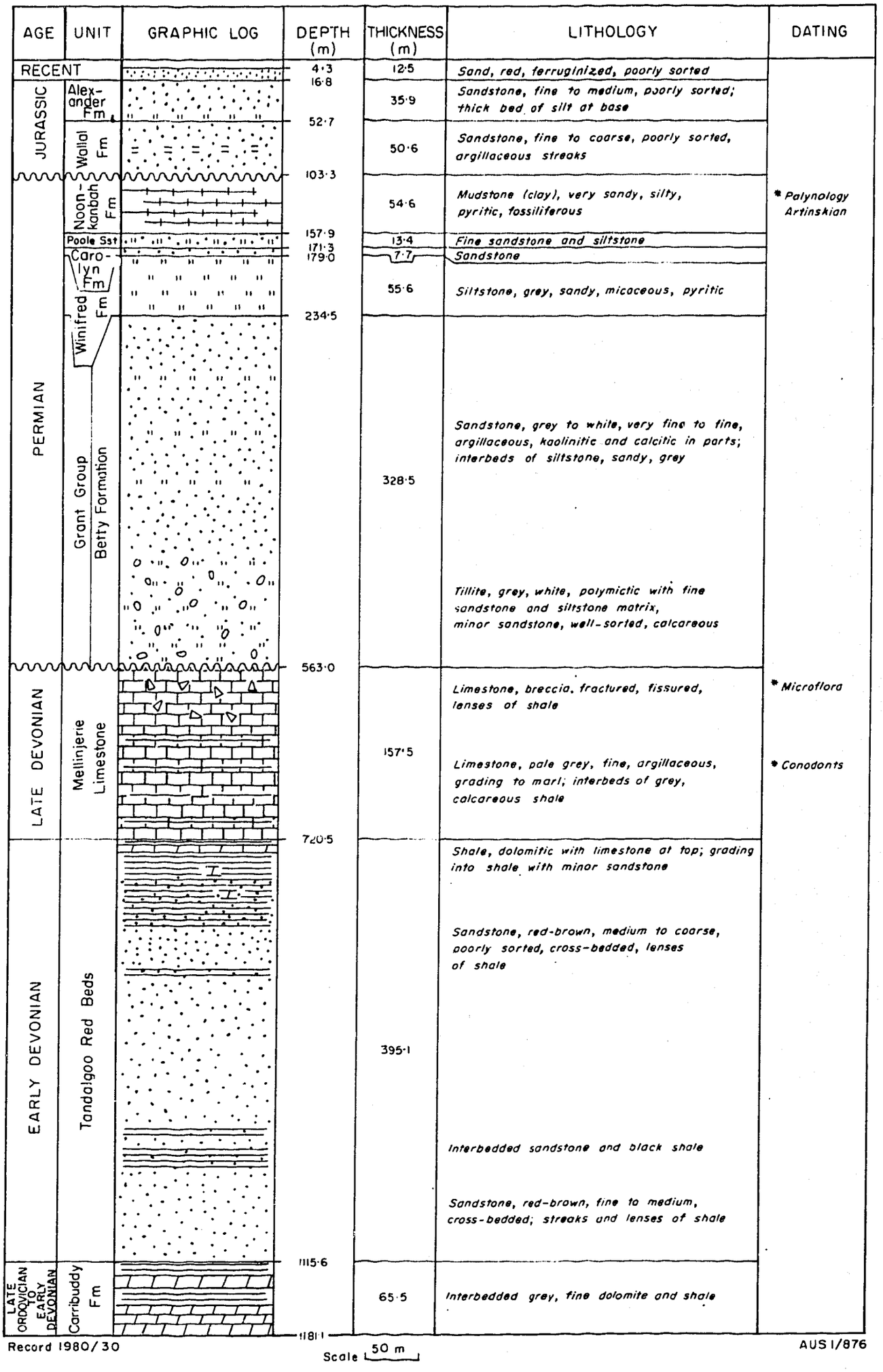


Fig. A13 Total Kemp Field 1

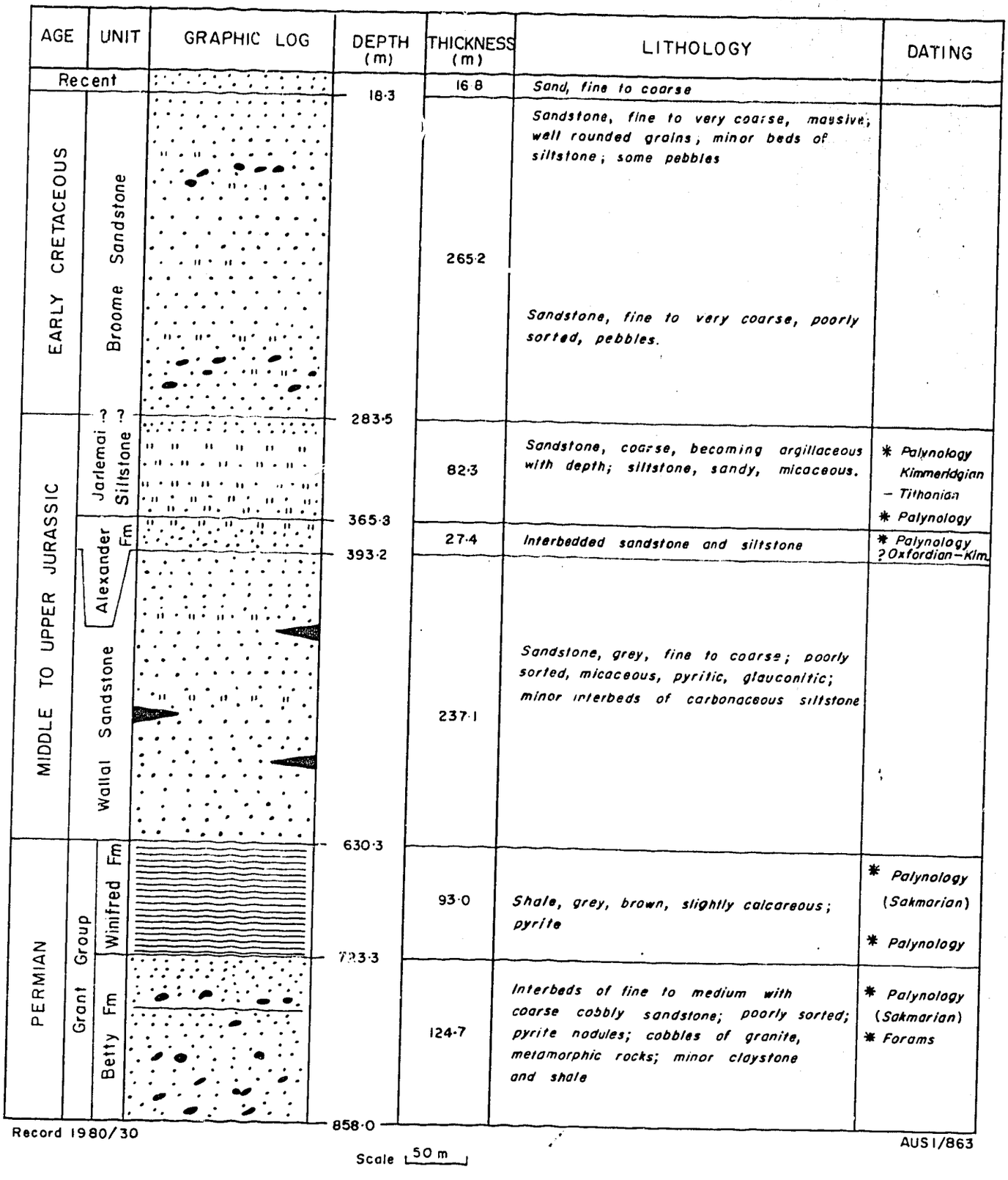


Fig. A 14 WAPET Willara Hill 1

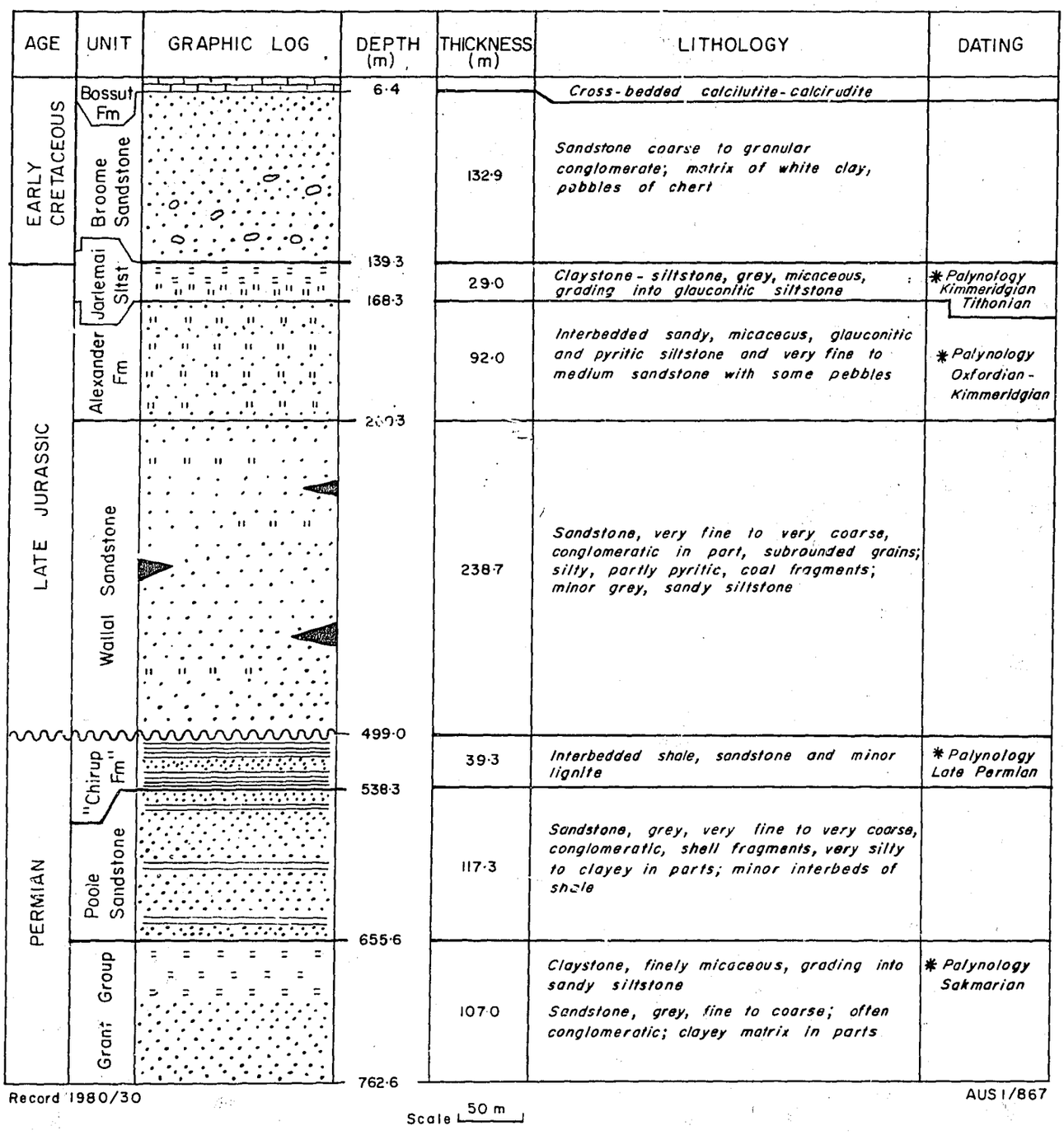


Fig. A 15 WAPET Chirup 1

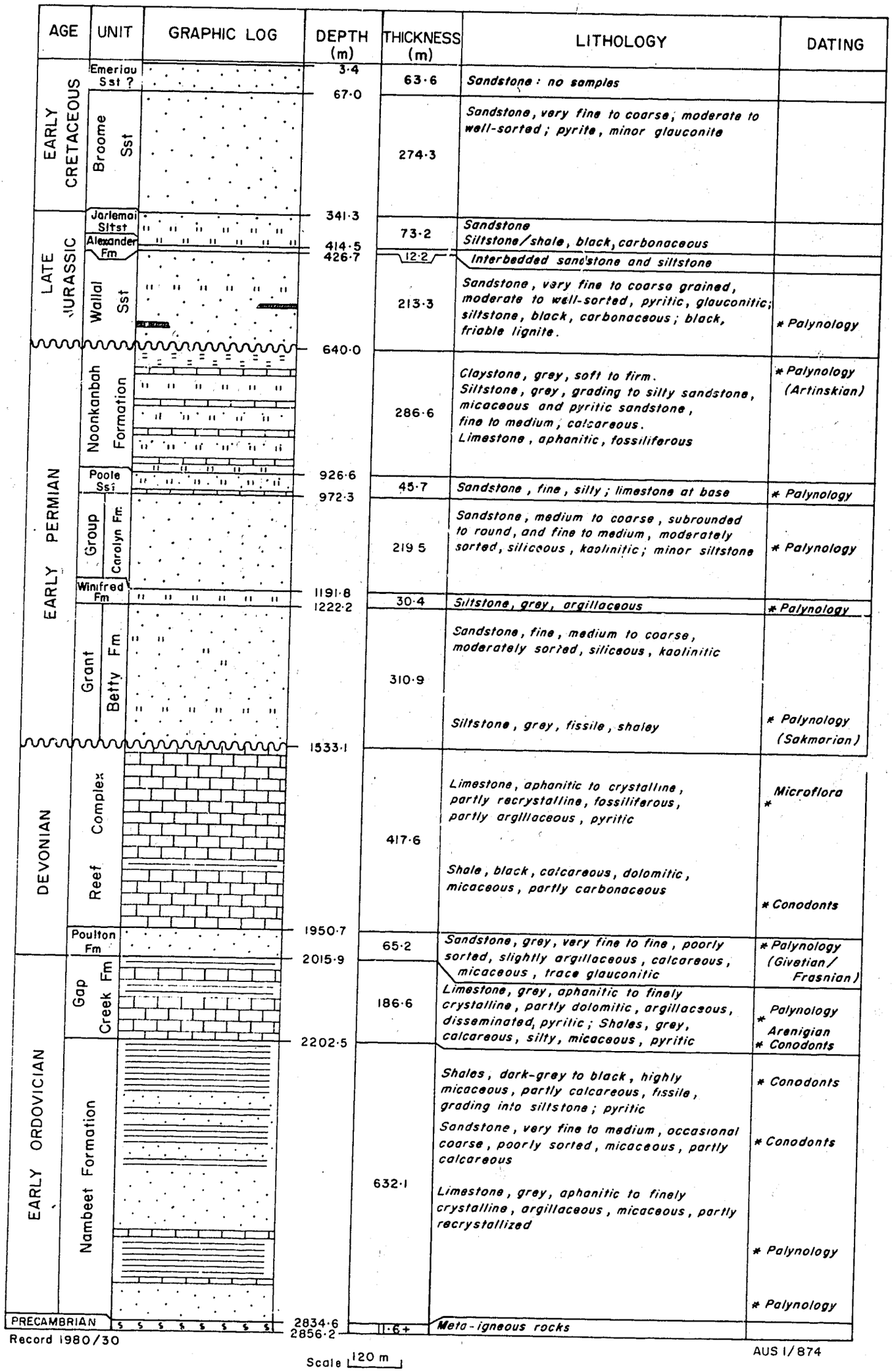


Fig. A 16 WAPET Tappers Inlet 1

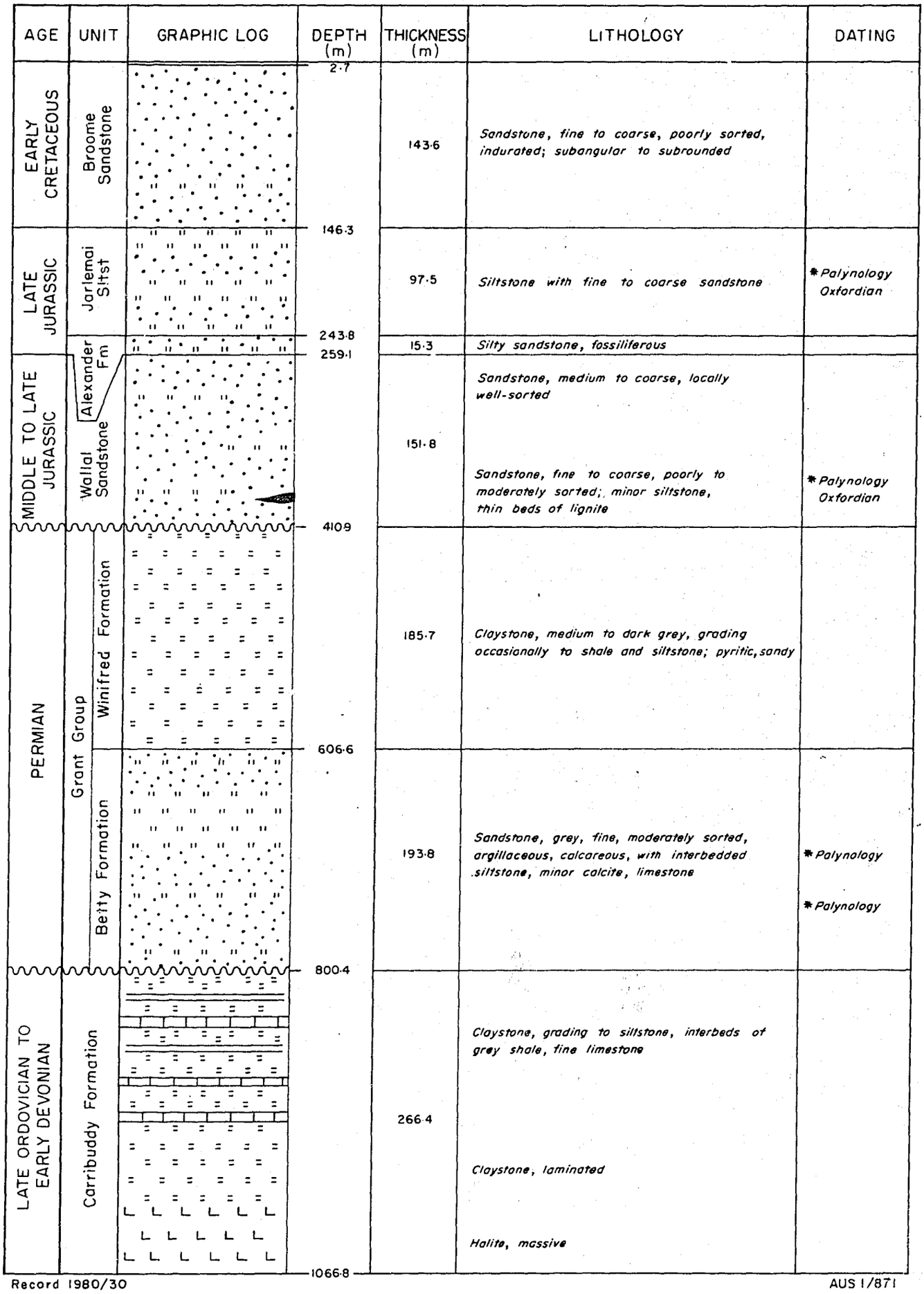


Fig. A 17 WAPET Munda 1

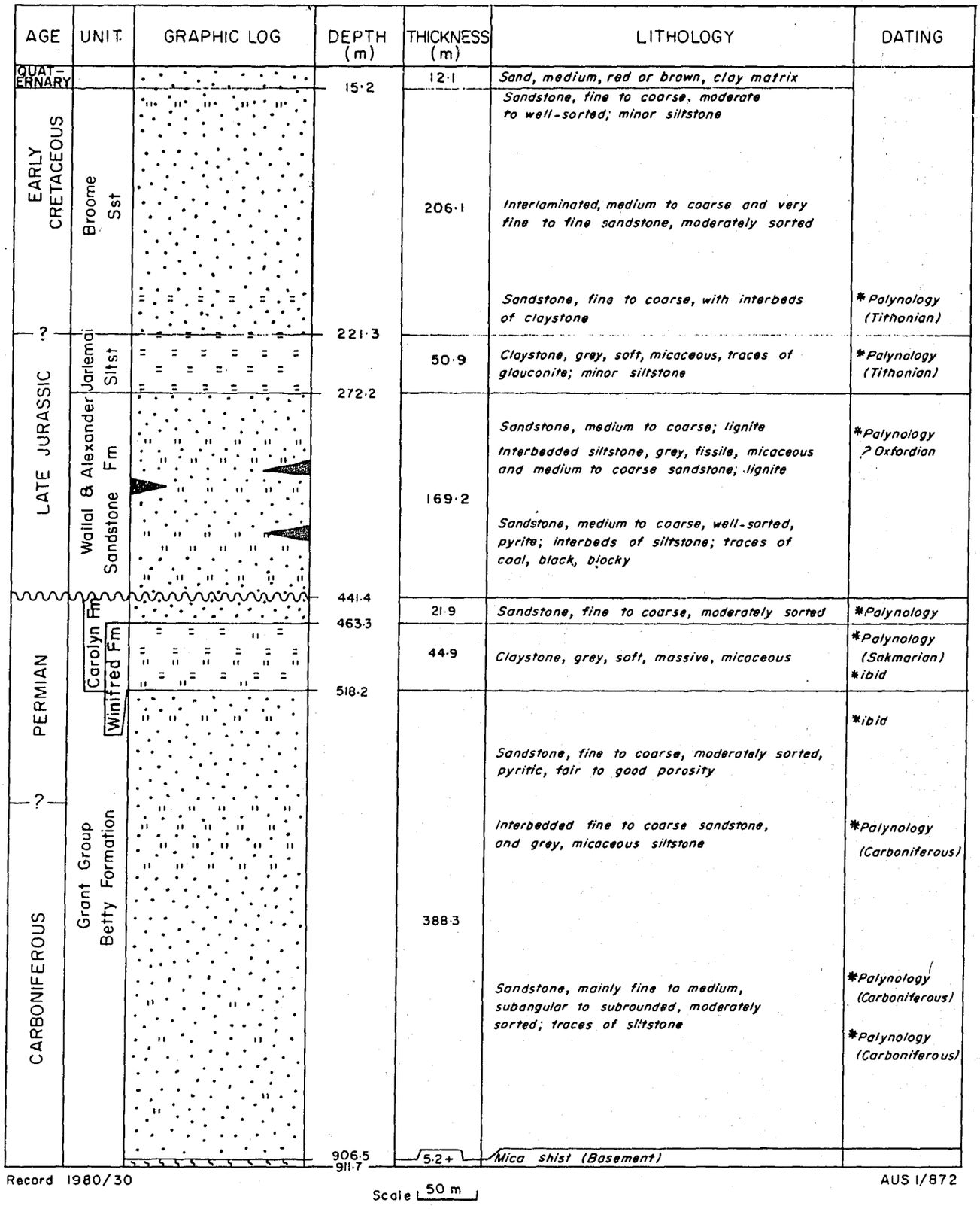


Fig. A 18 WAPET Pender 1

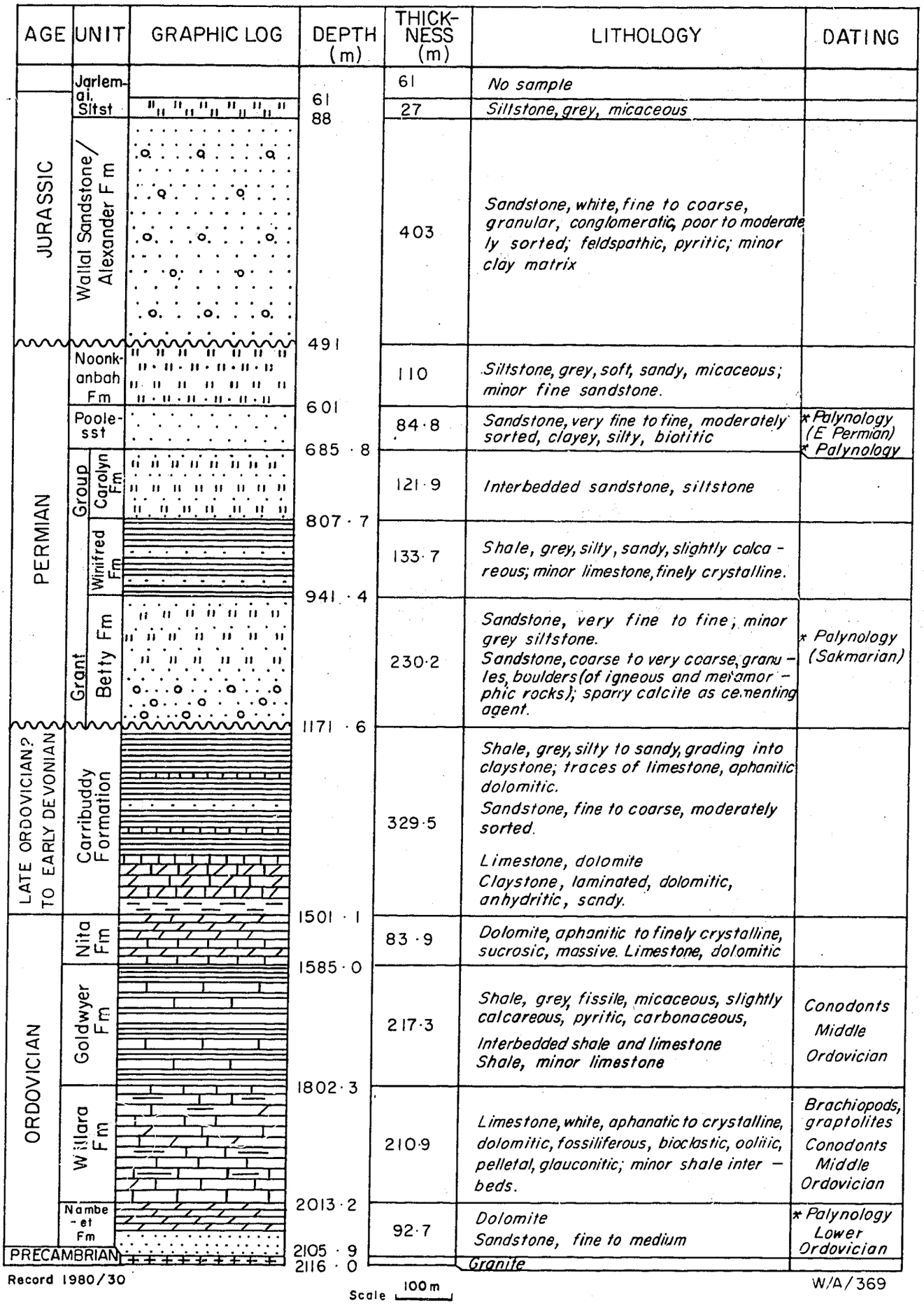


Fig. A 19 WAPET Munro 1

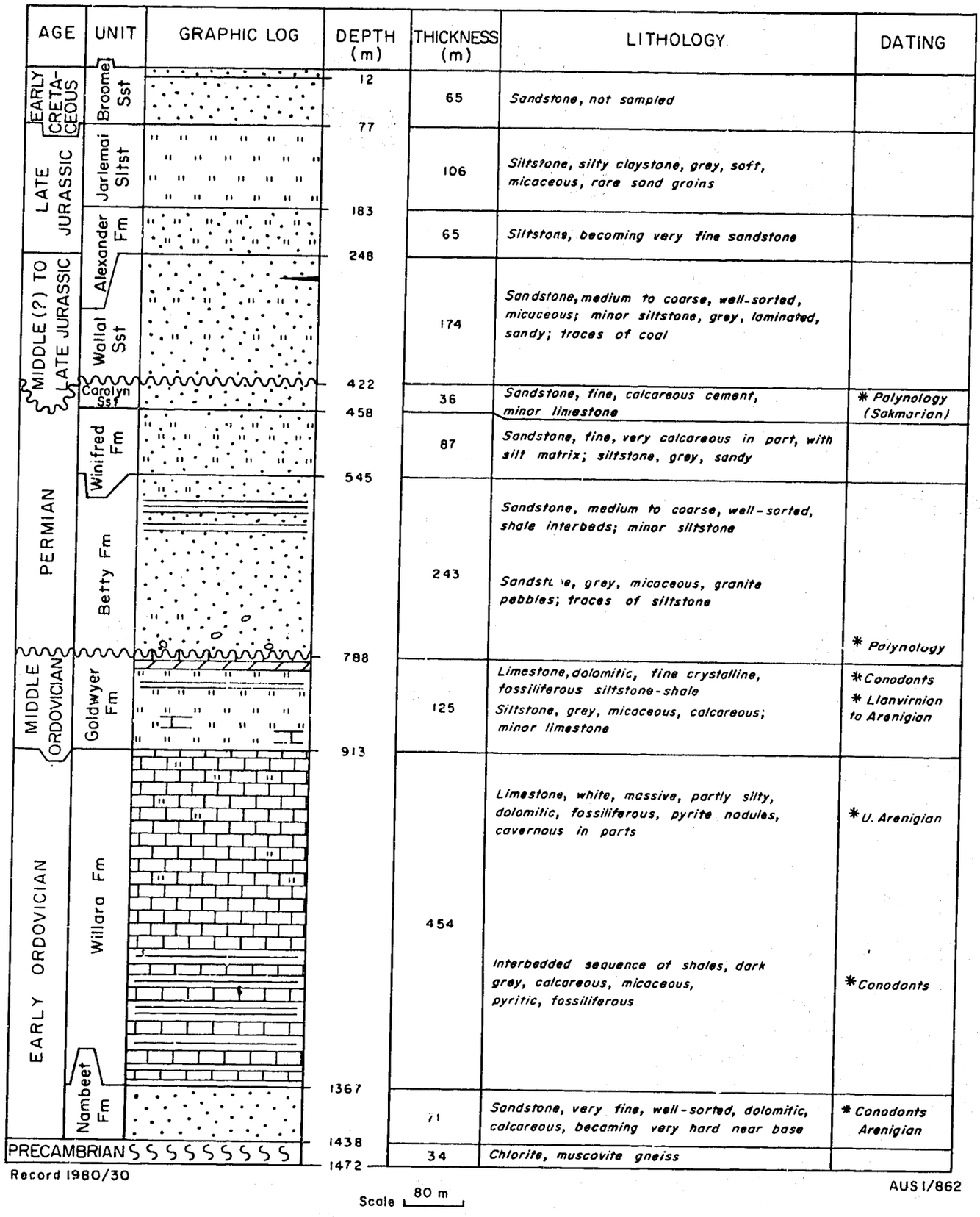
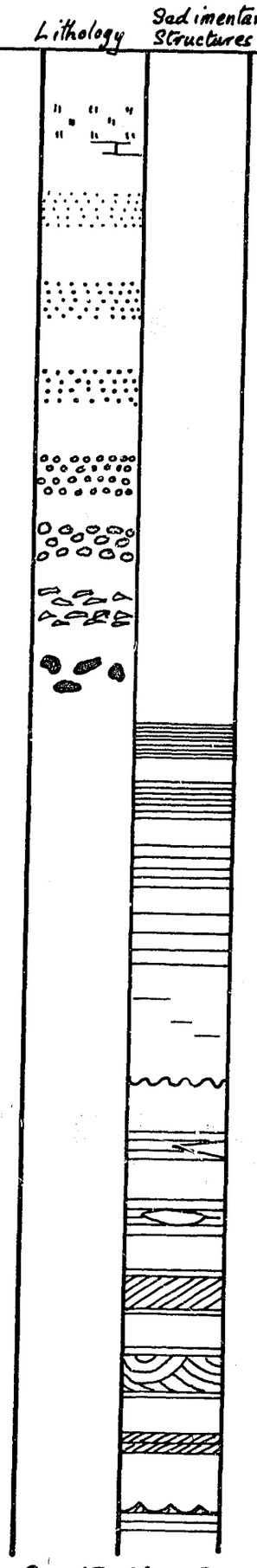


Fig. A 20 WAPET Thangoo 2

APPENDIX 3

MEASURED SECTIONS

REFERENCE FOR MEASURED SECTIONS



Mudstone – calcareous

Fine-grained sandstone

Medium-grained sandstone

Coarse-grained sandstone

Granule conglomerate

Pebble conglomerate

Clay-pellet conglomerate (intraformational)

Glacial dropstones

Laminated

Thin bedded

Medium bedded

Thick bedded

Poorly bedded or massive

Erosional boundary

Wedge-shaped bed

Lens

Planar cross-bedding } Large scale (greater than 5cm thick)

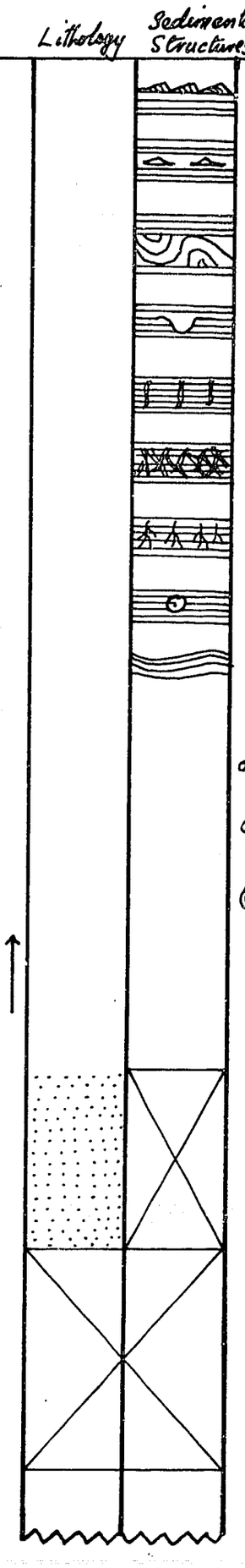
Trough cross-bedding }

Small-scale cross-bedding (less than 5cm thick)

Symmetrical ripple marks

CONTINUED

REFERENCE FOR MEASURED SECTIONS (CONTINUED)



Asymmetrical ripple marks

Flaser and/or lenticular bedding

Slump

Scour-and-fill structure

Burrows

Bioturbation

Fossil roots

Concretion

Wavy bedding

Fossil wood

Plant fossils

Marine macrofossils

Arrow indicates fining-upwards sequence. Length of arrow indicates thickness of sequence.

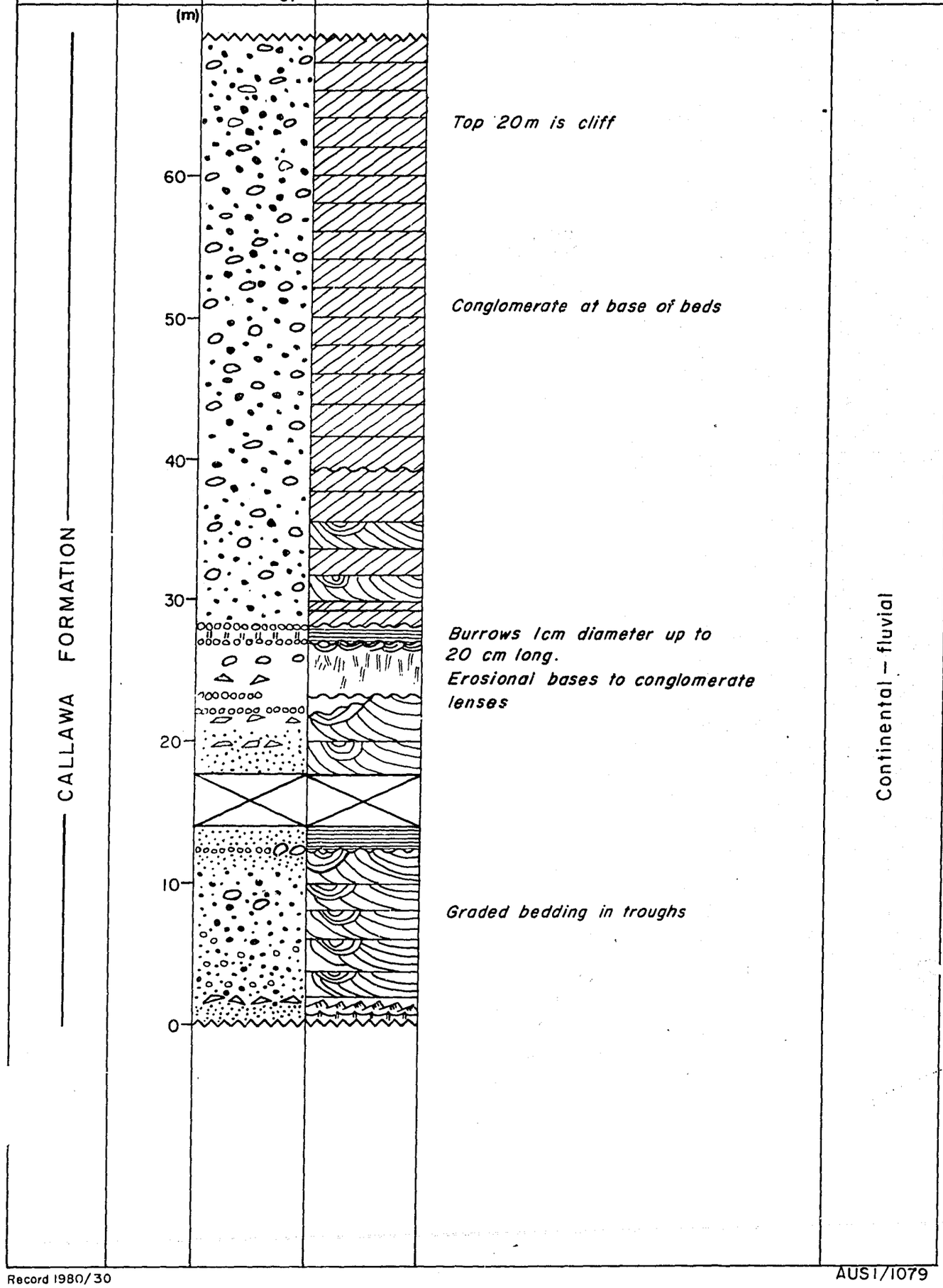
Section partly obscured by scree. Bedding not seen.

Section not exposed

Base of section.

NAME: NORTH OF CABBAGE TREE HILL
LOCALITY: YARRIE 20°02' S, 120°23' E

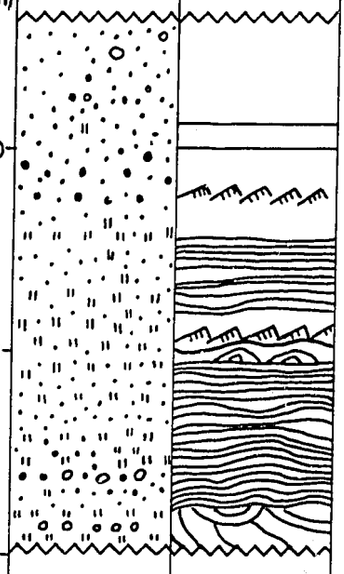
SECTION No 1



NAME: "TYPE SECTION" of "CUNCUDGERIE SANDSTONE" .

LOCALITY: PATERSON RANGE 21°04'S, 121°39'E

SECTION No 2

Unit	Thickness	Lithology	Sedimentary Structures	Remarks	Environmental Interpretation
POOLE SANDSTONE	(m) 20 10 0				Shallow water marine

NAME: KARROBRIDILL HILL

LOCALITY: MUNRO 19° 43' S, 122° 07 E

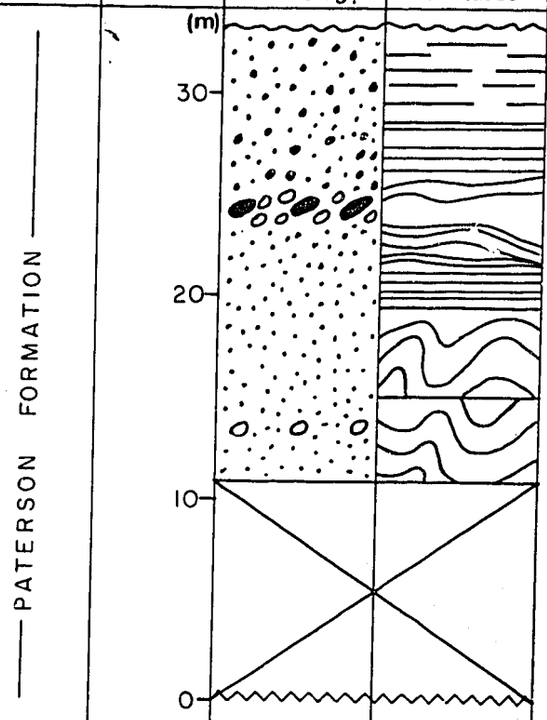
SECTION No 3

Unit	Thickness (m)	Lithology	Sedimentary Structures	Remarks	Environmental Interpretation
	20			Detail of facies A *Thin bedded-laminated mudstone with fine sandstone beds. Some graded bedding. Passes gradationally into.* B *Bioturbated fine to medium sandstone with bedding almost destroyed. Passes gradationally to slightly erosionally into* C *Very poorly sorted, angular, medium to very coarse feldspathic sandstone with granules; moderately bedded and ferruginous* *Facies A is identified with the Parda Fm, and Facies C with the Frezier Sst. Facies B appears to be transitional. The section is interpreted to be interfingering Parda Fm and Frezier Sst.*	Rapid changes in environment. Reliable interpretation not possible
	10				
	0		SCREE		

NAME: PATERSON FORMATION

LOCALITY: PATERSON RANGE 21° 45' S 122° 10' E

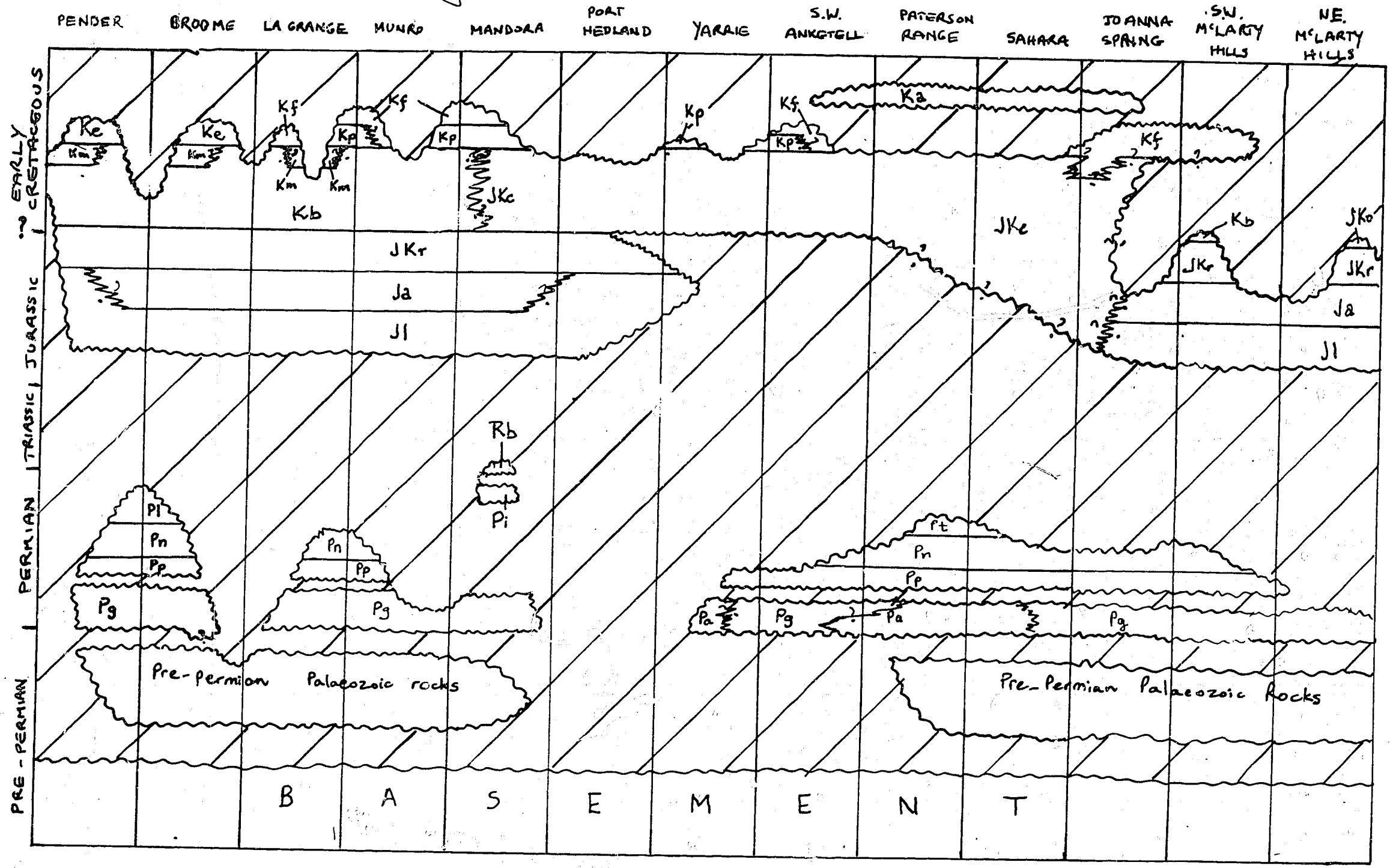
SECTION No 4



Unit	Thickness (m)	Lithology	Sedimentary Structures	Remarks	Environmental Interpretation
PATERSON FORMATION	30–20			Polymictic cgt, with boulder sized drop stones	GLACIAL – FLUVIAL
	20–10			Large scale slumps probably tens of m thick	
	10–0			Scree contains drop stones	

Record 1980/30

FIG. 35 Stratigraphic relationships



Note: Ages of Jurassic and Cretaceous rocks are not well known; and the occurrence of one or several units at the same level in different Sheet areas on this diagram does not necessarily imply similar ages within or between units.

Aus 1/1096

GEOLOGY OF THE CANNING BASIN

WESTERN AUSTRALIA

1983

SCALE 1:1 000 000

0 20 40 60 80 100 KILOMETRES

Lambert Conformal Conic Projection with Standard Parallels 17°45'S and 23°00'S

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Prepared in collaboration with the Geological Survey of Western Australia, issued under the authority of the Minister for National Development and Energy. Base map compiled by the Bureau of Mineral Resources from 1:1 000 000 scale BMR topographic map series and the 1:250 000 scale topographic map series supplied by the Division of National Mapping, Department of National Development and Energy.

© Commonwealth of Australia 1983

Geology 1972 by A.N.Yeates, V.L.Passmore, BMR, R.W.A.Crowe, GSWA
1973 by A.N.Yeates, R.R.Towner, L.A.Wyborn, BMR, R.W.A.Crowe, GSWA
1974 by R.R.Towner, BMR, R.W.A.Crowe, GSWA
1975 by A.N.Yeates, R.R.Towner, BMR, R.W.A.Crowe, GSWA
1976 by R.R.Towner, D.L.Gibson, BMR, R.W.A.Crowe, GSWA
1977 by R.R.Towner, D.L.Gibson, BMR, R.W.A.Crowe, GSWA
Compiled 1980-81 by R.R.Towner, D.L.Gibson, G.Butterworth, E.A.Russell
Edited 1981 by G.W.D'Addario, A.S.Mikulczak
Gravimetry by BMR and private companies
Design and Drafting by Cartography Section, BMR
Colour Design by R.A.Swoboda, J.N.Mason
Drawn by A.J.Maxwell
Printed by Mercury-Walch, Hobart, Australia

FOR STRATIGRAPHIC REFERENCE AND SECTIONS REFER TO PLATE 2

- Geological boundary
- Anticline
- Syncline
- Fault showing direction of movement

Where location of boundaries, folds and faults is approximate line is broken; where inferred, queried; where concealed, boundaries are dotted, faults are shown by short dashes

- Strike and dip of strata
- Prevailing strike and dip of strata
- Strike and dip of strata, dip 5°-15° (airphoto interpretation)
- Trend-line (airphoto interpretation)
- Lineament (airphoto interpretation)
- Joint pattern
- Macrofossil locality
- Plant fossil locality
- Fossil wood locality
- Vertebrate fossil locality
- Trace fossil locality
- Heavy mineral location
- Drillhole: B — stratigraphic hole, CR — core hole
- Petroleum exploration well, dry, abandoned
- Petroleum exploration well with show of oil, abandoned
- Petroleum exploration well with show of gas, abandoned
- Petroleum exploration well with show of oil and gas, abandoned
- Oil well
- Bore or well
- Bathymetric contour in metres
- Mangroves
- Sand dunes
- Principal road or highway
- Secondary road
- Minor road
- Railway
- Aerodrome
- Landing ground
- Town
- Settlement
- Homestead
- Telephone line
- Aboriginal reserve
- Abandoned
- Outstation
- Outcamp
- Bouguer anomaly contour (micrometres sec^{-2}), computer-plotter produced
- Gravity anomaly — relative high
- Gravity anomaly — relative low

Sandstone; Siltstone; Claystone; Limestone; Dolomite; Volcanics; Coal; Lithology uncertain; Dolerite; RT Rotary table; TD Total depth; 3644 Depth in metres

GRAVITY RELIABILITY DIAGRAM

Detailed traverse; A Detailed survey; B Reconnaissance

INDEX TO 1:250 000 MAP SHEETS

LOCALITY MAP

GEOLOGY OF THE CANNING BASIN 1:1 000 000 PLATE 1

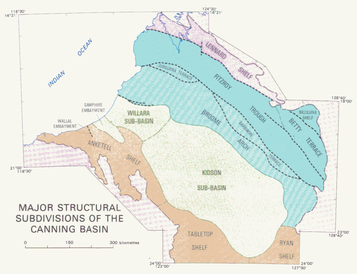
GEOLOGY OF THE CANNING BASIN
WESTERN AUSTRALIA

1983

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Prepared in collaboration with the Geological Survey of Western Australia. Issued under the authority of the Minister for National Development and Energy.
Base map compiled by the Bureau of Mineral Resources from 1:1 000 000 scale WAN topographic map series supplied by the Division of National Mapping, Department of National Development and Energy.

© Commonwealth of Australia 1983

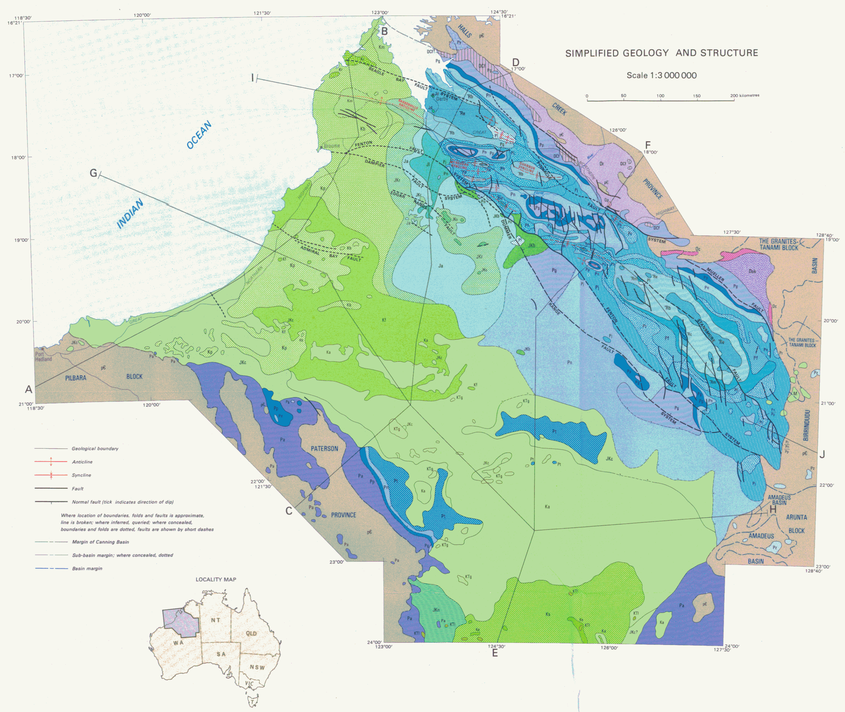
Geology 1972 by A.N. Yeates, V.L. Passmore, BMR, R.W.A. Crowe, GSWA
1973 by A.N. Yeates, R.R. Towner, L.A. Wyborn, BMR, R.W.A. Crowe, GSWA
1974 by R.R. Towner, BMR, R.W.A. Crowe, GSWA
1975 by A.N. Yeates, R.R. Towner, BMR, R.W.A. Crowe, GSWA
1976 by R.R. Towner, D.L. Gibson, BMR, R.W.A. Crowe, GSWA
1977 by R.R. Towner, D.L. Gibson, BMR, R.W.A. Crowe, GSWA
Compiled 1980 by R.R. Towner, D.L. Gibson, G.A. Young, P. Moffat
Edited 1981 by G.W. D'Addario, A.S. Mikkelsen
Design and drafting by Cartography Section, BMR
Colour design by R. A. Swoboda, J. N. Mason
Drawn by G.A. Young
Printed by Mercury-Walch, Hobart, Australia



SIMPLIFIED GEOLOGY AND STRUCTURE

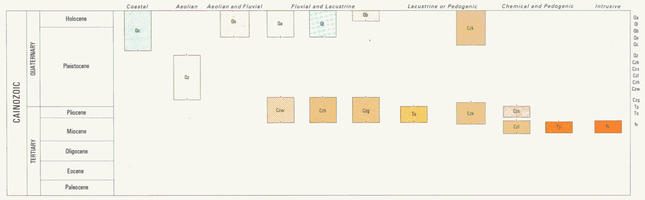
Scale 1:3 000 000

0 50 100 150 200 kilometres



LOCALITY MAP

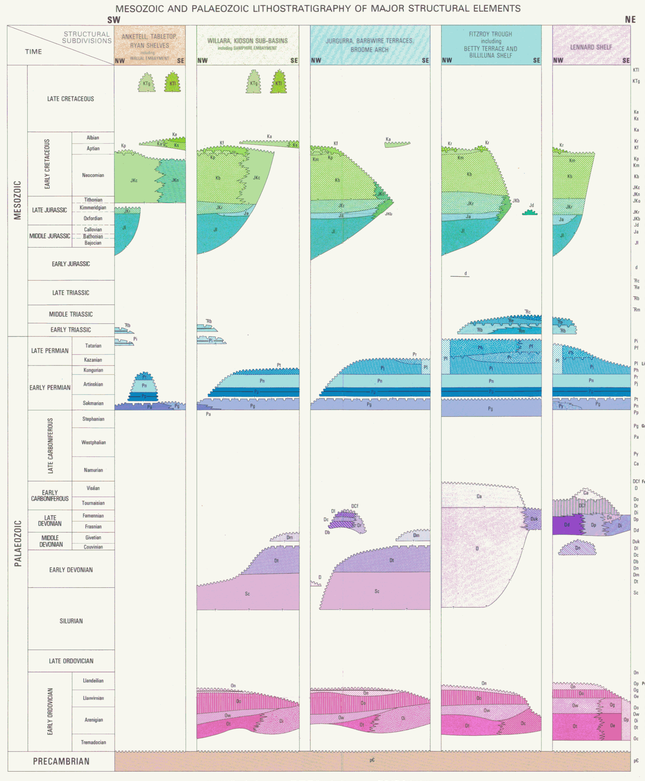
CAINOZOIC UNITS



ENVIRONMENT OF DEPOSITION

Qa		*Sand, silt, clay; minor gravel*	Fluvial
Ql		*Clay, silt, sand; minor possum*	Lacustrine
Qb		*Clay, silt; black soil*	Fluvial and lacustrine
Qa		*Sand, silt; minor gravel*	Mixed fluvial and aeolian
Qc		*Sand, silt, clay; organic clay; quartzose and calcareous sandstone; calcilutite, oolite; minor salt*	Coastal deposits
Qz		*Red quartz sand; minor silt*	Aeolian
Czk		*Calcrete; minor chalcedony*	Pedogenic, evaporitic
Czs		*Sand, silt, ferruginous pisolitha; minor gravel, clay*	Pedogenic
Czl		*Laterite; pisolitic or massive*	Pedogenic
Czh	**Merrinbah Conglomerate**	*Pebble and cobble gravel*	Fluvial
Czw	**Lawford beds**	*Calcrete, marl, sandy calcrete, calcareous sandstone; minor chalcedony, conglomerate*	Fluvial
Czg	**Lake Gregory beds**	*Variegated clay, silt, sand; minor gypsum, gravel*	Lacustrine
Tp	**Poondano Formation**	*Calcrete, limestone, sandstone, marl, gypsum*	Fluvial, chemical and pedogenic
Tb	**Bulimba beds**	*Cavernous sandstone, sandy limestone breccia and silica nodules; silicified limestone, chalcedony*	Lacustrine
Tv	**Fitzroy Lavaprovince**	*Leucite lamproite*	

MESOZOIC AND PALAEOZOIC LITHOSTRATIGRAPHY OF MAJOR STRUCTURAL ELEMENTS



ENVIRONMENT OF DEPOSITION

KTl	**Lampa beds**	*Sandstone, granule and pebble conglomerate; poorly sorted; intensely silicified*	Fluvial
KTg	**Lake George beds**	*Sandstone, granule conglomerate, poorly sorted; massive* — may range into Early Tertiary	Continental; partly pedogenic
	M	*Sandstone, siltstone, conglomerate; extent and relationship with other Mesozoic units unknown*	
Ke	**Bejah Claystone**	*Claystone; minor very fine sandstone; massive to poorly bedded*	Shallow marine
Ks	**Samuel Formation**	*Sandstone, fine to very fine; interbedded with siltstone, claystone; laminated to thin-bedded*	Shallow marine
Ka	**Askerall Sandstone**	*Sandstone, fine to medium; minor siltstone, claystone; sandstone and conglomerate; laminated to thin-bedded*	Shallow marine
Kr	**Seories Sandstone**	*Sandstone; minor conglomerate; poorly sorted*	Fluvial
Kf	**Fenton Sandstone**	*Sandstone, fine to coarse; minor conglomerate; poorly sorted; feldspathic in part; commonly ferruginised or pedogenically altered*	Fluvial to deltaic
Kp	**Parda Formation**	*Mudstone, fine sandstone; thin-bedded to massive*	Lagoonal or shallow marine
Km	**Mallogo Sandstone**	*Sandstone, fine to medium; well-sorted; pebbly in places; minor siltstone; cross-bedded*	Beach
Ks	**Sosono Sandstone**	*Sandstone, fine to coarse; mudstone, minor conglomerate; ripple-marked, cross-bedded*	Shallow marine, tidal
JKc	**Callawa Formation**	*Sandstone, conglomerate, poorly sorted; minor siltstone*	Fluvial
JKn	**Cronin Sandstone**	*Sandstone, fine to coarse, bioturbated; minor conglomerate, mudstone*	Fluvial
JKa	**Mowla Sandstone**	*Sandstone, fine to coarse, bioturbated; poorly sorted; conglomeratic in places; minor mudstone*	Fluvial to deltaic
JKr	**Jurlomal Siltstone**	*Mudstone, sandy in part; sandstone; poorly sorted; bioturbated*	Shallow marine, sub-tidal
JKb	**Barbwire Sandstone**	*Sandstone, fine to coarse; conglomeratic; minor siltstone*	Fluvial
Jd	**Mada Formation**	*Sandstone, fine to coarse; conglomeratic; minor siltstone; ferruginised*	Fluvial
Ja	**Alexander Formation**	*Sandstone, interbedded mudstone; cross-bedded, ripple-marked; minor conglomerate*	Shallow marine, tidal
Jl	**Wallal Sandstone**	*Sandstone; minor siltstone, conglomerate, lignite*	Continental to shallow marine
d		*Dolerite, gabbro sills. Section only*	
Tru	**Calvida Sandstone**	*Sandstone, coarse to fine; conglomeratic, siltstone*	Fluvial
Tw	**Erskine Sandstone**	*Sandstone, very fine to fine; laminated to thin-bedded; minor clay pellet conglomerate*	Deltaic
TRb	**Bliss Shale**	*Mudstone, minor siltstone, sandstone; thin-bedded*	Shallow restricted marine
TRm	**Mithiri Sandstone**	*Sandstone; minor siltstone, conglomerate; thin-bedded, ripple-marked*	Fluvial
	Pz	*Sandstone, siltstone; minor limestone*	
Pi	**Chinty Formation**	*Shale, with fine conglomeratic sandstone interbeds. Section only*	Lagoonal?
Pf	**Godfrey beds**	*Sandstone, fine to coarse, partly conglomeratic; minor siltstone; cross-bedded*	Lagoonal?
Pl	**Liveringa Group**	*Interbedded sandstone, mudstone; minor conglomerate*	Marine to continental
Pw	**Wardana Formation**	*Interbedded sandstone, mudstone; cross-bedded*	Marine
Pc	**Condros Sandstone**	*Sandstone, siltstone; minor conglomerate*	Fluvial
Pl	**Lightjack Formation**	*Fine sandstone, mudstone in lower part; medium sandstone in middle part; siltstone, sandstone, coal in upper part*	Shallow marine to lagoonal
Pt	**Triwhite Sandstone**	*Sandstone, fine to medium; micaceous; siltstone interbeds*	Shallow marine
Pn	**Noonkanbah Formation**	*Mudstone, fine sandstone; minor limestone*	Marine
Pp	**Poole Sandstone**	*Sandstone; minor siltstone; ripple-marked; thin-bedded; clay pellet conglomerate; calcareous sandstone and limestone at base*	Lagoonal to shallow marine
Pg	**Grant Group**	*Sandstone, siltstone, claystone; minor conglomerate; diagnostexus*	Marine to lagoonal?
Pa	**Paterson Formation**	*Coarse to conglomeratic sandstone and siltstone, laminated and ranvel claystone and siltstone, with diagnostexus*	Fluvial Lacustrine Glacial
Py	**Lilliboonoora Conglomerate**	*Boulder, cobble conglomerate, sandstone*	Fluvial
Ca	**Asabeeno Formation**	*Sandstone, siltstone, shale; minor limestone, dolomite, anhydrite. Section only*	Marine to continental
DCf	**Fairfield Group**	*Limestone, siltstone; minor dolomite, sandstone, shale*	Shallow marine
D		*Sandstone, siltstone, limestone, evaporite*	
Du		*Undivided sandstone, siltstone. Section only*	
Dr		*Conglomerate; Undivided Dd, Dg, Di*	
Di		*Calcarenite, calcilutite, siltstone, shale, mega-breccia; sandstone*	Marginal slope and basin
Dp		*Limestone, algal, stromatoporoid, coral; oolite; dolomite, sandstone; massive to poorly bedded*	Platform
Dd		*Calcarenite, siltstone, shale*	Marginal slope and basin
Dok	**Koobby Sandstone**	*Sandstone, siltstone, pebble conglomerate*	Fluvial
Sl	**Lulunjal Formation**	*Interbedded siltstone, shale, limestone, fine sandstone*	Marine
Ds	**Diamonon Siltstone**	*Siltstone, shale; minor limestone*	Marine
Db	**Bahrongan beds**	*Shale, siltstone; minor limestone, dolomite*	Marine
Dn	**Pualine Formation**	*Siltstone; minor shale, sandstone; traces of dolomite*	Marine
Dm	**Mellilanta Limestone**	*Limestone, dolomite, dolomitic shale; minor sandstone* — Section only	Marine
Dl	**Nellis Sandstone**	*Red sandstone; minor siltstone interbeds*	Continental
Sc	**Carribuddy Formation**	*Dolomite, dolomitic siltstone, claystone, evaporites; minor sandstone*	Shallow marine
Dn	**Nita Formation**	*Limestone, dolomite, interbedded shale. Section only*	Marine
Cp	**Prices Creek Group**	*Dolomite, limestone, shale, sandstone*	Marine
Dg	**Gap Creek Formation**	*Dolomite, sandstone, siltstone*	Marine
Dr	**Cronnor Formation**	*Limestone, shale, dolomite, sandstone*	Marine
Ds	**Sinlinore Formation**	*Shale, black,pyritic; interbedded limestone, dolomite, siltstone*	Marine
Dw	**Willara Formation**	*Limestone, dolomitic; minor shale, siltstone, sandstone* — Section only	Marine
Dl	**Wilson Cliffs Sandstone**	*Sandstone; minor siltstone, shale, limestone, dolomite*	Marine
Dt	**Nambeet Formation**	*Shale; interbedded limestone, dolomite, fine sandstone; very fine to medium sandstone towards base*	Marine
Gs	**Carnarvon beds**	*Sandstone, pebble and clay pellet conglomerate*	Marine
pC		*Igneous, sedimentary and metamorphic rocks surrounding the basin margin and underlying Canning Basin sequence*	

SECTIONS

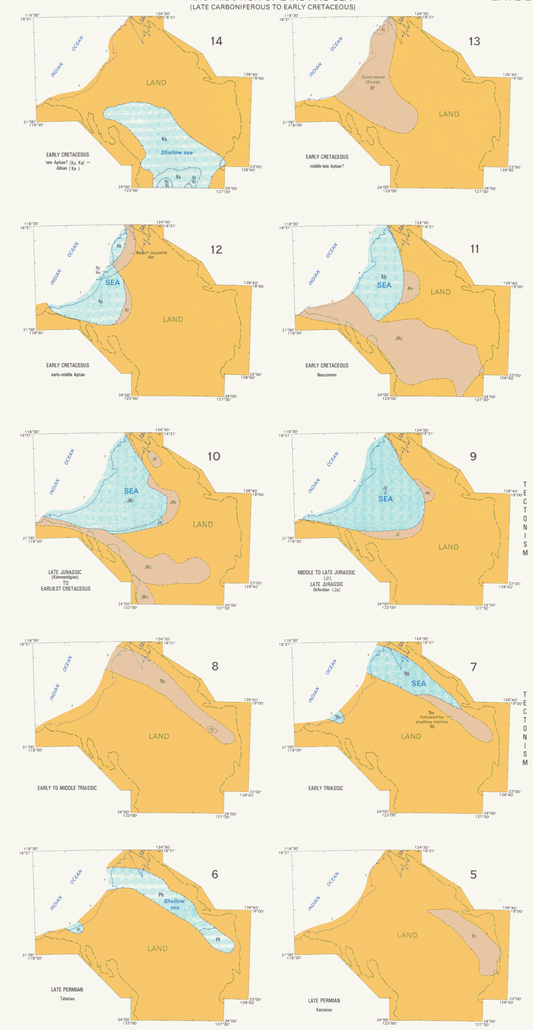
Cumulative subthenchs omitted

Scale $\frac{V}{H} = 4$

DISTRIBUTION OF LAND AND SEA

(LATE CARBONIFEROUS TO EARLY CRETACEOUS)

PLATE 2



SHHH
DON'T TELL
ANYONE
Copy 3

GEOLOGY OF THE
CANNING BASIN
PLATE 2