Geology of the Officer Basin

BMR Bulletin

206

M. J. Jackson
W. J. E. van de Graaff

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Geology of the Officer Basin, Western Australia

M. J. JACKSON & W. J. E. VAN DE GRAAFF

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ABSTRACT

The Officer Basin is a deep depression located between the Yilgarn Block and Musgrave Block in the Gibson Desert and Great Victoria Desert regions of Western Australia. It contains a gently folded and faulted sedimentary sequence several kilometres thick, which continues into western South Australia. Despite an extensive cover of Cainozoic soils and lack of relief reconnaissance mapping, drilling, and seismic studies indicate that in Western Australia the basin fill comprises a gently folded late Proterozoic to earliest Cambrian sequence about 5 km thick, overlain by relatively thin and flat-lying Cambrian, Permian, and Cretaceous rocks. Clastic, glacial, and evaporitic units in the late Proterozoic sequence can be correlated with Adelaidean units in the eastern Officer Basin, Amadeus Basin, and Adelaide Geosyncline. The basal unit of the unconformably overlying Palaeozoic sequence, the Table Hill Volcanics, is 575 $\pm$ 40 m.y. old and can be correlated with the Antrim Plaeau Volcanics of the Northern Territory. It is overlain by apparently unfossiliferous ?Cambrian sandstones of shallow marine origin. The disconformably overlying Permian rocks were deposited in a complex suite of lacustrine, fluvial, and glacial environments during the Gondwana Glaciation. They are overlain by fossiliferous marine Lower Cretaceous clastics up to 120 m thick. The Permian and Cretaceous rocks, in the form of dissected mesas, constitute most of the outcrops throughout this desert region.

The present land surface is dominated by an early Tertiary duricrusted peneplain, containing a well-preserved dendritic palaeodrainage system, which was formed during a wetter climate than the present. Within this relict landscape, arid features, such as salt lakes and sand dunes, have developed during subsequent drier climates.

Classical petroleum trap structures associated with diapirs and good reservoir rocks are known. Units from near the top of the late Proterozoic to earliest Cambrian sequence can be correlated with excellent hydrocarbon source rocks in the South Australian part of the basin. Extensive and thick valley calcretes draining surrounding basement blocks may merit investigation for uranium.

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INTRODUCTION

Area studied

This bulletin presents the results of a reconnaissance regional mapping project carried out in the Western Australian part of the Great Victoria Desert and the southern half of the Gibson Desert (Fig. 1). In this area a relatively thin veneer of nearly flat-lying Phanerozoic rocks overlies a thick, folded Proterozoic sequence. The sedimentary sequences in this area are collectively referred to as forming the Officer Basin in Western Australia. However, parts of the sequence are continuous with, or equivalent to, sequences in adjacent basins.

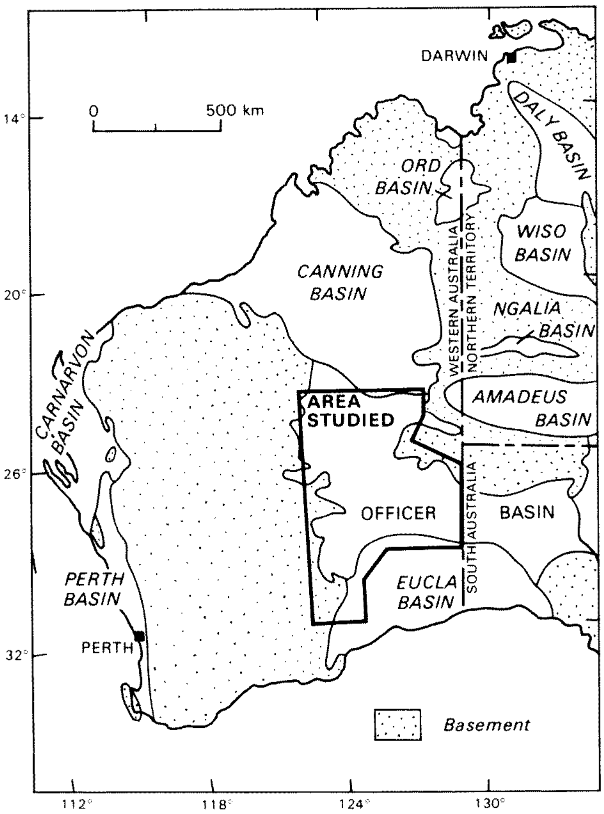


Fig. 1. Location of study area.

Owing to its remoteness and apparent lack of economic potential, this large area is one of the last in Australia to be systematically mapped at 1:250 000 scale.

Settlements, communications, and access

Apart from a few stations and three aboriginal missions on the fringe of the desert, there are no settlements. The population is probably less than 1000, and consists mostly of Aborigines living at the three missions. Aboriginal sites with stone arrangements, cave paintings or other artefacts were found in parts of the study area, but are most common around the Warburton Range.

The Laverton-Warburton Road is regularly maintained and can normally be used by two-wheel-drive vehicles, but four-wheel-drive vehicles are essential for all other roads (Fig. 2), as these are not maintained, and in places are covered with sand drifts or largely washed away. In addition to the roads shown on Figure 2 there is also, in the central part of the area, an extensive network of overgrown bulldozed tracks put in by Hunt Oil in the early 1960s.

Basic food supplies, petrol, and water can be obtained from the missions, and if pre-arranged, petrol can usually also be obtained from the various homesteads. If large quantities of petrol are needed it is advisable to pre-arrange this with the missions as supplies are limited. Alternatively, contractors from Laverton or Wiluna are able to supply bulk quantities of petrol to some parts of the area. However, because of the remoteness of the area, parties entering it should be well stocked with petrol, food, water, and essential parts and tools for their vehicles. As a safety precaution, parties should be equipped with radio transceivers capable of contacting the Royal Flying Doctor service in Kalgoorlie. Although basic food supplies can be obtained from the missions, or from Laverton, large supplies are best obtained from Perth or Kalgoorlie.

Permits to enter Aboriginal Reserves need to be obtained from the Department of Community Welfare, Perth, as most important roads cross parts of these reserves.

Laverton has a regular air service, and there are serviceable airstrips at the other settlements. A number of landing strips for light aircraft have been constructed from time to time throughout the area, but as these have not been maintained since construction, they may no longer be safe to use.

Climate, vegetation, and fauna

The area has a desert or arid climate. Annual rainfall is extremely erratic, but averages 150 mm to 230 mm; average yearly potential evaporation is in the range 2800 mm to 3300 mm. In January, normal daily minimum and maximum temperatures are about 18°C and 35°C, respectively, and in July, 4°C and 18°C (Australia, Bureau of Census and Statistics, 1973). Beard (1969) presented data from Giles, Peak Hill, Marble Bar, and Rawlinna, which can be considered representative for the study area.

Beard (1969) also described the botanical districts of Western Australia, and placed the Gibson Desert and the Great Victoria Desert in the Carnegie and Helms botanical districts, respectively. In the Gibson Desert vegetation is of the tree to shrub-type steppe, and is dominated by ubiquitous spinifex (*Triodia* sp.), and mulga (*Acacia aneura*), which usually occurs in dense stands in valleys and on pediments. In the Great Victoria Desert vegetation becomes denser southwards. Mulga is still common in valleys and on pediments, as is spinifex, which is most plentiful on sand plains. Mallee (*Eucalyptus pyriformis*), increases towards the southwest, as does the impressive marble gum (*Eucalyptus gongylocarpa*). More detailed information is given in Beard (1969) and the Western Australian Yearbooks.

The fauna in the area fluctuates considerably with the amount of rainfall. In dry years virtually the only animals commonly seen are reptiles and insects, whereas in wet years birds and mammals are abundant. As most of the mammals are small and secretive, they are rarely seen. In fact, apart from the dingo and kangaroo, recently introduced species such as camel, fox, and domestic cat are the most commonly seen mammals. Large birds such as the wedge-tailed eagle, bustard, hawk, galah and emu were seen occasionally. Further details are given in Burbidge & others (1976), McKenzie & Burbidge (1978), and the section on fauna in the Western Australian Yearbooks.

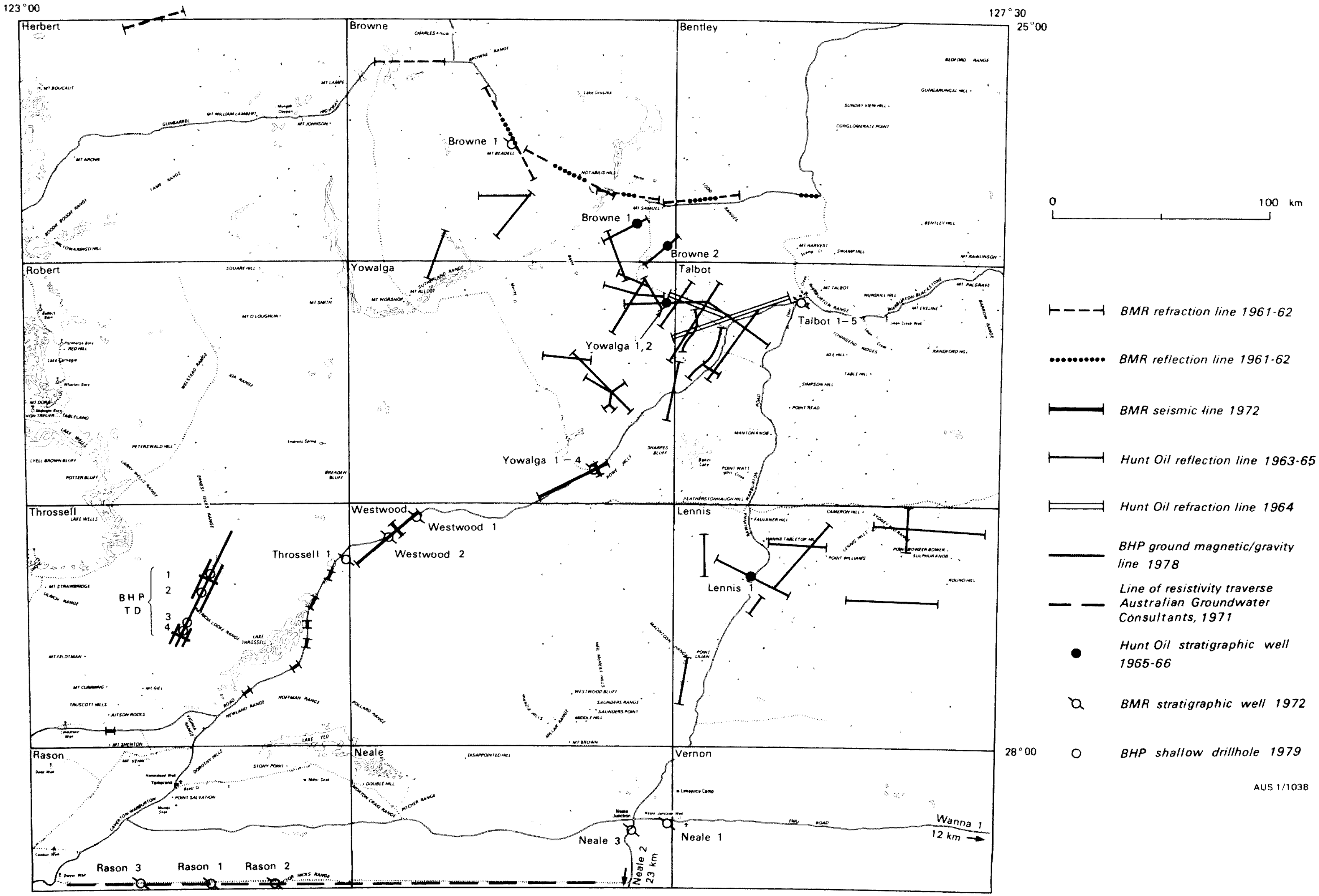


Fig. 2. Access to central part of area, showing roads, location of geophysical surveys, and stratigraphic drillholes.

Previous investigations

The study area was traversed in the late 19th century and early part of this century by several explorers, the most important of which were Forrest in 1874, Giles in 1873, 1874, 1875, and 1876, Lindsay in 1891-92, Carnegie in 1896-97, Wells in 1892 and 1896-97, and Hann in 1903 and 1906. These explorers named most of the natural features in the area, but only on one expedition was geological information systematically collected and reported. The Elder Exploring Expedition, led by Lindsay, and including a geologist, Victor Streich, explored a large part of Western Australia in 1891-92. The expedition crossed the area from the Barrow Range (TALBOT*) to Queen Victoria Spring (CUNDEELEE). Streich (1893) considered the Townsend Quartzite and overlying Proterozoic rocks to be Devonian, and the flat-lying sedimentary rocks southwest of these as Mesozoic with a cover of Tertiary surficial sediments.

Hann explored the Warburton Range area in 1903 and submitted gold-bearing samples from that area to the Geological Survey of Western Australia. Though an examination of that part of the State was first contemplated in 1905, it was not until 1916 that two Survey officers, H. W. B. Talbot and E. de C. Clade, were sent to the Warburton Range area. Though their main interest was in the auriferous rocks found by Hann, they made many significant observations on the sedimentary rocks and physiography of the area between the Yilgarn Block and Warburton Ranges. They recognised the glacial origin of rocks at the Wilkinson Range (now mapped as Permian Paterson Formation, but favoured a Mesozoic or Tertiary age for these. The Townsend Quartzite and Table Hill Volcanics of the Warburton area were considered by Talbot & Clarke (1917, 1918) to form part of a Townsend Range Series of Ordovician age. Forman (1933) made a reconnaissance in 1931 of roughly the same area as studied by Talbot and Clarke but correlated the Townsend Range Series with the Precambrian Nullagine Formation.

During the 1950s and 1960s parts of the area were investigated by companies exploring for oil, and several reports were written, but not published (e.g. Utting, 1955; Leslie, 1961). These reports confirmed the widespread occurrence of Permian fluvioglacial rocks and gave details of fossiliferous Mesozoic clastic sequences.

Prior to 1971 the Bureau of Mineral Resources (BMR) did reconnaissance geological mapping in the Gibson Desert (Veevers & Wells, 1959, 1961; Wells, 1963), together with aeromagnetic (Quilty & Goodeve, 1958; Goodeve, 1961), gravity (Lonsdale & Flavelle, 1963) and seismic surveys (Turpie, 1967) (Fig. 2). The geophysical surveys indicated that thick sedimentary sequences were present in the subsurface.

A consortium of Hunt Oil, Hunt Petroleum, Placid Oil, and Exoil (hereafter referred to as Hunt Oil) explored for oil in the area between 1961 and 1966, concentrating their effort in YOWALGA and TALBOT (Fig. 2). The consortium made a surface geological reconnaissance, photogeological studies (Hinds & Kaltenbach, 1963; Geophoto Services, 1963), an aeromagnetic reconnaissance (Brod, 1962), a land magnetic survey (Bazhaw & Jackson, 1965a), a gravity survey (Bazhaw & Jackson, 1965b), and several seismic surveys (Bowman & Harkey, 1962; Kendall & Hartley, 1964; Campbell, 1964; Mickleberry, 1966a, b) over parts of the basin. The exploration program culminated in 1966 in the drilling of four stratigraphic test wells, which intersected Proterozoic rocks at shallow depth (Jackson, 1966a).

An Alliance Petroleum-Union Oil consortium held leases in the Gibson Desert and made a photogeological survey (Alliger & Thomas, 1963) and an aeromagnetic survey (Lynch, 1965), in addition to surface reconnaissances (Wilson, 1964, 1967; Mack & Herrmann, 1965).

Small parts of the Officer Basin in Western Australia were mapped during mapping projects in the Eucla Basin (Lowry, 1970) and the Blackstone region (Daniels, 1974).

Present investigation

In 1970 the Geological Survey of Western Australia (GSWA) and the Bureau of Mineral Resources (BMR) began the present Officer Basin, W.A., project. D. C. Lowry and M. J. Jackson made a 5-week reconnaissance of the area to establish mapping techniques and to assess likely logistic problems (Lowry, 1971; Jackson, 1971). In 1971 a party consisting of D. C. Lowry, M. J. Jackson, W. J. E. van de Graaff, P. J. Kennewell, and J.-C. Boegli, mapped part or all of the following 1:250 000 Geological Sheets: BROWNE, COBB, HERBERT, LENNIS, MADLEY, MASON, MINIGWAL, NEALE, PLUMRIDGE, RASON, ROBERT, THROSSELL, VERNON, WAIGEN, WANNA, WARRI, WESTWOOD and YOWALGA. Minor parts of the following Sheet areas were also examined: BENTLEY, COOPER, JUBILEE, KINGSTONE, STANLEY, TALBOT and TRAINOR. Prior to the field season, black & white aerial photographs at 1:80 000 scale for the whole area were examined and outcrops and other places of interest marked and annotated on both photographs and base maps. During the field season these data were used to plan vehicle and helicopter traverses. The geological results of this field work are summarised by Lowry & others (1972).

In 1972 and 1973 mapping was continued on the predominantly Precambrian terrain near the southwestern margin of the basin by J. A. Bunting, W. J. E. van de Graaff, C. F. Gower, J.-C. Boegli, M. J. Jackson and R. G. Chin, thereby completing the systematic mapping of CUNDEELEE, MINIGWAL, NEALE, PLUMRIDGE, RASON, ROBERT, SEEMORE and THROSSELL. Twenty of the map sheets listed (with the exception of KINGSTON, STANLEY and TRAINOR) have been published as 1:250 000 geological maps with accompanying explanatory notes.

Owing to the lack of stratigraphic information in this poorly exposed area, a stratigraphic drilling project, seismic survey, and gravity survey were carried out to complement the subsurface data obtained by Hunt Oil. The drilling results are described in BMR Record 1975/49 (Jackson & others, 1975); the drill logs are contained in microfiche Appendix 1 of this Bulletin. The results of the geophysical survey are published separately (Harrison & Zadoroznyj, 1978). Parts or all of the basin were covered by reconnaissance gravity and aeromagnetic surveys in 1971-72 (Fraser, 1973a, 1973b, 1976) and 1976-1977, respectively. These surveys form part of BMR's systematic geophysical reconnaissance of Australia. The barometric altitude information from the reconnaissance gravity survey

* Names capitalised as such refer to the 1:250 000 Sheet area (see Plate 1 for index).

(11 km spacing) was used to compile formlines (at 25 m intervals) for the whole region. These are shown on the 1:250 000 First Edition maps and on Plate 2.

Mapping in the Officer Basin is difficult. Outcrops are widely separated and generally poor. Exposed stratigraphic sequences more than 25 m thick are rare, as the Phanerozoic strata are mostly flay-lying and the relief rarely exceeds a few tens of metres. Because of a lack of macrofossils and marker beds, the stratigraphic relationships between outcrops only a few kilometres apart can rarely be established. It is also impossible to reliably interpret bedrock types on aerial photographs as the lateritic weathering usually completely obscures all distinguishing characteristics. It is, for instance, often impossible on aerial photographs to differentiate Permian sediments from underlying granitic rocks, as both rock types are kaolinised and can form identical physiographic features. Added to this, there is an extensive cover of surficial deposits such as laterite, silcrete, aeolian sand, and colluvium.

In the 1970 and 1971 field seasons, when the mapping of the main part of the basin was completed, a total of about 600 locations were visited and described: i.e., an average of one outcrop per 450-500 km^2. Though these 600 locations represent most of the best outcrops in the Phanerozoic part of the area, the accuracy of the mapping could be improved by more detailed work. However, for a better understanding of the regional geology, additional subsurface information (e.g. seismic or deep drilling) is more necessary than an improvement of the quality of the map. A synthesis of the 1:250 000 maps forms the 1:1 000 000 geology and physiography maps (Plates 1 & 2). The explanatory notes and other project reports form the basis for much of this bulletin. Where this bulletin differs from the earlier maps and reports, the bulletin should be considered the more reliable.

Terminology used in text

The term *Officer Basin, W.A.* is used throughout the text to refer to the area and the underlying sedimentary rocks that were mapped during the project; it is defined later and its approximate boundaries are shown on Figures 1 & 63. The term *Officer Basin* refers to the sequences in W.A. & S.A. unless appropriately qualified.

Williams, Turner & Gilbert's (1954) sandstone classification as modified by Dott (1964) is used in petrographic descriptions, as we found it easy to use both in the field and in the laboratory for the sandstones in this area. Their terminology, such as quartz arenite or feldspathic arenite, is used where sandstone composition is specified, otherwise the general term sandstone is used. Quartzite is used to refer to intensely silica-cemented, unmetamorphosed sandstone of commonly quartz arenitic composition. Bedding terminology follows Ingram (1954) (thin, 10-100 mm; medium, 100-300 mm; thick, 300-1000 mm; and very thick bedded, > 1 m) for essentially parallel bedded units, and Allen (1963) for cross-stratified units.

Except for areas of Precambrian basement near the southwest margin of the basin, where detailed mapping was done, all localities visited during the project are shown on the 1:250 000 geological maps and are identified by a number. Owing to the lack of topographic names in the area, it is often easier to refer to this system when identifying localities, than to attempt to locate it by reference to the nearest named topographic feature. For example BROWNE 27 refers to locality number 27 in the BROWNE 1:250 000 Sheet area. Appendix 2 lists all such localities mentioned in the text with their corresponding latitude and longitude.

The GSWA and BMR use different subdivisions of the Precambrian. The GSWA scheme is used throughout the text and on Plate 1. The two scales are compared below;

Geological Survey of Western Australia	Bureau of Mineral Resources
UPPER PROTEROZOIC	
——— 900 m.y. ———	ADELAIDEAN
MIDDLE PROTEROZOIC	——— 1400 m.y. ———
——— 1640 m.y. ———	CARPENTARIAN
	——— 1800 m.y. ———
LOWER PROTEROZOIC	LOWER PROTEROZOIC
——— 2440 m.y. ———	——— 2300 m.y. ———
ARCHAEAN	ARCHAEAN

Drillholes are named after the operator and 1:250 000 sheet area within which they were drilled, e.g. BMR Browne 2 refers to the second hole drilled by BMR in the BROWNE (SG/51-8) Sheet area. All stratigraphic wells known to have been drilled in the area up to 1978 are shown on Figure 2 & Plate 1.

Acknowledgements

It is a pleasure to acknowledge the help we have received during this project from various quarters. We wish to thank personnel from the Warburton, Cundeelee, and Cosmo Newberry Missions for their help and hospitality. The staff of Seemore Downs, Yamarna and Carnegie stations were also most co-operative. Dr W. Compston, Australian National University carried out isotopic dating of the Table Hill Volcanics, which proved to be essential for an understanding of the stratigraphy, and Dr W. V. Preiss, South Australian Department of Mines, assisted by studying stromatolite assemblages. His colleagues R. B. Major and G. W. Krieg helped us to understand the relationships with the South Australian part of the Officer Basin.

PHYSIOGRAPHY

Virtually the whole region is characterised by very subdued relief. It is an undulating plain with elevations of around 500 m in the north and 200 m in the south. The monotony of this gently undulating plain is broken by breakaways, mesas, low hills and sand dunes with relief up to some tens of metres. Major indentations in the formlines (inset on Plate 2) outline the broad trunk valleys of a Tertiary palaeodrainage system.

The development of the physiography of the region has been dominated by two elements; an early Tertiary duricrusted peneplain with a dendritic palaeodrainage system, that was formed under a much wetter climate than the present one, and a group of topographic features (including mesas, sand dunes and salt lakes) formed under more arid conditions, that have developed by destruction of, or deposition on, this old peneplain. These two elements broadly correlate with the Old and New Plateaux, respectively, of Jutson (1934).

Since Jutson's paper, little additional information on the physiography of the region has been collected,

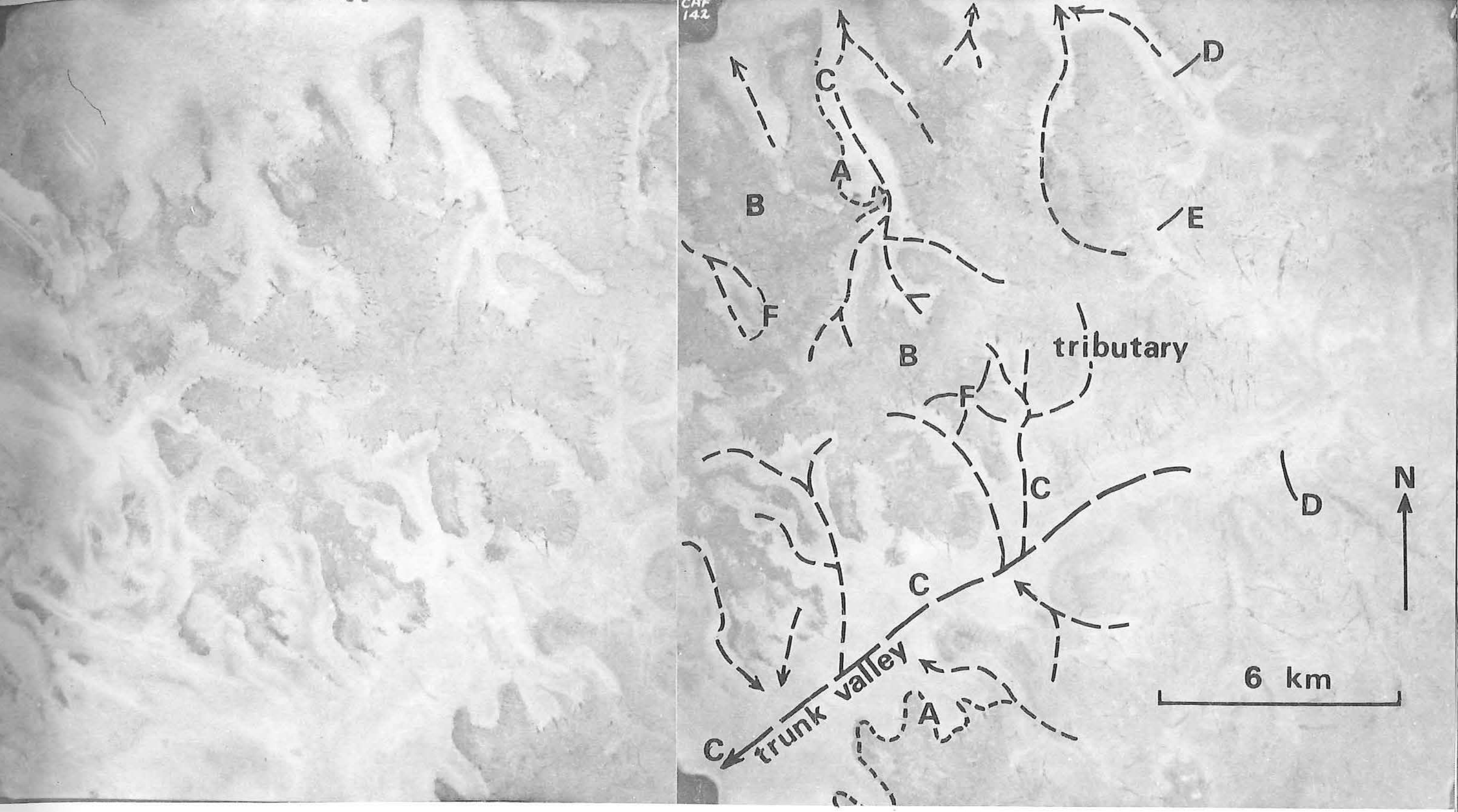


Fig. 3. Physiography of Gibson Desert area.

MORRIS F/51-16, CAF 142, Run 4, photos 158 and 160. Undulating duricrust plain with well-developed dendritic palaeodrainages (axes shown by broken lines). A—geological boundary between lateritic duricrust (dark grey) and aeolian/colluvial sand and silt filling hollows (light grey); this also represents a physiographic boundary between rounded rises of the undulating plains with sparse spinifex (B) and flat sandy depressions with denser spinifex (C). D—more densely vegetated areas receiving relatively higher groundwater inflow; incipient development of clay pans. lateritic duricrust (E). F—short, present-day ephermeral creek Note early stage in the development of breakaway by erosion of channels developed consequently on the sides of the relict trunk valleys.

and a systematic description of the physiography is therefore presented (Plate 2). A close spatial relationship exists between the physiography and the distribution of the Cainozoic surficial units (schematic section accompanying Plate 2).

Undulating duricrust plain

A lateritic and siliceous duricrust developed beneath an undulating surface during the Late Cretaceous to Early Tertiary under a much more humid climate than at present. Concomitant with the formation of this duricrust was the initiation and development of a dendritic river system which became recognisable throughout most of Western Australia (Plate 2). Bunting & others (1974) and Van de Graaff & others (1977) have defined palaeodrainage lines, palaeodrainage divides, and palaeodrainage provinces for these former rivers, and used them to elucidate the Tertiary climates and tectonics of the region.

Although ferruginisation and silicification of bedrock are evident throughout the region, the ferruginous laterite is best developed in the north and east, on more clay-rich bedrock, such as the Samuel Formation, while more siliceous weathering profiles are common in the areas underlain by Permian or older bedrock.

Over large areas, this duricrust, which formed as the B-horizon of a soil profile, has only been stripped of its overlying sandy A-horizon, and it thus preserves closely the topography of the Tertiary peneplain and its drainage system. The landscape is characterised by smooth rounded rises separated by long broad flat sandy depressions (Fig. 3). The rises are usually covered with numerous ferruginous pisoliths and irregular fragments of ironstone (Fig. 4), whereas the hollows are commonly carpeted by a thin layer of fine sand and silt that has either been blown in or washed down off the rises (Fig. 5). The duricrust plain is characterised by a sparse vegetation of spinifex and low shrubs, and was mapped as the mulga parkland by Beard (1973). The dark red-brown soils, sparse vegetation and regular undulations impart a distinctive uniform dark-grey photopattern (Fig. 3) which allows ready delineation of this subdivision.

The duricrust plain is especially well preserved in the northern part of the region (WARRI, BROWNE and WESTWOOD). The dominance of these stony plains in the landscape of this area distinguishes the Gibson or 'Stony' Desert from the Great Victoria or 'Sandy' Desert. In parts of the sandy desert, for example, in LENNIS and WAIGEN, only the higher parts of the peneplain are visible as most of the duricrust is covered by aeolian sand (Fig. 6). Where erosion has cut into the duricrust, incipient low breakaways are developing (Fig. 3). Where these breakaways are higher than a few metres or laterally extensive they have been included under Mesas.

Van de Graaff & others (1977) recognised seven palaeodrainage provinces in Western Australia and three of these are within the Officer Basin, W.A. (Inset on Plate 2). Throughout most of the region the rivers discharged towards the south into the ancestral Great Australian Bight before the emergence and development of the area now known as the Bunda Plateau, popularly referred to as the Nullabor Plain. However, parts of systems draining towards the Indian Ocean are preserved in the northwest and northeast. Most of the valleys slope fairly continuously toward

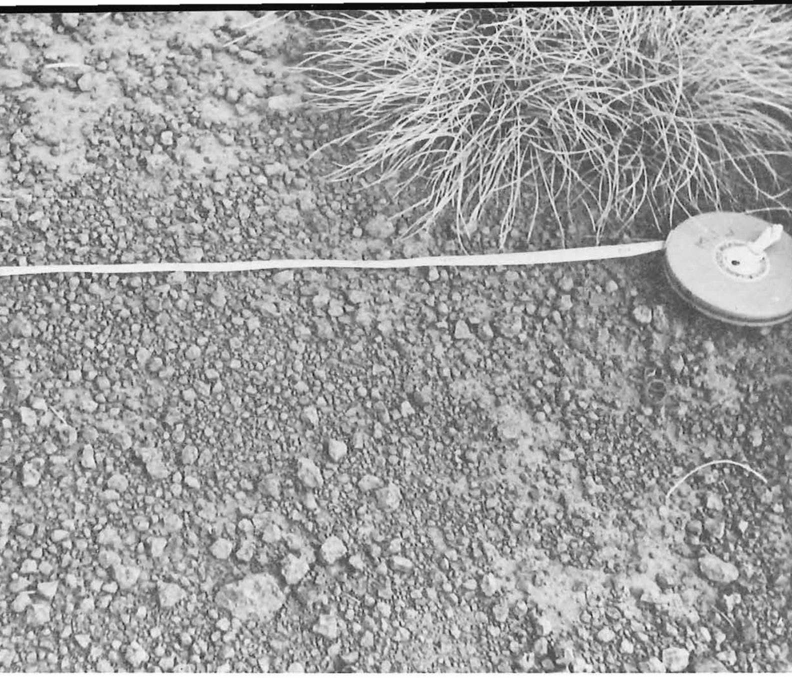


Fig. 4. Surface of rise within duricrusted plain with numerous angular fragments of ferruginous bedrock (cf. Fig. 5).
Characteristic of area A in Fig. 3 (0.90 m tape visible). (M/2238).

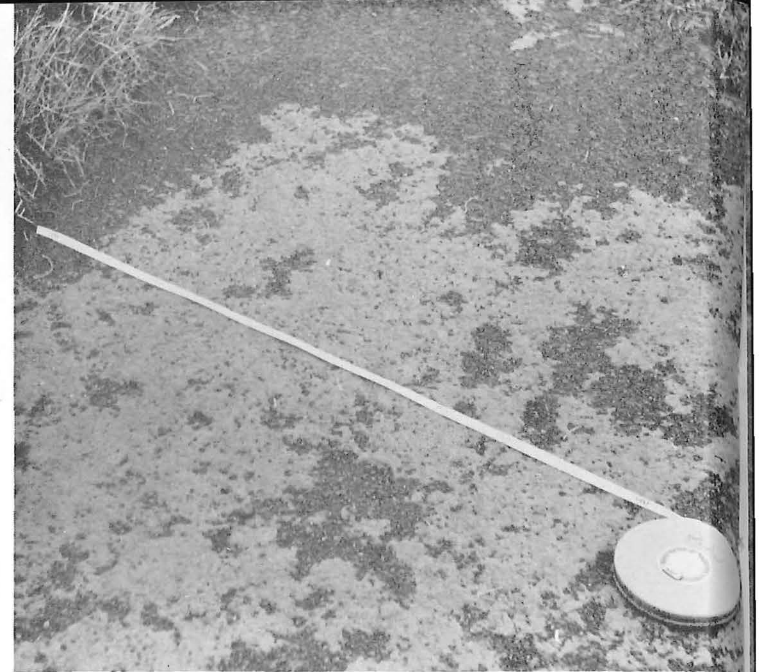


Fig. 5. Fine sand and silt with ironstone pisoliths carpeting hollows in duricrusted peneplains.
Characteristic of area B in Fig. 3 (1.10 tape visible). (M/2238).

the coast, and are therefore potential present-day drainages as well as palaeodrainages as was proved by the flow of Ponton Creek in 1975. The palaeodrainage patterns range from dendritic (e.g. Fig. 3) to trellis systems. The trellis patterns are due to a combination of gently tilted bedrock producing very subdued cuestas, and rectilinear joint or fault patterns. Within the northern part of the Officer Basin the palaeodrainages and associated duricrust peneplain are developed on Lower Cretaceous marine sediments and are, therefore, no older than early Late Cretaceous. Significant flow of water in the rivers had ceased by the Middle Miocene (the palaeorivers do not continue across the Bunda Plateau, which emerged soon after the Middle Miocene), but there is geomorphological and stratigraphic evidence to indicate that none of the drainage patterns changed much after the Late Eocene (Van de Graaff & others, 1977 p. 394).

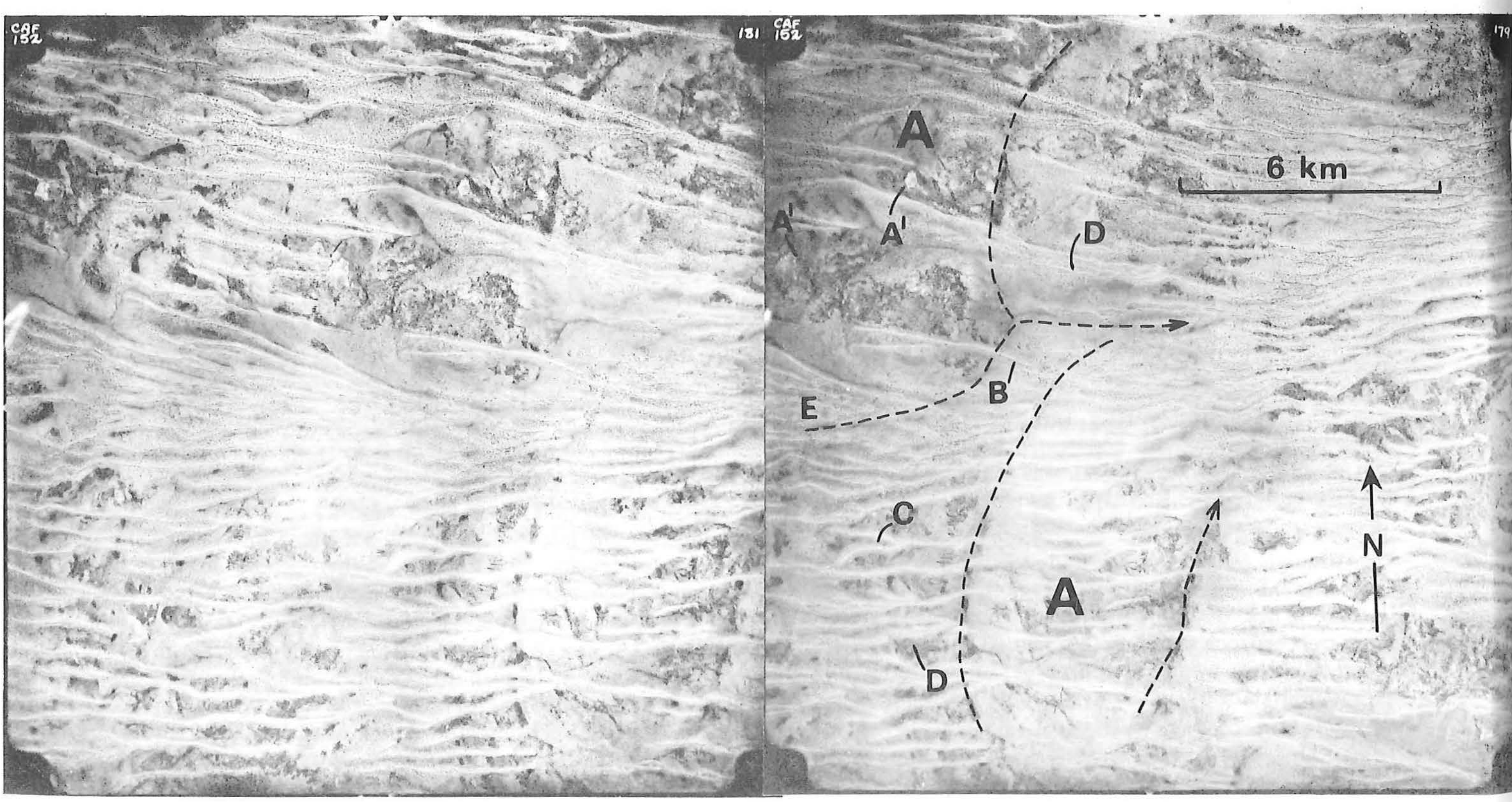


Fig. 6. Physiography typical of the Great Victoria Desert.
VERNON H/52-1, CAF 152, Run 2 photos 179 and 181. Undulating duricrust plain partially covered by aeolian sand. Relict palaeodrainages still visible, axes shown by dashed lines (cf. Fig. 3). A—rise covered by pisolitic laterite soil which is being eroded by ephemeral creeks and slope wash, with consequent development of incipient breakaways (A′). B—simple longitudinal dune on rise of duricrust plain. C—tuning-fork junction of dune opening upwind (e.g. wind from west). D—poorly developed chain longitudinal dune. E—thick cover of aeolian material with close-set dunes, completely covering underlying duricrust plain.

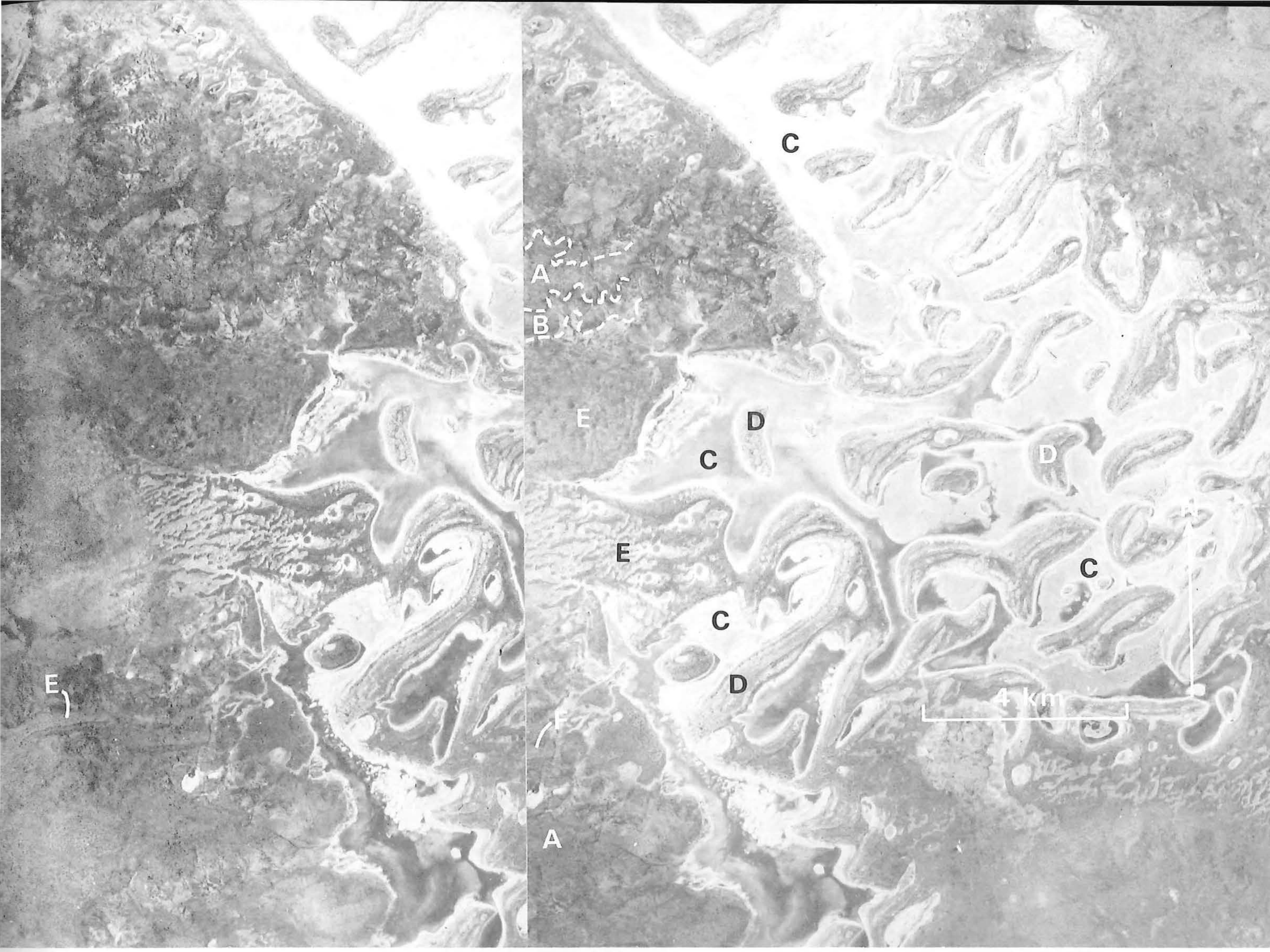


Fig. 7. Geology and physiography along southwestern margin of Lake Wells.
THROSSELL G/51-15, CAF 22, Run 2, photos 5010 and 5011. A—Mesa of fluvioglacial Paterson Formation unconformably overlying Proterozoic dolerite (B). C—surface of salt lake; irregular grey photo pattern is here caused by variations in salt bush communities on lake surface. D—'islands' within salt lake composed of white gypsiferous sand dunes. E—Areas marginal to salt lakes, where a complex intermixing of colluvial, alluvial, aeolian, and playa materials produces a complex physiography. F—a solitary, longitudinal red quartz sand dune (note grey tone compared with white of gypsiferous dunes). Line of sections shown in Plate 2.

In summary, this undulating peneplain with its palaeodrainages forms the oldest element of the present landscape, the other elements developing from, or on it.

Mesas

This subdivision includes mesas, buttes, and other rocky areas surrounded by cliffs, together with the extensive stony scree slopes and pediments that surround them (Fig. 7). The cliffs surrounding these features are referred to as breakaways in this part of Western Australia, and commonly form the boundary between the Old and New Plateaux of Jutson (1934). These landforms have developed by destructive weathering of the Old Plateau by headward erosion, gravity collapse and wind deflation. The bedrock is usually considerably decomposed, which in combination with the hard duricrust caps offers ideal conditions for formation of undercut cliffs. Talbot & Clarke (1918) and Jutson (1934) discuss the breakaways at length ; consequently, only a summary is presented here.

Breakaways vary greatly in size and shape from low, vertical to slightly undercut cliffs several tens of metres in lateral extent, to complex indented features several tens of metres high and many kilometres long. They face onto stony pediments or major valleys filled with debris. Breakaway complexes in the north are different from those in the south. This difference in development is related to the type, extent and durabilty of the duricrust present, which in turn is related to bedrock lithology.

In the north a predominantly ferruginous duricrust has developed on the widespread clay-rich Lower Cretaceous bedrock. There are smaller areas containing siliceous duricrusts, but these have developed on conglomerates of the Late Cretaceous Lampe Beds. The lateritic duricrust in the north has been extensively destroyed by erosion. In fact, in many areas remnants of the Old Plateau have only been preserved where a resistant cap of Lampe Beds has checked erosion. The resulting deeply dissected mesas form thin meandering belts (10 km wide by 100 km long) surrounded by wide pediments, (Section A-B, Fig. 8).

In contrast, the southern part of the area is characterised by a more siliceous lateritic duricrust, which is generally more resistant to erosion than the ferruginous laterites found in the north. This siliceous duricrust is developed on a more siliceous Lower Permian bedrock. The Old Plateau is therefore more extensively preserved in these areas although the lower parts of it

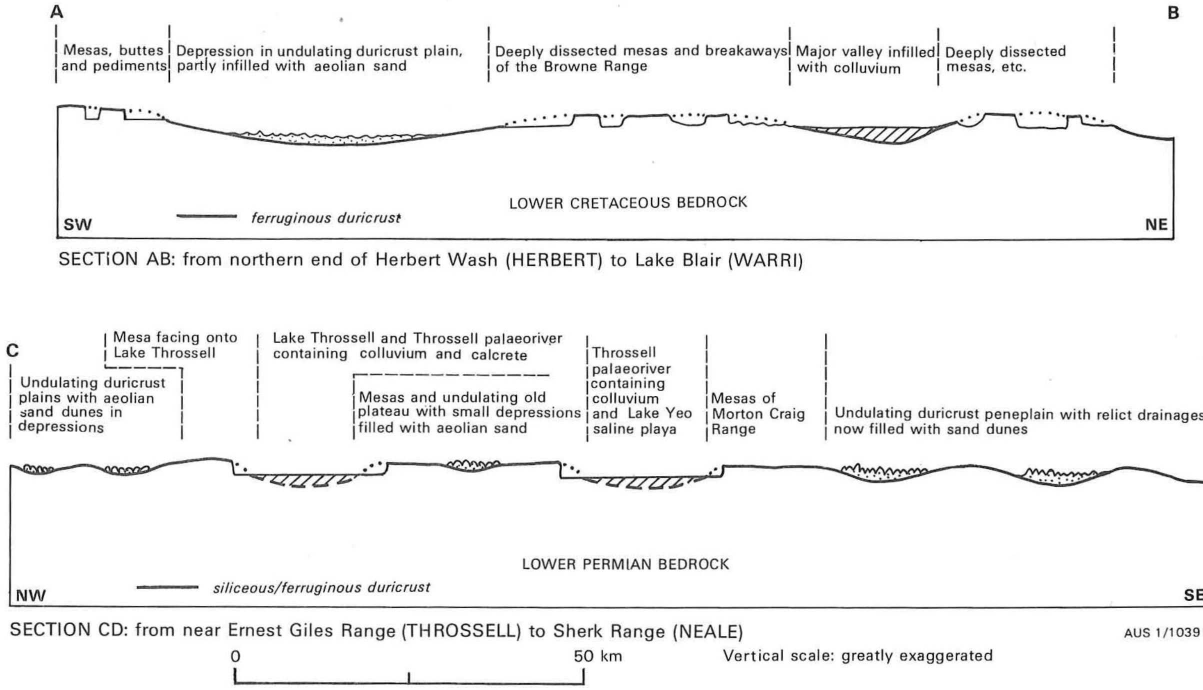


Fig. 8. Schematic topographic cross-sections, showing differences between the physiography in the Gibson Desert and that in the Great Victoria Desert.

are often covered by later aeolian sand sheets and dunes (Section C D on Fig. 8).

In detail, individual breakaways vary considerably in shape and size depending largely on the textures and structures in the bedrock and the type of duricrust present. Gently sloping stepped profiles are common on the well-bedded Lower Palaeozoic rocks in LENNIS and WAIGEN which do not have extensive duricrusts developed on them. In contrast, high, steep or vertical cliffs with narrow ledges are common in the Paterson Formation, especially where massive bedded rocks (e.g. tillites) contain thin beds of fluvial sandstone.

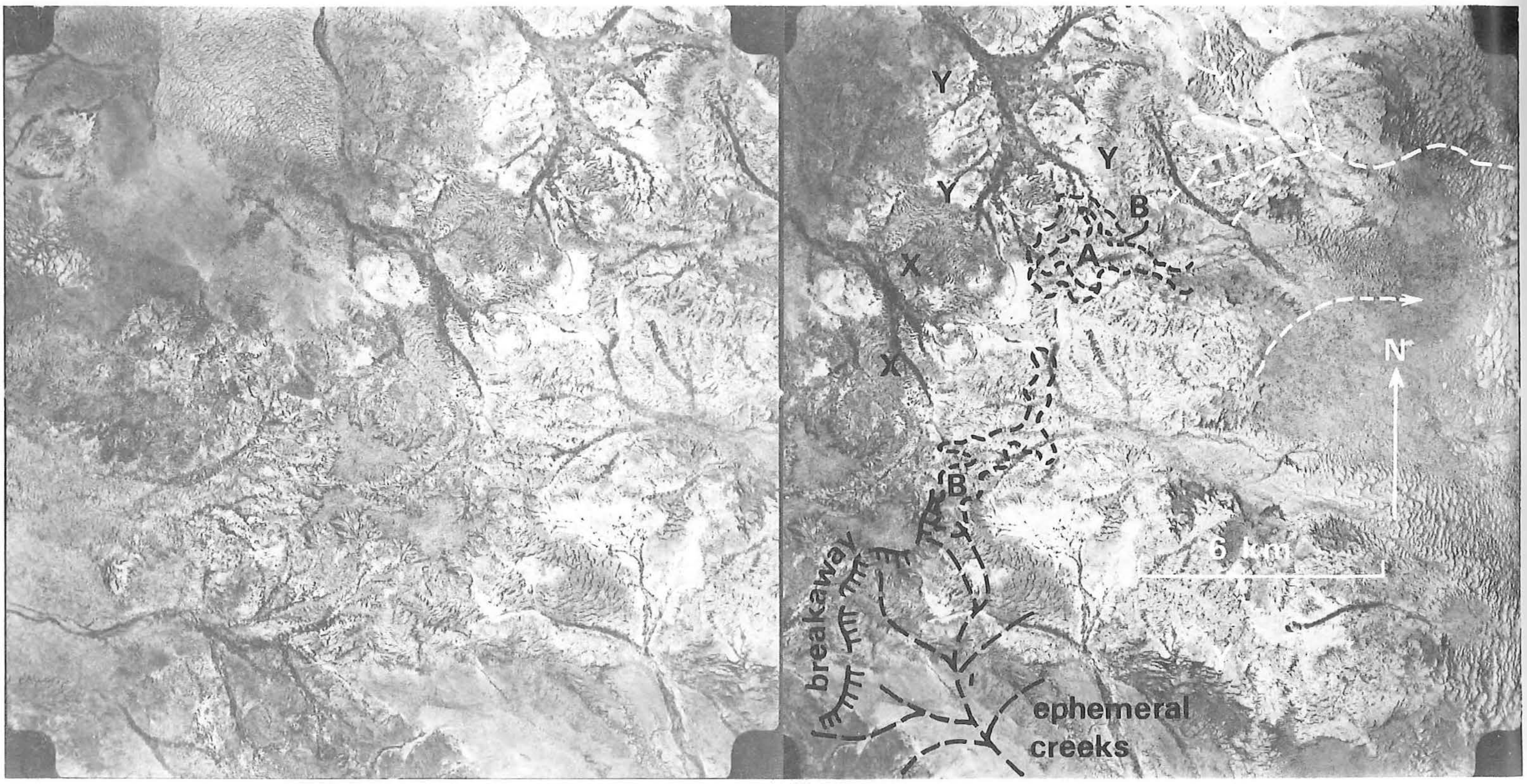


Fig. 9. Physiography of breakaway complex south of Mount Beadell.
BROWNE G/51-8, CAF 8, Run 6, photos 5056 and 5053. Siliceous Lampe Beds (A) forming a resistant cap to flat-lying Bejah Claystone (B). X—white outwash slopes comprising deeply weathered bedrock and rubble cut by densely vegetated ephermeral creeks (black zones). Y—gently sloping pediments of sand and silt with characteristic ribbed pattern.

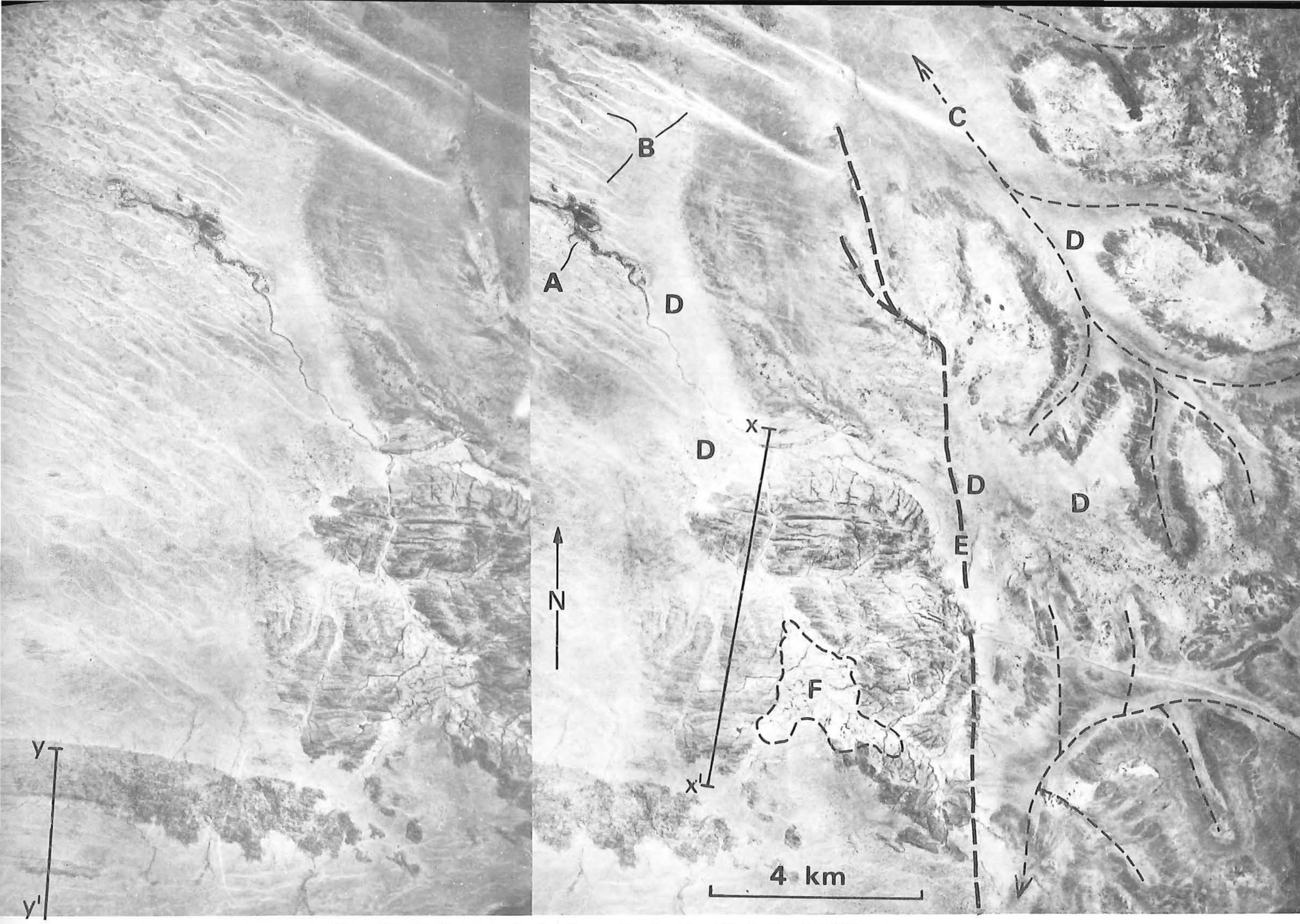


Fig. 10. Geology and physiography in the Clutterbuck Hills area.

COBB S/52-1, CAF 139, Run 5, photos 196 and 198. X—X′—distinctly bedded lower part of Clutterbuck Beds type section; Y—Y′—more massive conglomeratic upper division of unit producing blocky photopattern. A—location of photograph in Figure 59. B—longitudinal dunes on laterite plain. C—axes of dendritic palaeodrainages developed in the undulating laterite plains. D—areas of aeolian sand and colluvial material blanketing the duricrust plain. E—northern extent of Iragana Fault. F—thin Paterson Formation unconformably overlying Clutterbuck Beds.

Low, undercut breakaways containing caves commonly develop in fine sandstone and siltstone sequences and are capped by thick nodular ferricretes (e.g. parts of Paterson Formation, Samuel Formation).

Coalescing stony pediments, incised by ephemeral creeks, surround the mesas, buttes and breakaways. They grade outwards into the surrounding duricrust or aeolian plains. It is these extensive pediments of bare, stony colluvium, that show up as white and grey mottled and striped areas on the airphotos, cut by dark grey ephemeral creeks, that commonly form the most noticeable feature of the subdivision on the black & white airphotos (Fig. 9).

Large ephemeral creeks have developed in front of some breakaways (e.g. Cooper Creek, LENNIS). These creeks deposit sandy fans but they dissipate within a few kilometres of the ranges.

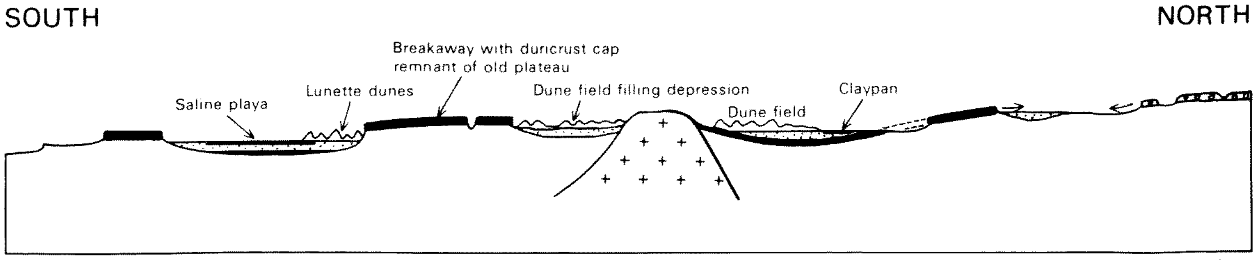
Ranges and hills

Although shown separately on Plate 2 these two subdivisions are described together. They include the major relief features developed on Precambrian basement rocks on either flank of the main sedimentary basin, and isolated monadrocks, such as the Clutterbuck Hills (Fig. 10), within it. The subdivision is most widespread in the northeast of the region, where a series of predominantly easterly trending strike ridges, commonly 50 m above adjacent colluvial flats, have developed on rocks of the Musgrave Block. The major ranges vary from long rounded ridges, through narrow steep-sided escarpments to large irregularly dissected upland areas. Daniels (1974) described and illustrated the physiography of this region in more detail; the distribution of the subdivisions on Plate 2 largely follows his Plate 1.

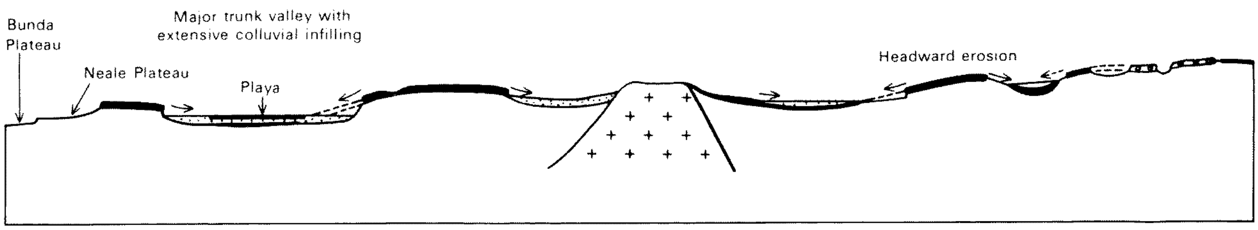
To the west of the Officer Basin area, steep-sided northwesterly trending ranges separated by low hills and rubbly rises occur on the non-grantic rocks of the Yilgarn Block. Mafic rocks produce prominent rounded hills, such as Mts Venn and Cumming; felsic rocks produce low rubbly mounds, such as near Yamarna; while banded iron formation and quartzite form discontinuous, step-sided narrow ridges. Most of the Yilgarn Block, however, consists of granite which weathers identically to the basin sediments, so that mesas and breakaways with siliceous duricrusts rather than ranges and hills are commonly developed. Nevertheless, low, exfoliated domes with prominent tors, which are characteristic of granite terrains, are present in a few areas (e.g. Mount Black), but, owing to their small size and relatively scarcity, cannot be distinguished at the scale of the map. Most of these ranges and hills would probably have stood out above the general level of the Old Plateau during its formation.

Major valleys

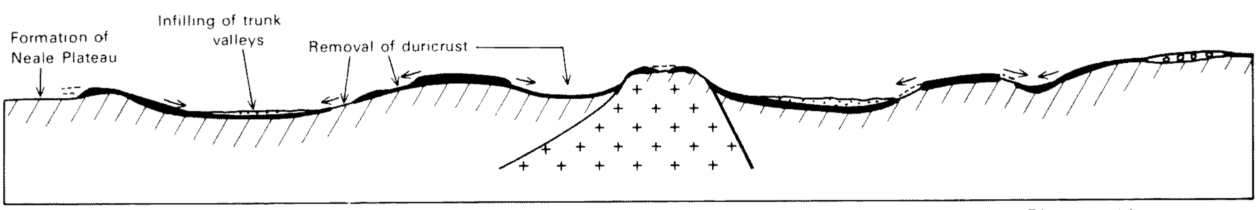
During the Tertiary extensive alluviation occurred in the major depressions within the area, because of the climatic change from humid to semi-arid. Deposition of material led to filling of the trunk valleys in the



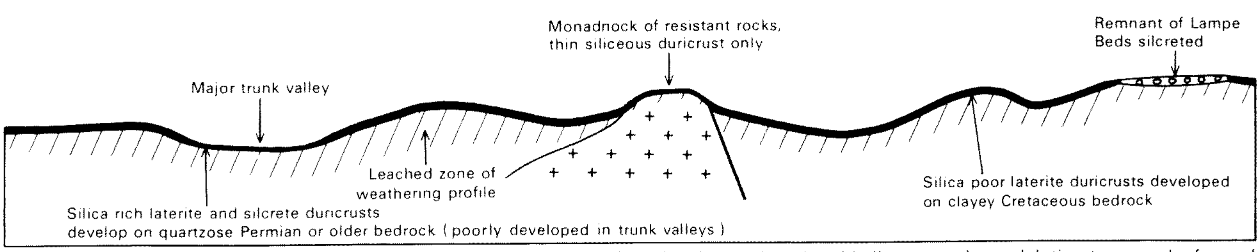
STAGE 5 Late Pleistocene — present: climate mainly arid, dune fields developed and then stablized by vegetation, lunettes formed on edges of playas. Continued headward erosion of mesas by ephemeral creeks with destruction of "Old Plateau". Calcretes replace parts of valley fills.



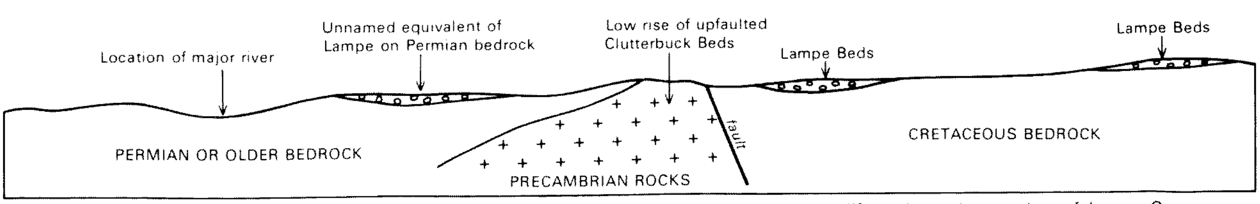
STAGE 4 Late Tertiary — Early Pleistocene: climate arid, lower parts of topography gradually filled up with debris; playas developed. Dissection of "Old Plateau" continued.



STAGE 3 Eocene — Miocene: climate changes from humid to arid. Dissection of "Old Plateau" commences. Rivers unable to transport material so depressions become choked with debris leading to initial playa development. Erosion of Neale Plateau in late Eocene and Bunda Plateau in early Miocene (see stage 4).



STAGE 2 Early Tertiary (Palaeocene ?): laterite and silcrete profiles develop under a humid climate on the undulating topography formed by the palaeodrainage. This peneplain is Jutson's "Old Plateau".



STAGE 1 Late Cretaceous — Early Tertiary: initiation of drainage after emergence, uplift and gentle warping of Lower Cretaceous, Permian and older bedrock. Erosion and minor sedimentation (Lampe Beds) with the start of the formation of a gently undulating land surface.

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Fig. 11. Evolution of the physiography.

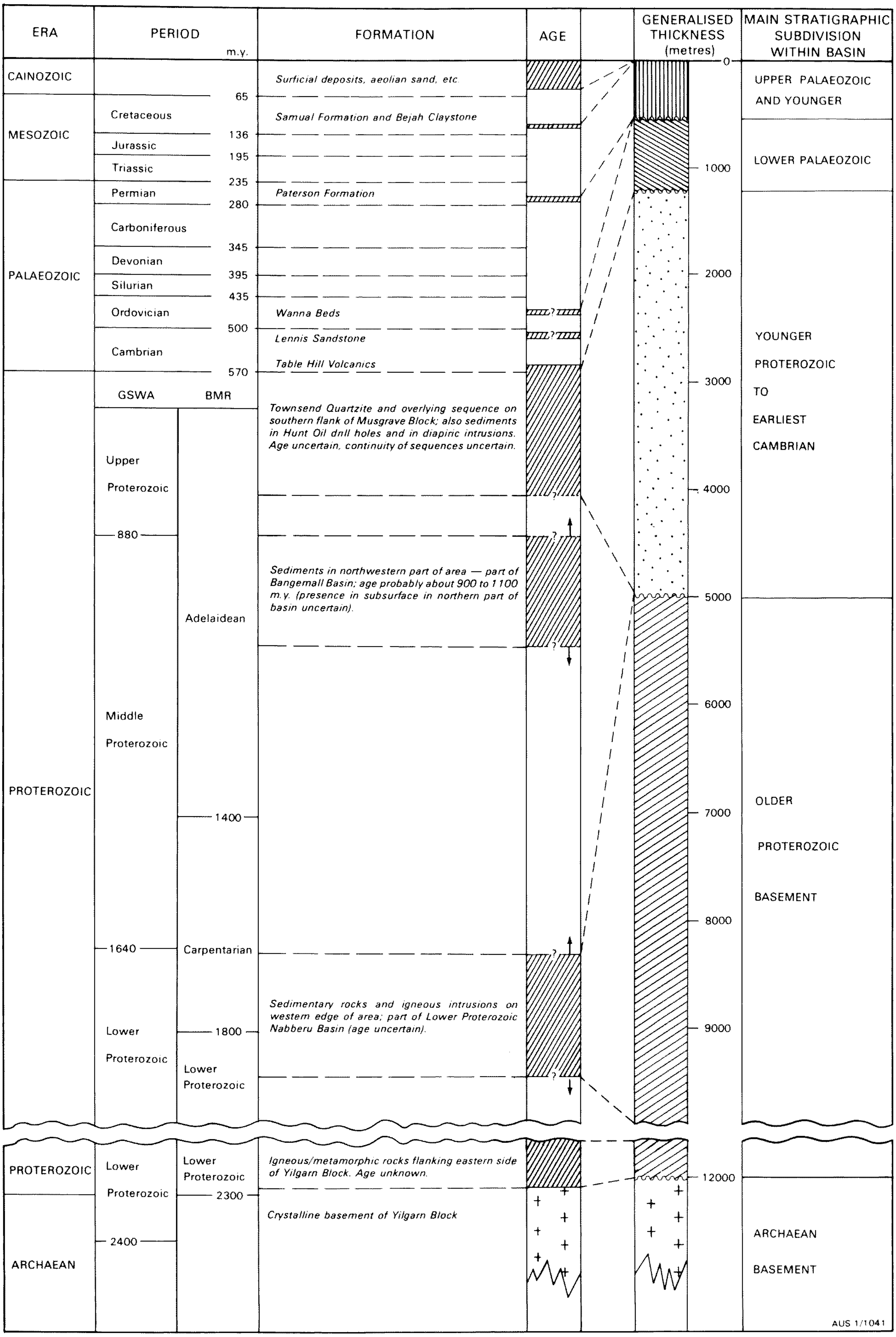


Fig. 12. Composite stratigraphic column, showing thickness and age of the main stratigraphic subdivisions of the basin.

duricrusted plain, and the resulting featureless valley-floors are mapped as major valleys (Plate 2). As they are the lowest parts of the topography, they are moister than average and their clayey soils support a tree savanna vegetation with softer grasses replacing spinifex. In some areas where calcrete has replaced and cemented the alluvium and colluvium, there are low rubbly mounds of stony calcareous earths. These calcreted fills of major valleys commonly contain small karst features, such as sinkholes, solutions cavities and caves, and are characterised by dense stands of mallee. Extensive deposits of calcrete have been separated on the map as *calcrete-floored valleys*.

Playas

This subdivision includes not only the generally large dry or salt lakes (Fig. 7) but also the usually smaller freshwater claypans (Fig. 3). Playas are confined to the lowest parts of the topography on both the regional and local scale and they are the best developed along the axes of the major valleys e.g. Throssell and Disappointment Palaeorivers (Plate 2).

The salt lakes are circular to irregularily shaped, flat and bare surfaces of evaporation and deflation, ranging in size from a few hundred metres to several tens of kilometres across. Some are isolated features: for example, Baker Lake (SW TALBOT); but many are more-or-less connected in long strings: for example, Lake Wells (NW ROBERT). In fact, it was the long series of chains of partly interconnected playas that led Gibson (1909) and Gregory (1914) to suggest that they were the remnants of Miocene rivers.

After heavy rain the lakes may be covered with a few centimetres of water, but for most of the time they are dry. The surfaces of the salt lakes are exceptionally smooth and level and are made up of a thin crust of white halite, capping brine-saturated silt and clay that is rich in authigenic gypsum crystals up to a few centimetres long. Many playas lack vegetation, but others have a low cover of saltbush and samphire which traps aeolian material and builds it up in irregular clumps. Some of the salt lakes, especially those in the southwest, are bordered by breakaways on their western sides and by white gypsiferous dunes (dunettes) of material blown off the lake surface, on their eastern sides. 'Islands' of gypsiferous dunes ranging from several tens to hundreds of metres across are common in the larger salt lakes (Fig. 7).

The claypans are mostly smaller than the saline playas but range up to a few kilometres across. They are commonly circular, and have a hard and bare, sunbaked surface of clay. They originate as deflation hollows which are filled with a thin layer of silt and clay brought in by rare floods. The larger and better developed claypans, such as Lakes Hancock, Cohen, and Gruszka, occur in the north of the area within that part of the basin that has clayey Cretaceous bedrock. In contrast, the playas within areas of Permian or older bedrock are invariably saline.

The fact that the major playas mark the trunk valleys of palaeodrainage systems rules out an origin as tectonic downwarps or as essentially random erosion features as argued by Jutson (1934), except possibly for an isolated major playa such as Baker Lake. The only plausible interpretation of their origin is that when the climate changed from humid to arid the tributary streams supplied more sediment than could be removed from the trunk valleys, thus locally damming them. After initial formation, a playa would be self-perpetuating as its bare surface is relatively susceptible to wind erosion, and although some lateral shifting of playas has occurred, the major playas have remained essentially stationary with the progressive infilling of the palaeodrainage valleys during the Late Cainozoic.

Sand plains and dunes

Aeolian sand has been deposited in sheets or blown into dunes throughout almost the entire area, and in general, becomes more abundant southwards. In the Gibson Desert, thick deposits of aeolian sand are restricted to the larger valleys, where they commonly replace alluvial and colluvial valleys as the most distinctive landforms. In VERNON and WANNA over 80 percent of the surface is covered by dunes; only the highest parts of the duricrusted plain are sand free (Fig. 6); so that, in the southeast of the region, the landscape everywhere is dominated by sand dunes to the virtual exclusion of other physiographic elements. The preponderance of sand dunes and plains in the south and their scarcity in the north is directly related to geology. The sand-rich Paterson Formation forms the bedrock throughout much of the Great Victoria Desert. It is commonly capped by a siliceous duricrust, the breakdown of this and the overlying 'A' horizon releases large quantities of sand. Bedrock throughout the Gibson Desert is the Cretaceous Samuel Formation and Bejah Claystone which consist largely of claystone and siltstone. The ferruginous duricrusts developed on these clayey rocks do not contain as much quartz sand as those developed further south, and the development of dunes in the north is therefore inhibited by this lack of a suitable source of sand.

Wilson (1972) divided aeolian bed forms into three mutually exclusive groups characterised by wavelength and height: ripples, dunes and draas (large bed forms with wavelengths between 500 m and 5km). All three groups are present in this area. Sand sheets with ripples and small dunes are common in the southwest, especially on areas with Archaean bedrock, which probably reflects coarser grainsizes in this region (cf. Wilson, 1973, p. 104). Dunes are present throughout most of the region and rare draas (e.g. Streich Mound, CUNDEELEE) are known, even though Wilson (1972, 1973) suggested that there are no draas in Australian deserts.

The sand dunes are mostly longtiudinal (Fig. 6) and range from a few metres high and several tens of metres long to ridges up to 30 m high and many tens of kilometres long. An average dune would be between 5 to 10 m high and several hundred metres to two kilometres long. Veevers & Wells (1961) subdivided the dunes in the Great Sandy Desert (north of this area) into five categories. Crowe (1975), simplified their classification and reduced it to three types which he argued represent different stages in evolution. Crowe's threefold classification can be extended south into the Gibson and Great Victoria Deserts without significant modification. The three types are: *simple longitudinal* dunes, mainly straight with single crests; *chain longitudinal* dunes, mainly straight, but with linked multiple crests; and *net-like* dunes with complex branching crests, commonly net-like in plan. In the Great Sandy Desert the dunes increase in complexity towards the depressions where the sand is thicker. The major depressions in the Great Victoria and Gibson Deserts have acted as sand traps, and here also a trend from simple to complex dunes towards many of the trunk valleys is evident.

The simple longitudinal dunes are formed under the influence of helicoidal wind vortices in the lower bounding layer of the atmosphere (Folk, 1971a, b). Crowe (1975) argued that the increasing complexity of dunes towards the sand-filled depressions reflects greater supply of sand, which led to coalescence of growing dunes and the concommittant breakdown of simple helicoidal flow.

Dune orientation ranges from predominantly northwest in the Gibson Desert to west in the Great Victoria Desert (Plate 2). Daniels (1969) produced a simplified plan of the sand ridges of part of the Gibson and Great Victoria Deserts that covers all but the southern extremity of the area described in this Bulletin. He divided the area into a northern part with regular northwest-trending dunes produced by the southeast Trade winds, and a southern part with west-trending dunes produced by westerly winds. A corridor along the 26° parallel and separating the two areas is characterised by a more complex dune pattern. He interpreted this as being produced by an interplay between the two dominant wind systems, the seasonal shifts in the latitudes of these winds, and the effect of the ranges in the Warburton area. Daniels also noted sixteen zones where the regional pattern were interrupted. Most delineate major trunk valleys where the sand is thicker. The age of the dunes is uncertain, but, following Bowler (1976), the preserved dune patterns are thought to have formed from 25 000 to 13 000 years B.P., i.e. the maximum age of the latest glacial phase of the Pleistocene. Although earlier aeolian deposition during previous arid glacial phases may have taken place, no clear evidence of any such deposits was recognised in the Officer Basin area.

Comparison between aerial photographs taken in 1960 and 1970 indicates that the vegetation cover has effectively stabilised the dunes. Modification to dune shape occurs only in burnt-out areas where the vegetation has not re-established.

Neale Plateau

The name Neale Plateau was introduced by Van de Graaff & others (1977) for a sand-blanketed, gently undulating plateau, 300 to 325 m high, that occupies the southern third of NEALE and parts of adjacent MINIGWAL and PLUMRIDGE. It is bounded to the north and east by a gently curved scarp, consisting of lateritised Paterson Formation, which is up to about 25 m high (Plate 2), and is truncated by the Carlisle Plain to the south. The smoothly curved shape of the scarp and the flatness of the plateau suggests a marine origin for both features. Bunting & others (1974) traced the Neale Plateau to the southwest to an area near Ponton Creek, where there is an isolated occurrence of Upper Eocene marine sediments, indicating that the Neale Plateau and scarp probably formed during the Late Eocene transgression.

Carlisle Plain

The Bunda Plateau (or Nullarbor Plain) is the physiographic unit that equates with the Eucla Basin. Lowry (1970) divided the Bunda Plateau into six physiographic regions characterised by different vegetation, soil, topography, climate and geological history; one of those, the Carlisle Plain, forms the southern extremity of the area described in this Bulletin (Plate 2). The Carlisle Plain is a flat area of sandy soil with sparse myall and mulga scrub and studded with enclosed depressions up to 30 m deep and 4 km across containing claypans. The northern margin of the Carlisle Plain is characterised by numerous saline playas, which, with the exception of Jubilee Lake, are concentrated near the discharge points of the major palaeodrainages.

Development of the physiography

The evolution of the landscape, from the time when the early Cretaceous sea retreated from the area to the present, is summarised below. For simplicity, the complex sequence of events has been condensed into five stages on a schematic north-south section through the area (Fig. 11).

SUMMARY OF STRATIGRAPHY

Cainozoic superficial units up to about 30 m thick blanket about ninety percent of the area. Outcrops in the remainder consist mainly of flat-lying, thin Mesozoic and Palaeozoic units, with sparse outcrops of Proterozoic rocks. The lack of outcrop together with a lack of both reliable age dating and subsurface information renders our knowledge of the stratigraphy very fragmentary. However, the pre-Cainozoic sediments of the area can be conveniently grouped into four subdivisions each of which has certain unifying features; these subdivisions are—Upper Palaeozoic and younger rocks; Lower Palaeozoic rocks; younger Proterozoic to earliest Cambrian rocks; and older Proterozoic rocks (Fig. 12). A synthesis of the stratigraphy follows and the most important features are summarised in the stratigraphic table (Table 1). An interpretation of the Pre-Cainozoic geology forms an inset to the 1:1 million geological map (Plate 1). A detailed unit-by-unit description of the stratigraphy follows the summary and forms the bulk of this chapter.

Older Proterozoic

The 1972 BMR seismic survey delineated a trough containing up to about 12 000 m of layered rocks between the Yilgarn Block and the Musgrave Block. The lower part of this sequence consists of older Proterozoic rocks, which do not crop out. They are thickest in the southwest and thin towards the northeast as the overlying younger Proterozoic thickens (Section EF on Plate 1). This older Proterozoic is characterised by high seismic velocities (5900-6500 m/s) and the layering in it is markedly discordant to that of the overlying younger Proterozoic (Harrison's & Zadoroznyj's regional unconformity 'B' is the discontinuity between them). The older Proterozoic forms part of the basement to the Officer Basin.

Shallow drilling by BHP in the central part of THROSSELL in 1979 indicated that in this area the layered older Proterozoic sequence comprises igneous and metamorphic rocks. To the northeast of THROSSELL the older Proterozoic may include lateral equiva-

TABLE 1. SUMMARY OF PRE-CAINOZOIC STRATIGRAPHY (excluding Eucla Basin Units)

Age	*Rock unit and symbol (1:1 000 000 map)*	*Lithology*	*Maximum thickness & comments*	*Stratigraphic relations*	*Environment of deposition*
CRETACEOUS OR TERTIARY	Lampe Beds KT 1	Cream, white and grey; poorly sorted very coarse grained sandstone and pebble conglomerate; minor siltstone and claystone; bedding indistinct, mainly thick; rare channels	About 5 m, but only usually 2-3 m preserved on tops of mesas.	Discomformable on Bejah Claystone, Samuel Formation and other fine-grained units.	Terrestrial, dominantly fluvial but probably also colluvial
				disconformity*	
EARLY CREATACEOUS	Bejah Claystone Kle	White, pink, orange and purple radiolarian claystone; light weight and porous minor siltstone and fine sandstone; bedding indistinct, ranges from laminated to thick, but is commonly destroyed by bioturbation; usually silicified to form porcelanite in upper parts of most outcrops.	About 35 m, gradually thins towards the edges of the area.	Conformable on Samuel Formation; disconformable on Paterson Formation in ROBERT.	Marine, open shelf
	Samuel Formation Kls	Variegated siltstone, sandstone and claystone; thin-bedded to laminated dominantly moderate to well sorted; micaceous, carbonaceous and glauconitic beds; planar cross-lamination and bioturbation common; rare fining upward and coarsening upward cycles.	About 80 m, thins gradually towards edges of the area.	Discomformable on Paterson Formation.	Marine, shallow water; some intervals of very shallow water indicated by palynomorphs.
				disconformity	
EARLY PERMIAN	Paterson Formation Plp	Wide range of lithologies; during mapping most outcrops were referred to one or more of three facies: 1. fluvial: mainly poorly sorted coarse pebbly sandstone with trough cross-stratification. 2. lacustrine: mainly fine sandstone to claystone, commonly parallel-bedded, varves, dropstones and slumping. 3. glacial: diamictite; rapid variation in lithology is diagnostic of formation; burrows, bioturbation and ferruginisation common.	About 450 m, but deposited on very irregular disconformity surface therefore thickness variable; thins towards edges of the area.	Discomformable on all older units.	Non-marine; complex mixture of fluvial, glacial and lacustrine environments.
				disconformity and angular unconformity	
EARLY CAMBRIAN TO EARLY PERMIAN	Wanna Beds Pzw	Predominantly white-weathering fine to medium sandstones with minor claystone interbeds; mainly medium to very thick bedded; large scale cross-stratification in WANNA; rare burrows.	140 m in Birksgate 1 thinner to west; only known in southern part of area.	Conformably overlies Lennis Sandstone; transitional contact in BMR Neale 1.	Mainly shallow marine; subtidal wit with megaripples in MASON and WANNA
	Lennis Sandstone Pzl	Predominantly red-brown, fine to medium sandstone, commonly micaceous; micaceous siltstone interbeds present in LENNIS; medium to thick bedded, commonly cross-stratified; brecciated and slumped beds in NE LENNIS.	425 m in Lennis 1; elsewhere thinner than about 300 m.	Disconformable on Table Hill Volcanics in Yowalga 2.	Mainly shallow marine in WAIGEN but possibly also fluvial in NE LENNIS and COOPER.
				disconformity	
EARLY CAMBRIAN	Table Hill Volcanics Ꞓlt	Purple and grey, finely crystalline flow-banded amygdaloidal and vesicular tholeiitic basalt; minor sandstone.	117 m in Hunt Yowalga 2.	Unconformable on folded Proterozoic rocks in Yowalga 2 and on seismic sections.	Subaerial extrusion with intervals of ?fluvial sandstone deposition; in NE ROBERT Pahoehoe type of lavas present
				angular unconformity	
LATEST PROTEROZOIC TO EARLIEST CAMBRIAN	Babbagoola Beds Ᵽob	Shale, siltstone, sandstone, anhydrite and gypsum.	More than 203 m	Unconformably overlain by Table Hill Volcanics, base not seen	Marine, evaporitic
	Woolnough Beds Ᵽoo	Gypsum, stromatolitic dolomite, siltstone, chert, and sandstone.	More than about 400 m	Unconforambly overlain by Paterson Formation	Shallow marine, evaporitic

Distribution	Remarks	Regional correlations: Canning	Regional correlations: Officer Basin (WA/SA)	Regional correlations: Elsewhere
NW of area	Everywhere intensely silicified to form a silcrete; also called 'billy'; poorly developed hexagonal jointing; lithologically identical to silicified conglomeratic Paterson Formation.	Lampe Beds		Silcrete, billy
NW of area	Lithology remarkably uniform over wide area; contains well preserved *Aptian* pelecypods, gastropods, radiolaria, one cephalopod, trails and burrows; intense silicification may be due to high content of radiolaria; flat-lying except at diapirs.	Bejah Claystone	Cadna-owie Fm	Lower part of Madura Formation Windalia Radiolarite
Northern to central part of area	Aptian pelecypods and gastropods, trails and burrows (Rhizocorallium); well preserved Aptian palynomorphs; flat-lying except at diapirs, and major faults.	Samuel Formation and Anketell Formation	Cadna-owie Fm	Loongana Formation
Throughout most of the area	Well-preserved Lower Permian palynomorphs; flat-lying except at diapirs, and major faults.	Paterson Formation and part of Grant Group		
Most of the area south of 27°S	Commonly contains clay matrix which is probably formed by decomposition of feldspar; apparently unfossiliferous; flat-lying.		Possibly equivalent to part of the Cambro-Ordovician sequence, Trainor Hill Sandstone, Mt Chandler Sandstone, Indulkana Shale, Blue Hills Sandstone and Cartic Beds, of NE part of Basin in S. Australia.	
Central and NE part of the area	Possibly originally calcareous in part; red colour characteristic of formation; apparently unfossiliferous; flat-lying, regional dips (from seismic) less than 0.1°.		Possibly equivalent to part of the Cambro-Ordovician sequence, Trainor Hill Sandstone, Mt Chandler Sandstone, Indulkana Shale, Blue Hills Sandstone and Cartic Beds, of NE part of Basin in S. Australia.	
WNW zone through north central part of the area	At the four localities where a full section is known the formation consists of two flows separated by a thin sandstone unit. Dated at 575 ± 40 m.y. (Compston, 1974).	none known	Kulyong Volcanics (by continuity of outcrop over State border).	Antrim Plateau Volcanics of NT
(equivalent to Petermann Ranges Orogeny)				
in the subsurface of central part of area	Intersected only in BMR Throssell 1 and Hunt Yowalga 2; no known surface outcrops; contains microfossils of earliest Cambrian age.		Possibly equivalent to Woolnough Beds	Equivalent to Observatory Hill Beds in SA
In NW of area	Only known from the Woolnough Hills, Madley diapirs; contains late Proterozoic to early Cambrian stromatolites.		Possibly equivalent to Babbagoola Beds	

TABLE 1. SUMMARY OF PRE-CAINOZOIC STRATIGRAPHY (excluding Eucla Basin Units)

Age	*Rock unit and symbol (1:1 000 000 map)*	*Lithology*	*Maximum thickness & comments*	*Stratigraphic relations*	*Environment of deposition*
UPPER PROTEROZOIC	Wirrildar Beds Ꝑow	Khaki, micaceous sandstone, siltstone; thin dolomite, arkose and feldspathic sandstone.	Not measured in WA; more than 2700 m in SA	Overlies Punkerri Beds, contact not seen	?Marine
	Clutterbuck Beds Ꝑac	Well sorted, cross-bedded feldspathic arenite; siltstone and conglomerate interbeds.	More than 4500 m	Contacts not exposed; unconformably overlain by Paterson Formation	Marine
	Punkerri Beds Ꝑok	Pink quartzite and feldspathic sandstone, siltstone, minor conglomerate.	Not measured in WA; more than 1260 m in SA	Disconformable on Wright Hill Beds in SA	Marine, shallow water
	Turkey Hill Beds Ꝑot	Sandstone, siltstone and claystone, minor tillite.	At least several hundred metres	contact not exposed, but probably overlies granite basement, unconformably overlain by Paterson Formation	?Marine glacial
	Lupton Beds Ꝑog	Tillite, cross-bedded sandstone minor siltstone.	Minimum of about 250 m, but top not seen.	Conformable on Lefroy Beds in Ainslie Gorge	Transitional from marine through glacial to fluvial
	Pinyinna Beds Ꝑay	Dolomite, limestone and siltstone?	—	—	—
	Madley Beds Ꝑon	Evaporites (gypsum, anhydrite, minor halite).	Unknown, ?hundreds of metres	Diapirically intrudes Proterozoic and Phanerozoic rocks	Evaporitic
	Browne Beds Ꝑoe	Dolomitic limestone, calcareous shale, anhydrite, gypsum and halite.	More than 254 m	Diapirically intrudes Proterozoic and Phanerozoic rocks	Evaporitic
	Neale Beds Ꝑod	Stromatolitic and oolitic dolomite, limestone, minor quartzite; carbonates extensively silcreted with partial preservation of textures.	Few tens to hundreds of metres	Contacts not seen, unconformably overlain by Paterson Formation	Shallow marine (part intertidal)
	Ilma Beds Ꝑoi	Stromatolitic and oolitic dolomite and limestone, chert, sandstone.	Unknown, few tens of metres exposed	Contacts not seen, unconformably overlain by Colville Sandstone	Shallow marine (part intertidal)
	Wright Hill Beds Ꝑop	Siltstone, sandstone, quartzite minor black oolitic chert.	Unknown in WA; 3400 m in SA	Not known in WA	Marine?
	Lefroy Beds Ꝑof	Laminated to thin bedded siltstone, and fine sandstone, minor claystone.	About 250 m at type locality	Conformable on Townsend Quartzite, transitional contact	Probably marine
	Robert Beds Ꝑor	Quartz arenite and feldspathic sandstone, minor chert.	Few tens of metres	Contacts not exposed, unconformably overlain by Paterson Formation	Marine

Distribution	Remarks	Regional correlations: Canning	Regional correlations: Officer Basin (WA/SA)	Regional correlations: Elsewhere
Part of southwesterly dipping sequence exposed along south margin of Musgrave Block on TALBOT and COOPER and in adjacent SA	Only seen as float in WA and NE corner of WAIGEN		Possibly equivalent to Clutterbuck Beds on COBB	Maybe in part equivalent to Babbagoola Beds
North-east of area; part of western Amadeus Basin sequence.	Forms a steeply dipping inlier in west of COBB.		Punkerri Beds and/or Wirrildar Beds; Wells (1963) suggests correlation with Carnegie Fm, Ellis Sst. or Maurice Fm.	
	Crops out only in NE corner of WAIGEN and central TALBOT; in SA contains Ediacara-type fauna which is considered to be latest Precambrian in age.		May be equivalent to Clutterbuck Beds on COBB	Ediacara fauna of Pound Quartzite (Adelaide Geosyncline).
Southwestern margin	Steeply dipping outcrops; restricted to a small area in NE RASON; new stratigraphic unit.		Equated with Lefroy and Lupton Beds	
Part of southwesterly dipping sequence exposed along south margin of Musgrave Block on TALBOT and COOPER.	Very poorly exposed, only measured in two sections, upper contact not seen, formerly called 'Proterozoic Glacial rocks' (Daniels, 1974).		Chambers Bluff Tillite Sturtian age, in EVERARD.	Bolla Bollana Fm (Umberatana Group) Adelaide Geosyncline.
Eastern COBB only; part of western Amadeus Basin sequence.	Photo-interpretation only.			Equivalent to Bitter Springs Fm in Amadeus Basin.
Only known in core of Woolnough and Madley Diapirs.	Intrusive core of northern diapirs; contains blocks of dolomite which contain microfossils similar to those seen in Bitter Springs Formation; new stratigraphic unit.		Possibly equivalent to Browne Beds	Equivalent to Bitter Springs Fm in Amadeus Basin.
In the subsurface of central part of area.	Intersected only in two drillholes, Hunt Browne 1 & 2 which were drilled on a diapir in SE corner of BROWNE; no known surface outcrops, but presence in subsurface inferred on seismic records.		Possibly equivalent to Madley Beds	Equivalent to Bitter Springs Fm in Amadeus Basin.
Southern margin.	Gently dipping outcrops restricted to central NEALE; contains *Baicalia* cf. *B. burra* (Preiss, 1975); probably younger than about 1000 m.y.; new stratigraphic unit.		Correlated with Ilma Beds	
Southeast margin	Poorly exposed, restricted to NW of MASON, contains *Baicalia* cf. *B. burra* (Preiss, 1975).		Correlated with Neale Beds	
Part of southwesterly dipping sequence exposed along south margin of Musgrave Block on TALBOT and COOPER in adjacent SA.	Only mapped on COOPER, very poorly exposed; contacts not seen.			
	Very poorly outcropping formerly called Brown Range Siltstone (Daniels, 1974).		May equate with upper part of Pindyin Beds or part of Wright Hill Beds	
Central west	Forms discontinuous outcrops along eastern border of ROBERT; flat-lying to steeply dipping; new stratigraphic unit.		Correlated with Townsend Quartzite	

TABLE 1. SUMMARY OF PRE-CAINOZOIC STRATIGRAPHY (excluding Eucla Basin Units)

Age	*Rock unit and symbol (1:1 000 000 map)*	*Lithology*	*Maximum thickness & comments*	*Stratigraphic relations*	*Environment of deposition*
UPPER PROTEROZOIC	Townsend Quartzite Ꞓos	Dominantly medium to coarse, well sorted quartz to feldspathic arenite; minor conglomerate and shale beds; commonly cross-stratified.	370 m	Conformable or disconformable on Musgrave Block near Warburton; angular unconformity further east.	Marine, mainly littoral to sublittoral possibly some deltaic

BASEMENT
SW Margin — igneous and metamorphic rocks of the Yilgarn Block
NE Margin — igneous, metamorphic and sedimentary rocks of the Musgrave Block
W Margin — sedimentary rocks of the Nabberu and Bangemall Basins

* Footnote: The term *angular unconformity* is used where there is an angular relationship visible (at outcrop or slightly larger scale e.g. few tens of metres) between the beds overlying and underlying the erosional surface. The term disconformity is used where there is a substantial break in the geological record, but where the overlying and underlying beds are essentially parallel (over a distance more than a few tens of metres).

lents to the mainly shallow marine sediments that crop out in the Nabberu and Bangemall Basins. Further northeast (TALBOT) this sequence may include buried equivalents of the older part of the Musgrave Block.

Younger Proterozoic to earliest Cambrian

A younger Proterozoic to earliest Cambrian sequence up to about 6000 m thick with seismic velocities between 3300 and 5700 m/s overlies the older Proterozoic in the central, northern, and eastern parts of the area (Sections A-D and E-F, Plate 1) and forms the deeper fill of the Officer Basin. It includes most of the Proterozoic formations shown in Table 1. Units belonging to this sequence have been penetrated in drillholes Hunt Oil Yowalga 2, Browne 1 & 2, and BMR Throssell 1, where they are represented by the Babbagoola Beds and Browne Beds. Near the margins of the area it can also be correlated with exposed Proterozoic sequences. There is good correspondence between the geophysical and regional geological data along the southern margin of the Musgrave Block (TALBOT), and here the younger Proterozoic to earliest Cambrian comprises the Townsend Quartzite and overlying sequence (Lefroy Beds up to and including the Wirrildar Beds) which is up to a few thousand metres thick. Along the BMR seismic line between Warburton and Cosmo Newberry the younger Proterozoic is thickest beneath SE YOWALGA; from here it thins gradually southwest to nothing along the eastern edge of ROBERT, where the Robert Beds (laterally equivalent to the Townsend Quartzite) appear to unconformably overlie the basal parts of the Nabberu Group. It is also possible that the Bangemall Group could form part of this younger Proterozoic fill in the north of the area (HERBERT, BROWNE).

Lower Palaeozoic

Three flat-lying Lower Palaeozoic formations with a combined thickness of about 600 m, crop out in the southeastern part of the area, and underlie the central part of the area. The oldest unit, the Table Hill Volcanics, is a widespread tholeiitic basalt about 100 m thick, of Early Cambrian age (575 ± 40 m.y.), which crops out intermittently, and can be traced seismically, throughout most of the area southeast of 26°S. It also crops out in South Australia in the west of BIRKSGATE where it is known as the Kulyong Volcanics. The Table Hill Volcanics are a lithologically and seismically distinct, isochronic marker horizon which has been critical in elucidating the structural history of the area. It is separated from the underlying younger Proterozoic to earliest Cambrian rocks by an angular unconformity and therefore approximately delineates the Phanerozoic sequence of the basin from the underlying Proterozoic sequence.

The basalts are disconformably overlain by shallow-marine to marginal-marine clastics (Lennis Sandstone and Wanna Beds) with a combined maximum thickness of about 500 m.

Upper Palaeozoic and younger rocks

A complex suite of fluvial, glacial, and lacustrine deposits of Sakmarian age (Paterson Formation) and fossiliferous Aptian shallow marine rocks (Samuel Formation and Bejah Claystone) up to about 600 m thick form a flat-lying cover, to the basin. The Paterson Formation is the most widespread: remnants of it are preserved in all parts of the area mapped. The Samuel Formation and Bejah Claystone are thickest and best preserved in the northwest of the area. These rocks are continuous and identical with similar units in the southern Canning Basin. Remnants of a widespread, but thin, Late Cretaceous to Early Cainozoic fluvial/soil unit called the Lampe Beds are preserved on tops of mesas in the Gibson Desert.

Lateritic and siliceous profiles developed on these rocks during the Cainozoic, and aeolian, alluvial, and colluvial materials have been deposited in depressions usually less than about 30 m deep.

DETAILED STRATIGRAPHY

BASEMENT

Archaean and Proterozoic igneous and metamorphic rocks form the crystalline basement to the Officer Basin, W.A., at its southwest and northeast margins, and sedimentary rocks with intrusions belonging to the Nabberu and Bangemall Basins form basement in the northwest. The crystalline basement is briefly discussed below under the following structural subdivisions: Yilgarn Block, Albany-Fraser Province, and Musgrave Block. The sedimentary rocks of the Nabberu and Bangemall

Distribution	Remarks	Regional correlations: Canning	Regional correlations: Officer Basin (WA/SA)	Regional correlations: Elsewhere
Base of southwesterly dipping sequence exposed along south margin of Musgrave Block on TALBOT and COOPER and in adjacent SA.			Laterally continuous with Pindyin Beds	Heavitree Quartzite /Dean Quartzite of Amadeus Basin

Basins are collectively referred to, and described under, the older Proterozoic. The extent of the crystalline basement blocks and adjacent basins below the Officer Basin is largely unknown, but generalised relationships are shown on Plate 1, and discussed in the chapter on Structure.

Yilgarn Block

The eastern part of the Archaean Yilgarn Block extends into THROSSELL, RASON, MINIGWAL, and CUNDEELEE (Plate 1), and except for CUNDEELEE the north-northwest trends of the eastern Yilgarn Block are clearly defined by greenstone belts and aeromagnetic features on a regional scale, and by foliation and bedding at outcrop scale.

Granitic and migmatitic rocks predominate, their compositions ranging from tonalite through granodiorite and adamellite to granite (*Agg* & *Agm**). Mafic and ultramafic extrusive and intrusive rocks (*Am*) form the bulk of the greenstone belts. They have been subjected to varying degrees of regional metamorphism, up to the almandine-amphibolite facies, and are also partly contact-metamorphosed near granitic intrusions. The remainder of the greenstone belts consist of felsic intrusive and extrusive rocks, and sediments (*Av*). Like the mafic parts of the greenstone belts, the felsic rocks have been subjected to regional metamorphism up to the almandine-amphibolite facies; they are schistose in part.

Albany-Fraser Province

The Yilgarn Block is bounded to the southeast by a Proterozoic mobile belt, the Albany-Fraser Province. The boundary between the two which follows approximately a line from Cundeelee Mission to Bobbies Point (Plate 1), is marked by a sharp increase in metamorphic grade from greenschist and amphibolite facies in the Archaean rocks to a high-grade terrain in the Albany-Fraser Province. Along this boundary the northeast-trending structures of the mobile belt truncate the north-northwest trends of the Yilgarn Block. Bunting & others (1976) divided the Province into four main subdivisions, which have been adopted in this Bulletin: (1) a transition zone, in which the Archaean rocks of the adjacent Yilgarn Block have been reworked and intruded by Proterozoic granite (units *AꝐfg*, *AꝐfq* & *AꝐfm*); (2) a western gneiss and granite zone of Proterozoic igneous rocks (units *Ꝑfd*, *Ꝑfs*, *Ꝑfg*); (3) the Fraser Complex, of granulite facies mafic rocks (*Ꝑfx*); and (4) an eastern gneiss and granite zone, which is largely unexposed (*Ꝑfn*).

Rb-Sr age determinations (Bunting & others, 1976) indicate that the thick sequence of sediments that accumulated on the southeast flank of the Yilgarn Block during the early Proterozoic was deformed, metamorphosed and intruded together with part of the Yilgarn Block, at various times between 1900 and 1590 m.y. ago. A later orogenic event at about 1300 m.y. metamorphosed the rocks in the Fraser Range area to granulite facies.

Musgrave Block

The Musgrave Block is considered by Daniels (1974) to comprise the area in central Australia bounded by the Officer, Canning, Amadeus, and Eromanga Basins where Precambrian igneous, metamorphic and minor sedimentary rocks are exposed.

The older basement rocks of the Musgrave Block consist of a variety of igneous and high-grade metamorphic rocks, mostly granulite, migmatite, and granite. Two main varieties of granulite are distinguished: a poorly banded orthoclase-bearing type (*Ꝑmn*), and a well-banded microline-bearing type (*Ꝑmh*). The former was probably an orthogneiss and may represent an older basement. Overlying this is the well-banded granulite, which probably represents an arenaceous deposited on the older basement. The granulite complex is considered to be the end-product of a period of high-pressure, high-temperature metamorphism, acid igneous injections, and intense deformation. The western part of this basement complex consists of migmatised granulite intruded by a large volume of adamellitic material.

The basement complex is overlain by a sedimentary and volcanic sequence, which has been divided into the Pussy Cat (*Ꝑmp*), Tollu (*Ꝑmt*), Cassidy (*Ꝑmc*) and Mission Groups (*Ꝑmm*). Daniels (1974) grouped these units with the Townsend Quartzite and Lefroy Beds in the Bentley Supergroup.

The Pussy Cat and Tollu Groups are probably lateral equivalents. The Pussy Cat Group (*Ꝑmp*) occurs in TALBOT and consists of a thick sequence of basic lava, tuff, sediments, and a major ignimbrite unit. The Tollu Group (*Ꝑmt*) crops out in COOPER and consists of a thick sequence of mixed volcanic rocks with sandstone and conglomerate at the base.

The Pussy Cat Group is unconformably overlain by the Cassidy Group (*Ꝑmc*), a sequence of alternating acid and basic volcanics with minor associated sediments. The Mission Group (*Ꝑmm*) conformably overlies the Cassidy Group, and consists of 4000 m of conglomerate, basalt, dolomite, shale, and quartzite.

Partly coeval with these thick sedimentary and volcanic sequences are three cauldron areas; the Scamp, Skirmish Hill, and Palgrave cauldrons (*Ꝑmv*). All three display an association of acid volcanics and intrusive granitic material (*Ꝑmg*) with only minor basic igneous rocks. Intrusion of the Giles Complex (*Ꝑmo*)

*Rock symbols refer to legend on Plate 1 took place partly before and partly simultaneously with the formation of the cauldrons; it is a layered basic intrusive complex, confined mainly to the northern part of COOPER.

Older Proterozoic

A sequence of mainly sedimentary rocks of older Proterozoic age (Preiss & others, 1975) is discontinuously exposed in the west of ROBERT, HERBERT, and MADLEY. In ROBERT the sequence includes quartzose, arkosic, and glauconitic sandstone interbedded with fine-grained sandstone and siltstone, stromatolitic dolomite, chert, and ironstone (Ᵽ*n*) which forms gently north-dipping strike ridges as far east as Breaden Bluff. This sequence is an eastern extension of the Lower Proterozoic Nabberu Basin (Hall & Goode, 1975). At Mount Elizabeth and near the Ida Range the sequence is intruded by a dolerite sill (Ᵽ*d*) dated at 1050 m.y. (Compston, 1974).

In the northwest of HERBERT and west of MADLEY, discontinuous strike ridges and monadnocks of gently folded quartz arenite with siltstone and conglomerate beds (Ᵽ*l*) and stromatolitic dolomite, micaceous siltstone, quartzite and feldspathic sandstone (Ᵽ*b*) were mapped. Work by GSWA (Williams & others, 1976), shows that the arenites (Ᵽ*l*) are part of a Lower Proterozoic unit called the Yeneena Group, and the carbonates and clastics (Ᵽ*b*) are probably part of the Skates Hills Formation and McFadden Sandstone, which are part of the overlying Middle Proterozoic Bangemall Group.

OFFICER BASIN UNITS

Introduction

The Officer Basin, W.A. sequence consists of a thick pile of slightly folded and faulted Upper Proterozoic sediments, unconformably overlain and almost completely obscured by a cover of virtually flat-lying Palaeozoic & Mesozoic rocks. The only area where a stratigraphic sequence of Proterozoic units can be established is along the southern margin of the Musgrave Block, near Warburton. In that region a basal sandstone, the Townsend Quartzite, is overlain by the shallow-marine Lefroy and Wright Hill Beds, and these in turn are overlain by the glacial Lupton Beds. The upper part of the sequence, about 4500 m thick, is very poorly exposed, but includes the Punkerri Beds and Wirrildar Beds. This sequence probably constitutes the major part of the younger Proterozoic basin fill in the Warburton area, where geophysical data indicate that the basin is 5 km to 6 km deep. On the cross-sections on Plate 1 the Proterozoic part of the Officer Basin, W.A. is referred to as Younger Proterozoic in areas where the constituent formations are not known. The age of the various units can only be inferred from a few radiometric dates and from lithological correlations with similar sequences in the Officer Basin in South Australia (Krieg, 1972) and the Amadeus Basin (Wells & others, 1970).

The other exposed or drilled Proterozoic units in the basin cannot confidently be related to the Warburton sequences or to each other, but their possible relationships and correlations outside their area are included in Table 1 and shown in the legend of Plate 1.

Age of the Warburton area sequence

The age of the Proterozoic sequence in the Warburton area is discussed in terms of the succession as a whole, as a separate discussion of the age of individual formations would be highly repetitive.

The Townsend Quarzite which forms the basal part of the sequence, unconformably overlies the Tollu Group, which was dated by Compston & Nesbitt (1967) at 1060 ± 140 m.y. This maximum age for the Townsend Quartzite means that the basal part of the Officer Basin sequence could conceivably correlate with part of the Bangemall Group, which has been dated at about 1100 m.y. (e.g. Gee & others, 1976). However, a correlation of the Bangemall Group with

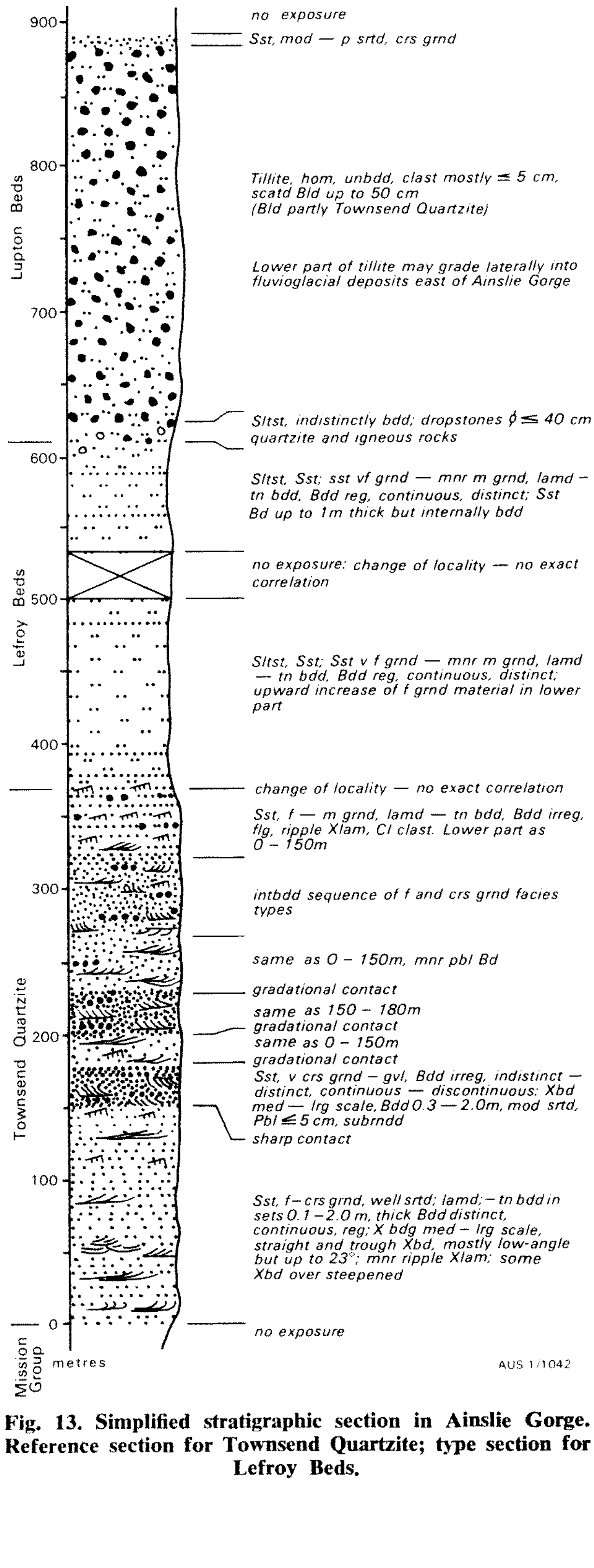


Fig. 13. Simplified stratigraphic section in Ainslie Gorge. Reference section for Townsend Quartzite; type section for Lefroy Beds.

the volcanic sequence of the Musgrave Block as implied by Gee & others (1976) is considered to be more likely on the available geochronological and geological evidence.

The top of the sequence is formed by the Wirrildar Beds and these are unconformably overlain by the Table Hill Volcanics, which were dated at 575 ± 40 m.y. by Compston (1974). Therefore, the Warburton area sequence is in the range Middle Proterozoic to early Palaeozoic.

PROTEROZOIC TO EARLIEST CAMBRIAN

The sequence Townsend Quartzite, Lefroy Beds, Wright Hill Beds, and Lupton Beds, together with their South Australian equivalents, comprises a basal sandstone, a middle interval with finer grained siliciclastics, and an upper unit consisting of glacial deposits. On the northern side of the Musgrave Block, the Heavitree Quartzite, Bitter Springs Formation, Areyonga Formation, and their lateral equivalents form a similar sequence. An important difference between the two sequences is that south of the Musgrave Block the middle interval contains little exposed carbonate, whereas carbonate predominates in the Bitter Springs Formation. The broad similarity of the two successions, and especially the presence of glacial deposits, which are good lithostratigraphic and time-stratigraphic marker beds (Preiss & others, 1978), strongly suggests a correlation. The Bitter Springs Formation is presently believed to be about 950 m.y. old (Schopf & Blacic, 1971; Preiss, 1972), although the possible age range is from abut 750 m.y. to 1075 m.y. (cf. Preiss & others, 1978 p. 50). The overlying glacial deposits of the Areyonga Formation and their probable correlatives, the Lupton Beds in WA and Chambers Bluff Tillite in SA, were probably deposited during the Sturtian glaciation, which occurred about 750 m.y. ago (Rankama, 1973). An alternative interpretation that these glacial deposits were formed during the Marinoan glaciation, about 670 m.y. ago, is considered less likely. However, both interpretations are possible, as the Ediacara-type fauna, which is present in the Punkerri Beds (which overlie the Lupton Beds), has a probable age range of 600-700 m.y. (Glaessner, 1972).

Townsend Quartzite

The name Townsend Quartzite was proposed by Sofoulis (1962) for the quartzitic sandstone sequence which forms the Brown Range and Townsend Ridges. Jackson (1966a), Daniels (1971, 1974) and Lowry & others (1972) all referred to this unit as Townsend Quartzite. Daniels (1971, 1974) evidently considered a section 5.6 km east of the Lilian Creek gorge as the type section.

We measured a reference section for the Townsend Quartzite in good outcrops in Ainslie Gorge (38 km W of the type section). To the south of this gorge the contact with the overlying Lefroy Beds is exposed and a fairly complete section through the Townsend Quartzite, Lefroy Beds and Lupton Beds is present in this area (Fig. 13).

Lithology

The Townsend Quartzite consists of cross-bedded, well-sorted, medium-grained sandstone and very coarse-grained, pebbly sandstone, of quartz arenitic to feldspathic arenitic composition. Because of intense cementation by silica, porosity has been virtually obliterated, and the sandstones are mostly quartzites.

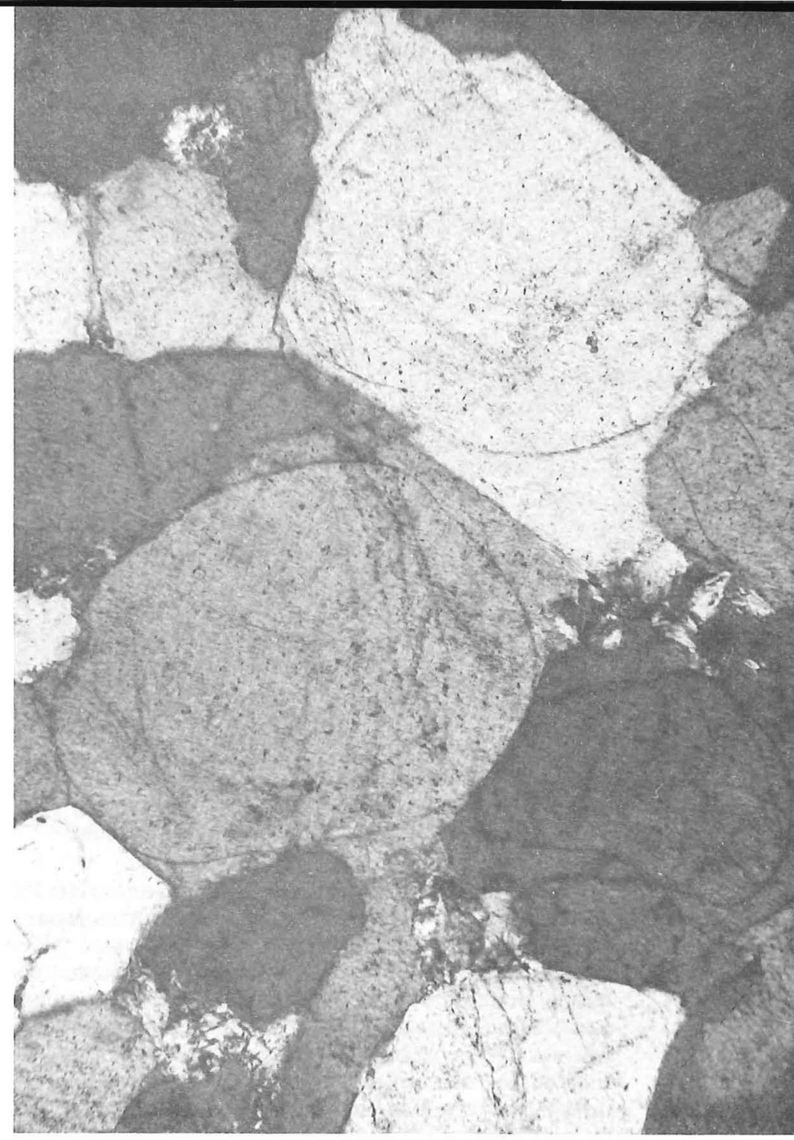


Fig. 14. Dust rings on overgrown, well-rounded quartz grains in fine-grained facies of the Townsend Quartzite; partly crossed nicols (GSWA thin section 29037).

The following description of the type section, near the Lilian Creek Gorge, has been amended from Farbridge's (*in* Daniels, 1971, 1974), who distinguished a lower and upper unit. The lower unit, 85 m thick, consists of partly flaggy, thin to thick-bedded sandstone. The sandstone is slightly micaceous and in places also feldspathic. A few pebble and shale flake beds are present. Planar cross-bedding is common, but minor trough cross-bedding is also present. The cross-sets are up to 50 cm thick. Ripple marks, desiccation cracks and frondescent markings occur on bedding planes and a possible mud volcano was noted.

The upper unit is 171 m thick, and consists of coarse to very coarse-grained sandstone with conglomeratic intercalations and minor shale flake beds. The clasts are predominantly quartzitic and are up to 18 cm in diameter. Bedding ranges from thick to very thick, and large-scale cross-beding is common, with individual cross-sets up to 1.5 m thick. The foresets are planar and some are graded. Some cross-sets are partly overturned, owing to slumping.

The distinction of a lower and an upper unit is also valid in the Ainslie Gorge reference section, but here the lower unit is thicker and the upper unit contains numerous intercalations of evenly bedded, well-sorted, fine-grained sandstone.

Fig. 15. Distinctive regular bedding in fine-grained facies of the Townsend Quartzite at TALBOT 9.

The lower part of the Ainslie Gorge section (0-153 m) consists of well-sorted, fine to coarse-grained, quartzitic quartz arenite, with the different sized grains mostly separated into distinct laminae or beds. The quartz arenite is very mature and only a few chert and schist fragments are present in addition to accessories such as zircon (no feldspar was observed; cf. Farbridge's description). The presence of dust rings in the quartz grains shows that the constituent grains were well rounded before cementation (Fig. 14). Little or no pressure solution of the rounded grains appears to have taken place prior to cementation to a quartzite but minor sericitisation has taken place since cementation.

Bedding is mostly distinct, regular and continuous (Fig. 15). Bedding thickness ranges from laminated to very thick bedded. The thicker beds are mostly internally laminated or cross-stratified or both. The cross-sets grade laterally into evenly bedded or laminated strata. Trough cross-bedding with foresets that flatten tangentially in sets several tens of centimetres to a metre thick is common. In a few places the upper part of the cross-sets is overturned and deformed through slumping. Allen & Banks (1972) argue that this type of recumbently folded cross-bedding is caused by downstream current drag on recently deposited sands which were liquified due to events such as earthquakes. Planar cross-sets up to 2 m thick with steeply dipping foresets (23°) are also present, but most of the planar cross-sets are of the low-angle type (< 10°) and are no thicker than a few tens of centimetres.

Above about 100 m bedding in this lower unit becomes irregular due to the presence of small-scale cross-stratification, which on bedding planes can be seen to be related to small-scale ripples.

The upper, coarser-grained unit of the Ainslie Gorge section (Fig. 13) overlies the lower part with a fairly sharp contact. This unit consists largely of a moderately sorted, very coarse-grained to conglomeratic quartz arenite to ?feldspathic arenite. Subangular to rounded pebbles (< 5 cm) occur scattered or concentrated in streaks. The pebbles are subangular to rounded and consist of quartz and quartzite. The proportion of lithic fragments here is slightly higher than in the lower part of the sequence. Dust rings again indicate that most of the quartz grains were well rounded before the onset of cementation which produced the present quartzitic texture. Apart from the poorer sorting, there seems to be little compositional difference between the two facies.

Bedding is fairly distinct, but irregular and somewhat discontinuous. Bedding thickness ranges from about 0.1 to 2 m, but is mostly 0.3 to 1.5 m. The beds are mostly internally cross-bedded on a medium to large-scale. Size grading along the foresets is common. Cross-bedding includes both planar and trough-type; foresets are either flat and steep or flatten tangentially.

Interbedded with these coarser grained arenites are well-sorted, finer grained, quartz arenites of the same facies as those in the lower part of the sequence. Contacts between the two facies are mostly gradational. In the upper 60 m of the formation the proportion of fine-grained, thinly bedded sandstone increases upward. Bedding in these finer-grained intervals is mostly somewhat irregular, because of ubiquitous ripples, some of which are symmetrical. Clay pellet horizons and desiccation-crack like features, which form an irregular pattern, are also common in this interval.

Stratigraphic relations

In the Warburton area the Townsend Quartzite appears to overlie the Mission Group conformably as the strike and dip of the two units are parallel. As the contact is not exposed, however, the possibility of a disconformable or paraformable relationship cannot be excluded (Daniels, 1974, p. 77, incorrectly states the contact to be unconformable). Further east the Townsend Quartzite progressively oversteps older units, and is separated from these by an important unconformity.

Daniels (1974, p. 82) included the Townsend Quartzite, of which he considered the Lefroy Beds to form part, in the Bentley Supergroup. We consider the Townsend Quartzite, however, as part of the Officer Basin sequence, as it is the basal sandstone of 4-5 km of essentially conformable Proterozoic sediments which unconformably overlie the Musgrave Block.

The formation is conformably overlain in the Brown Range by the Lefroy Beds. The contact between the two units is gradational.

The Townsend Quartzite is the lateral equivalent of the lower sandstone part of the Pindyin Beds in BIRKSGATE (Major, 1973b). The Pindyin Beds consist of a lower sandstone and quartzite unit, which unconformably overlies granites of the Musgrave Block, and an upper unit of shale and minor siltstone which from the description appears to be similar to the Lefroy Beds.

Because of similarities in overall stratigraphic sequences we tentatively correlate the Townsend Quartzite with the Heavitree Quartzite of the Amadeus Basin. This also implies a correlation with the Dean Quartzite in SCOTT and RAWLINSON as Wells & others (1970) correlate the Dean and Heavitree Quartzites. Daniels (1974), however, does not accept this correlation.

Distribution and thickness

In addition to the outcrop belt along the southern edge of the Musgrave Block, the Townsend Quartzite may also occur on the western side of the basin (eastern ROBERT) where a similar quartzitic sandstone, the Robert Beds, crops out. If this correlation is correct the combined unit could be present in the subsurface over a large area between the Musgrave Block and the eastern side of ROBERT and THROSSELL.

The Townsend Quartzite is about 370 m thick at Ainslie Gorge. Further east near Lilian Creek Gorge the unit is about 110 m thick, and at the type section it is 256 m thick (Daniels, 1974). It is not clear from the descriptions of the latter two sections whether these are true thicknesses or whether the sections measured were incomplete. The sandstone unit of the Pindyin Beds (SA) which correlates with the Townsend Quartzite is about 200 m thick.

Age

The age of the Townsend Quartzite is in the range 1060 ± 140 m.y. to about 750 m.y. These are the respective ages of the underlying Tollu Group and overlying Lupton Beds.

Environment of deposition

The compositionally and texturally mature character of the Townsend Quartzite indicates slow deposition with prolonged reworking of the sand in a high-energy environment. The good sorting, even bedding, and types of cross-bedding in the lower, fine-grained part of the formation all suggest a sub-littoral to littoral environment of deposition. Apart from the low-angle planar cross-sets, most of the cross-bedding was formed by migrating large-scale ripples. The cross-bedding in the interval 40-60 m in the Ainslie Gorge section probably originated as a channel-fill. The same interpretation of a sub-littoral to littoral environment is given to the finer-grained intervals in the upper, generally coarse-grained part of the formation.

The presence of subrounded pebbles in a matrix of mostly rounded sand grains in the coarse-grained part, indicates a supply of texturally immature material in an environment where mature sediment was already present. Such an influx of coarse-grained, immature material is most likely to take place near a river mouth. As no definite fluviatile deposits were recognised, the coarse-grained facies with its moderate sorting is tentatively interpreted as a deltaic intercalation in a littoral sequence. The finer-grained sandstone intervals in the coarse-grained sequence represent changes in the rate of supply of material at a given locality so that the sediment could be thoroughly reworked.

The Townsend Quartzite is overlain with a gradational contact by the Lefroy Beds, which consist of evenly laminated to thinly bedded claystone, siltstone and fine-grained sandstone. These fine-grained deposits were probably formed in deeper waters than the underlying sandstone, as they represent a low-energy environment. The finer-grained top of the upper part of the Townsend Quarzite is therefore believed to have formed in gradually deepening waters where currents were not strong enough to produce large-scale cross-bedding, but where wave-action still produced abundant ripples.

The features described by Farbridge (*in* Daniels, 1974, p. 82) as dessication cracks are difficult to accept as such. It is unlikely that clean sand would have sufficient cohesion to crack upon loss of water. An alternative interpretation is that these crack-like features are water-escape structures due to syneresis and are comparable to those described by Burne (1970). The presence of a mud volcano mentioned by Farbridge would support this interpretation.

Daniels (1974) interpreted the lower, fine-grained unit as a strandline or nearshore deposit, which corresponds well with the interpretation given here. The upper unit however, was interpreted as having formed in deeper water. This is in contrast with our interpretation where the coarser grained facies is believed to have formed in deltaic and littoral environments.

Robert Beds

The name Robert Beds is here proposed for a sandstone unit which crops out only along the eastern margin of ROBERT and northeast THROSSELL.

Lithology

The unit is well exposed at Breaden Bluff (southeast ROBERT) where it consists of fine to medium-grained well-sorted quartz and feldspathic arenite composed predominantly of sub to well-rounded quartz grains with accessory heavy minerals. It is commonly surface-silicified to a quartzite and weathers white or pale brown. It is distinctly parallel bedded on a thick to very thick scale. At locality ROBERT 24, (21 km north of Breaden Bluff) well-preserved straight-crested, parallel wave ripples are present. Thin beds containing nodules of chert and shallow oval depressions up to about 70 mm in size (clay clast impressions) are also present.

Stratigraphic relations

Little is known of the stratigraphic relations as neither contacts have been seen. The Robert Beds sporadically crop out in a north-trending belt in sand plain along the eastern margin of ROBERT. Bedding in the individual outcrops dips from steeply south, through gently southeast, to gently northeast, suggesting that the formation is folded. The north-trending outcrop belt and the predominant easterly dips distinguish this Proterozoic sandstone unit from those cropping out in the rest of ROBERT, in which bedding always trends east-west and dips gently north. The Robert Beds are therefore interpreted as unconformably overlying these Older Proterozoic, Nabberu Basin sediments. When projected south along strike from the area of Breaden Bluff, the Robert Beds cut the line of the BMR 1972 seismic survey (approximately equivalent to cross-section EF, Plate 1) exactly where the Younger Proterozoic fill of the Officer Basin wedges out. It is likely, that the Robert Beds are the basal unit of this Younger Proterozoic and are therefore laterally equivalent to the Townsend Quarzite, which shows a similar relationship to the seismic results and basement in TALBOT. It is possible however that the Robert Beds equate with one of the sandstone units mapped in the Bangemall Basin (Williams & others, 1976), 150 km to the northwest.

At Breaden Bluff the Robert Beds are unconformably overlain by fluvioglacial Paterson Formation.

Distribution and thickness

The Robert Beds crop out only along the eastern margin of ROBERT and northeast THROSSELL, but if the correlation with the Townsend Quartzite is correct they will probably be extensive in the subsurface, at the base of Younger Proterozoic sequence, to the east of here. At Breaden Bluff about 60 m of sandstone was measured, but neither the top nor bottom is exposed.

Age

There is no direct evidence of age, but they are post-Nabberu (?Lower Proterozoic) and pre-Permian. Correlation with the Townsend Quartzite implies they are Middle Proterozoic.

Environment of deposition

The good sorting, distinctive bedding and wave ripples indicate a shallow-water marine environment.

Lefroy Beds

The name Lefroy Beds was proposed by Lowry & others (1972) for the siltstone-sandstone sequence that overlies the Townsend Quartzite in the Brown Range. This unit had previously informally been referred to by Jackson (1966a) as the Brown Range Siltstone, and he described it as grey to maroon, shaly, very argillaceous, micaceous siltstone. Daniels (1974) included this sequence in the Townsend Quartzite. The type section of the Lefroy Beds is located near Ainslie Gorge (26°14'S, 126°38'E), where the unit is about 250 m thick (Fig. 13).

Lithology

The Lefroy Beds consist of white to purple-weathering, distinctly, evenly, and continuously bedded siltstone or very fine-grained sandstone with minor claystone. Bedding thickness is mostly laminated to thin-bedded, with intercalations of medium to thick-bedded, quartzitic sandstone. Bedding is indistinct in the upper part of the unit. The thicker sandstone intercalations are identical in appearance to the fine-grained parts of the Townsend Quartzite. At TALBOT 21 the contact between Townsend Quartzite and Lefroy Beds is well exposed and a transition zone a few metres thick is present, in which siltstone and fine-grained sandstone are interbedded. In the upper part of the formation a few isolated cobbles and boulders up to 0.4 m across are present in indistinctly bedded siltstone, which appears to grade upwards into fine-grained tillite of the Lupton Beds.

Stratigraphic relations

The Lefroy Beds conformably overlie the Townsend Quartzite with a transitional contact, and at the type locality the unit is in turn conformably overlain by the Lupton Beds. However, the presence in the Lupton Beds of clasts probably derived from the Townsend Quartzite indicates that towards the hinterland the conformable contact with the Lupton Beds graded into an unconformity.

In BIRKSGATE (SA) the upper part of the Pindyin Beds is described by Major (1973b) as a white-weathering, laminated to thinly bedded shale with minor siltstone, chert, and dolomite. As the lower part of the Pindyin Beds correlates with the Townsend Quartzite, the shaly unit is thought to be the lateral equivalent of the Lefroy Beds. The upper part of the Lefroy Beds probably correlates with the Wright Hill Beds as mapped in South Australia.

Distribution and thickness

The Lefroy Beds have been recognised in outcrop only along the southwest side of the Brown Range, but the correlation with the upper part of the Pindyin Beds in South Australia, supports their continuity along the southern margin of the Musgrave Block. At the type locality the unit is about 250 m thick. If the Wright Hill Beds in South Australia, which are over 3400 m thick, do correlate with the Lefroy Beds, it implies considerable thickening of this interval eastwards.

Age

Like the underlying Townsend Quartzite, the Lefroy Beds have an age in the range 1060 ± 140 m.y. to about 750 m.y.

Environment of deposition

The inferred great lateral extent of the formation, the regularity and continuity of bedding, and the fine-grained nature of the sediments, indicate deposition below wave base in a marine environment. The isolated clasts in the uppermost part of the sequence are interpreted as dropstones from melting ice, and precursors of the overlying tillite.

Wright Hill Beds

The name Wright Hill Beds was proposed by Major (1973c) for a sequence of siltstone, quartzite and minor oolitic chert which occurs in the BIRKSGATE and LINDSAY areas in South Australia. The type section is at approximately 27°35'S, 131°E. Although it is likely that the unit continues into Western Australia and possibly crops out on COOPER, it has not been examined by us.

Lithology

In the type section the exposed parts of the formation consist of medium to coarse-grained feldspathic sandstone and quartzite, ?limestone, oolitic and brecciated chert, and minor siltstone.

Stratigraphic relations

In South Australia the Wright Hill Beds are underlain by the Pindyin Beds and overlain by the Punkerri Beds, but exposure is so poor that the nature of the contacts cannot be established. It is thus possible that the shale member of the Pindyin Beds is in fact the lower part of the Wright Hill Beds. The Punkerri Beds are believed to overlie the Wright Hill Beds disconformably, as they contain pebbles of oolitic chert from the upper part of the latter unit. Similarly, the Chambers Bluff Tillite, in EVERARD in the eastern part of the Officer Basin, contains erratics of oolitic chert, indicating that an erosion surface separates it from the Wright Hill Beds. As the Chambers Bluff Tillite probably correlates with the glacial Lupton Beds, the inference is that the Wright Hill Beds correspond to part of the Lefroy Beds as developed in the Warburton area.

Distribution and thickness

In the type area in South Australia, the Wright Hill Beds are at least 3400 m thick. Their thickness in Western Australia is unknown, but airphoto-interpretation in the Skirmish Hill area suggests that they may be about 2000 m thick in this area. If their correlation with the Lefroy Beds is correct, they must pinch out and grade into the Lefroy Beds between here and the Ainslie Gorge section.

Age

The age of the Wright Hill Beds like that of the underlying two formations is in the range 1060 ± 140 m.y. to about 750 m.y.

Environment of deposition

The Wright Hill Beds formed in a shallow marine environment.

Ilma Beds

The Ilma Beds are a very poorly exposed, folded sequence of sandy oolite with dolomite and chert that crop out in the northwest of MASON. Lowry (1970) nominated a type locality and gave a description of the unit to which the reader is referred for details. A stromatolite collected by Lowry and identified by A. E. Cockbain as *Cryptozoon australicum* Howchin, (in Lowry, 1970) has been re-examined and identified as *Baicalia* cf. *B. burra* (Preiss, 1975). This stromatolite also occurs in the Neale Beds (central NEALE) and the two units are correlated. Preiss (1977, Table I), in a paper on the biostratigraphic potential of Precambrian stromatolites, suggested a stratigraphic correlation between the Ilma and Neale Beds and the Bitter Springs Formation. On the poor regional information available, it is possible that the Ilma and Neale Beds are the counterparts of the Lefroy Beds, which which crop out along the northeast margin of the Officer Basin (TALBOT & COOPER areas). Although there is a very little structural information in the NEALE, VERNON and MASON areas, extrapolation of seismic and other geophysical results from surrounding areas suggests that the Proterozoic of this southern area could in fact be equivalent to that in the TALBOT and COOPER areas (see section GH on Plate 1).

Neale Beds

The name Neale Beds is here proposed for a gently dipping sequence of dolomite with minor limestone, are correlated with the Bitter Springs Formation, and chert, and quartzite that is exposed in the general area around 28°15′S, 125°15′E (central NEALE). Outcrops are poor and consist mostly of rubbly slopes covered with fragments of silicified bedrock.

Lithology

In a small collapsed cave at NEALE 28, the sequence consists of dololutite and minor limestone with distinct, irregular to nodular bedding on a thin to medium scale, grading upwards into a less well-exposed alternation of dololutite and dolorudite (oolitic to intraclastic). Stromatolites of various types are plentiful in the fine-grained parts of this interval, and they form laterally extensive biostromal layers. Nodular chert concretions are common. Most other outcrops consist of intensely silicified material, silcrete, in which original features are locally well preserved.

At NEALE 29, quartzitic sandstone and silicified dolomite are poorly exposed. The sandstone is a well-sorted, medium to coarse-grained quartz arenite. The presence of some dust rings indicates that the quartz grains were originally well rounded.

Stratigraphic relations

Lithological similarities, position within the basin, and the presence of *Baicalia cf. B. burra* indicate that these sediments are equivalent to the Ilma Beds. The sequence is unconformably overlain by the Paterson Formation.

Distribution and thickness

The Neale Beds are restricted to central NEALE. Without any subsurface information in the surrounding area, it is impossible to estimate their lateral extent. Though there is some minor but irregular folding around NEALE 28, the sequence as a whole is only very gently dipping ($< 5°$) and from a few tens to a few hundred of metres thick. Correlation with the Ilma Beds implies that the Neale Beds may be present in the subsurface in VERNON and MASON i.e., near the assumed southern margin of the Officer Basin.

Age

Upper Proterozoic—see discussion under Ilma Beds.

Environment of deposition

The combination of oolitic dolurudites, intraclastic, intraformational conglomerates, and stromatolitic biostromes suggests a shallow marine environment of deposition in partly agitated conditions. The presence of compositionally and texturally mature quartz arenite indicates fairly stable conditions in which prolonged reworking of sand removed all unstable components. The specimen of *Baicalia cf. B. burra* from NEALE 28, is characterised by broken columns, indicating penecontemporaneous erosion and reworking in situ under high energy conditions.

Browne Beds

The name Browne Evaporites was proposed by Jackson (1966b) for a sequence of evaporites intersected in two drill holes in southeast BROWNE. Peers & Trendall (1968) published the name, but without adequate definition, and, as the unit had not been found on the surface or intersected in any other drill holes, Lowry & others (1972) modified the name to Browne Beds.

Lithology

The Browne Beds consist of brecciated and bedded dolomite, limestone, calcareous shale, anhydrite, gypsum, and halite. The following description is based solely on that in Jackson (1966b), which was based on four cores from Hunt Oil Browne 1, and two cores from Hunt Oil Browne 2:

> 'Interbedded dolomitic limestone, calcareous shale, anhydrite and salt. The limestones are light grey to brown, hard, fine-grained with poor to well-developed vuggy and fracture porosity. Abundant clear to pink calcite and dolomite in the vugs and fractures suggest partial secondary crystallization. The shales are soft to firm, waxy to earthy, and contain occasional anhydrite inclusions. The anhydrite, gypsum and salt occur as thin beds or as secondary fracture filling. It (sic) is hard to soft, white to pink, and opaque to translucent. The cores from both holes show that the entire section is brecciated and highly contorted'.

Lithological logs of Browne 1 and 2 are given in microfiche Appendix 1.

Distribution and thickness

The unit has been identified only in the two BROWNE drill holes, (17 km apart), both of which were spudded over diapiric structures located by geophysical surveys. In Browne 1 they were intersected between 132.59 and 386.79 m. They are therefore at least 254 m thick. In Browne 2 they were intersected between 262.13 and 292.61 m; that is, they are at least 30.5 m thick. Both of these figures should be treated with caution as it is impossible to tell how the diapirism has affected the attitude of the beds. No exposures of correlatable evaporites are known in the general area, but diapiric intrusions containing evaporites have been mapped in the Woolnough Hills and Madley diapirs, about 260 km to the northwest in WARRI. If these two occurrences of evaporites are from the same unit, it implies a widespread subsurface distribution of the Browne Beds in the northern half of the Officer Basin.

Stratigraphic relations

The original stratigraphic position of the Browne Beds in the Officer Basin sequence is unknown, since

Browne 1 and 2 were drilled on diapiric structures and the evaporites have been displaced vertically upwards. In both wells the Browne Beds are unconformably overlain by the Permian Paterson Formation. Seismic work that preceded the drilling of Browne 1 and 2 indicates that the Browne Beds have penetrated upwards from below the Lower Cambrian Table Hill Volcanics into the Phanerozoic sequence. Although the overlying Mesozoic has been folded and faulted, the evaporitic core has not reached the surface. Jackson (1976) reinterpreted the seismic results and suggested that the evaporites have originated from beds at least 4000 m deep. Tentative correlations between Hunt Oil seismic lines in southeast BROWNE and northeast YOWALGA indicate that although the Browne Beds originate from stratigraphically below the Babbagoola Beds, there does not appear to be any major break in this younger Proterozoic sequence. If the diapirs in BROWNE and WARRI are equivalent, then the Browne Beds would equate with the Madley Beds.

Age

Other than the above described stratigraphic relationships, which would indicate a Precambrian age, there is no direct information on the age of the Browne Beds. However, Kemp (1976) examined core material from both holes for microfossils to enable a comparison with the Babbagoola Beds to be made. She found an abundance of organic material from a limestone, shale and gypsum interval from core 3 in Browne 1 (256-259 m) and from the bottom of Browne 2. None of the material recovered is as well organised as the microfossils from the Babbagoola Beds in Yowalga 2. The fauna is therefore probably older, thus supporting the interpretations from the seismic results. In the Amadeus Basin, thick evaporites associated with diapiric intrusions occur in the Bitter Springs Formation, and a lithological correlation between the two is possible.

Environment of deposition

Evaporitic.

Pinyinna Beds

Following the completion of mapping, several small interdunal areas of folded and dipping rocks were photo-interpreted in the eastern part of COBB (Plate 1) and were assigned to undivided Proterozoic. These outcrops have not been visited by members of the BMR/GSWA party, but A.C.M. Laing of Alliance Oil (personal communication) visited the outcrops in 1971 and considers them to be equivalent to the Upper Proterozoic Pinyinna Beds, which rest conformably on the Dean Quartzite.

The Pinyinna Beds are a unit of dolomitic limestone, siltstone and shale that crops out in the western part of the Amadeus Basin (Wells & others, 1970). The outcrops are poor, but fine-grained sandstone, siltstone, and minor limestone are present. These outcrops are unconformably overlain by the flat-lying Permian Paterson Formation. By definition, they are the lateral equivalent of the Bitter Springs Formation (Wells & others, 1970); by implication, therefore, they are also equivalent to the Lefroy, Neale, Ilma, and Madley Beds.

Lupton Beds

The name Lupton Beds was proposed by Lowry & others (1972) for a sequence of conglomeratic diamictite and sandstone cropping out south of the Musgrave Block that had been referred to as *Proterozoic glacial rocks* by Daniels (1974). The type section is at the Lupton Hills (central COOPER), where a lower unit of conglomeratic diamictite and an upper unit of interbedded conglomerate, sandstone, and siltstone are present.

Lithology

At the type locality, the poorly exposed lower member of the Lupton Beds consists of unbedded, very poorly sorted pebble to boulder conglomerate. Compositionally, the conglomerate is a lithic wacke. The clasts of quartzite, sandstone, and various types of igneous rocks are up to 0.8 m in diameter. The conglomerate member is overlain by a sequence of fine to medium-grained, mostly well-sorted, medium to thick-bedded, quartz arenitic sandstone with interbeds of siltstone and conglomerate. In the upper part of the sequence, fining-upward cycles up to one metre thick are present. The fining-upward units have sharp bases, some have a basal conglomerate, and in the sandstone-siltstone part of a vertical succession of parallel lamination, decimetre-scale cross-bedding, and centimetre scale cross-lamination are present.

In the Ainslie Gorge area (140 km to the west) quite different rock types occur. In the only exposure of the lower part of the Lupton Beds, there is a gradational sequence from laminated siltstone (Lefroy Beds) to indistinctly bedded siltstone with isolated cobbles and boulders up to 0.4 m in diameter (Fig. 16). This is overlain by a thick sequence of mostly fine-grained diamictite with scattered larger boulders, which are most likely derived from the Townsend Quartzite. At TALBOT 27, approximately 3 km southeast of the Ainslie Gorge section, an intricately folded sequence of diamictite, fine-grained, well-bedded sandstone, and

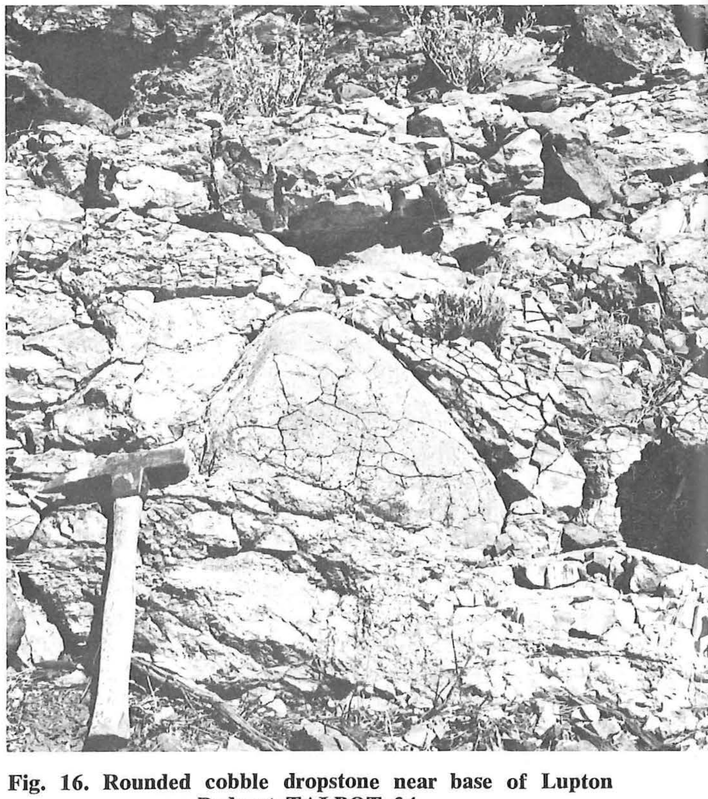


Fig. 16. Rounded cobble dropstone near base of Lupton Beds at TALBOT 24.

coarse-grained, cross-bedded sandstone is exposed. Isolated boulders of granite and quartzite up to 0.9 m in diameter are present in the sandstone part of this sequence.

Daniels (1974) reported the presence of clasts of oolitic chert in outcrops of Lupton Beds near the Hocking Range, but these have not been found elsewhere.

Stratigraphic relations

The Lupton Beds appear to conformably overlie the Lefroy Beds in the Ainslie Gorge section, but elsewhere the contact is not exposed. However, the presence of clasts of Townsend Quartzite and older rocks in the Lupton Beds indicates that though the contact at Ainslie Gorge appears conformable, it grades towards the hinterland into an unconformity. The correlation of the Wright Hill Beds with part of the Lefroy Beds implies that the Lupton Beds also overlie the former unit. The Chambers Bluff Tillite, which correlates with the Sturt Tillite in the Adelaide Geosyncline (Major, 1973c), is a likely lateral equivalent of the Lupton Beds. If the tillite at Miller Soak (part of the Turkey Hill Beds) is considered as Proterozoic it is also a likely lateral equivalent of the Lupton Beds.

The nature of the upper boundary of the Lupton Beds is unknown, as it is nowhere exposed.

Distribution and thickness

Known minimum thicknesses of the Lupton Beds are 240 m at the type section and about 250 m at Ainslie Gorge. These figures are not comparable, as neither base nor top of the formation is exposed at Lupton Hills. Here the measured thickness of the ?tillite member is about 175 m, whereas at Ainslie Gorge tillite constitutes the complete section. Daniels (1974) included in his *Proterozoic glacial rocks* several isolated outcrops including one of quartzitic sandstone near Axe Hill, implying a thickness of about 3700 m for this unit. However, these outcrops are now mapped as Punkerri Beds.

The Lupton Beds have only been mapped on TALBOT and COOPER, but if they do correlate with the Chambers Bluff Tillite and the sequence at Miller Soak, they are much more extensive.

Age

The correlation with the Sturtian Chambers Bluff Tillite implies an age younger than 867 ± 32 m.y. (see discussion in Preiss, 1977).

Environment of deposition

The diamictite and other rock types present in the Ainslie Gorge area are identical in appearance to some of the facies of the Permian Paterson Formation. The latter is interpreted as consisting of glacial, fluvioglacial, and lacustrine deposits, and the reasons for this interpretation are discussed later. Because of their similar rock types, the Lupton Beds are also interpreted as glacial and fluvioglacial deposits.

An important difference between the Paterson Formation and the Lefroy Beds is that the Proterozoic tillite overlies a presumed marine sequence (Lefroy Beds) with a gradational contact, suggesting that part or all of the tillite is also of marine origin. Somewhere in the tillite unit, however, there is a a transition from a marine to a nonmarine environment, as the fining-upward sequences in the upper part of the type section are interpreted as cyclic fluviatile deposits.

Turkey Hill Beds

The name Turkey Hill Beds is here proposed for a locally steeply dipping (up to 65°), sandstone, siltstone, claystone, and minor diamictite sequence, which is best exposed at Miller Soak (28°09′S; 124°15.5′E) in northeast RASON. The sequence was first described by Gower & Boegli (1977).

Lithology

Sandstone and fine-grained diamictite are exposed at Miller Soak. The sandstone is a very fine to fine-grained, moderate to well-sorted quartz arenite with subangular to rounded constituent grains. Ripple-drift cross-lamination, predominantly of the trough type, but also of the straight-crested type, is common. Bedding is on a thin to medium scale and is generally distinct, but the cross-laminations cause it to be irregular and discontinuous in many places. Some of the cross-sets have been deformed by slumping. Graded beds and minor intraformational conglomerate are present. The graded beds have sharp bases and tops, parallel laminations in the lower parts, and ripple-drift cross-laminations in the upper parts.

The diamictite is a fine-grained, sparsely pebbly, massive deposit, containing indistinct lenses of very poorly bedded sand.

The Turkey Hill Beds also crop out 8 km to the northwest of Miller Soak, and near Munjil Soak (north central RASON), where they consist of gently dipping, medium-bedded sandstone, siltstone, and claystone.

Stratigraphic relations

No contacts with older rocks are exposed, except near Munjil Soak, where the Turkey Hill Beds dip at 30° and overlie granitic basement without the contact being exposed.

The steeply dipping sandstone sequence at Miller Soak is in faulted contact with the fine-grained diamictite, which is interpreted as a tillite. Both tillite and steeply dipping sandstone are overlain by flat-lying conglomeratic sandstone of the Paterson Formation. One of the faults separating the two sequences has a visible throw of several metres, but only slightly displaces the overlying fluviatile sandstone of the Paterson Formation. The presence within the tillite of lenses of poorly bedded sandstone and siltstone with dips similar to that of the adjoining sandstone unit indicates that both units form a single sequence. Faulting and tilting of this sequence took place before deposition of the flat-lying outwash deposits of the Paterson Formation. Although the possibility of ice having deformed an originally flat-lying Permian tillite and sandstone sequence cannot be excluded, the close association of the Miller Soak exposures with tilted, lithologically similar sandstone siltstone and shale, strongly indicates that the whole sequence is Proterozoic. This interpretation implies a correlation with the Lefroy Beds and the overlying glacial Lupton Beds near Warburton.

Distribution and thickness

The sandstone sequence has only been mapped in two areas, one between Miller Soak and Stony Point in northeast RASON; the other in north central RASON near Munjil Soak. In the Miller Soak-Stony Point area the unit is at least several hundreds of metres thick, as dips are mostly in the range of 10° to 30° and outcrops are hundreds of metres wide.

Age

No fossils have been found, and the age of these sediments can only be inferred from their general setting. Known Phanerozoic rocks in the Officer Basin are in general flat-lying to very gently tilted; where they are tectonically deformed, the main deformation is post-Early Cretaceous. The steep dips of the Turkey Hill Beds therefore indicate a Precambrian age. The unmetamorphosed character of the unit and the fact that near Point Salvation it appears to nonconformably overlie granitic rocks suggests a correlation with either the older Proterozoic sequence on ROBERT or the Warburton area sequence. The preferred correlation with the Lefroy and Lupton Beds implies a Late Proterozoic age for these sediments.

Environment of deposition

The cross-bedded, well-sorted, fine-grained sandstone was deposited in a moderately agitated, shallow-aquatic environment. The associated sandy to pebbly mudstone is intepreted as a tillite.

Punkerri Beds

The name Punkerri Beds was proposed by Major (1974) for a sequence of red and white sandstone cropping out in the BIRKSGATE and LINDSAY areas of South Australia. The type section is in the Punkerri Hills (eastern BIRKSGATE), where a minimum of 1200 m of sandstone is exposed. Several isolated outcrops of Punkerri Beds have been identified in Western Australia, south of the Musgrave Block.

Lithology

At the type section the Punkerri Beds consist of a lower, purple or red-brown, micaceous flaggy sandstone at least 265 m thick, and an upper white, pink, and red feldspathic sandstone and quartzite with minor siltstone, which is at least 935 m thick (Major, 1974) and which contains an Ediacara-type fauna.

A section through the Punkerri Beds was measured in prominent south-dipping strike ridges at the western end of the Patricia Johnson Hills in the northeast of WAIGEN. Here also a lower unit (about 200 m thick) and an upper unit (400 m thick) can be distinguished. The lower unit is a parallel-bedded reddish brown sandstone, which is fine-grained and well-sorted near the base, but coarser-grained moderately-sorted and conglomeratic towards the top. The coarser-grained part is extensively cross-stratified with both planar and trough sets up to 1 m thick. The upper unit consists of white fine to medium-grained, moderately to well-sorted quartz arenite with beds of fine-grained sandstone and siltsone near the middle of the sequence. The rocks are mainly thin to thick parallel-bedded, but planar cross-stratified sets 20 to 30 cm thick are also present. The upper and lower contacts of the formation were not seen.

Stratigraphic relations

Owing to the lack of outcrop and formation contacts, the stratigraphic relations in Western Australia are not known. Similarly, the contacts are not seen in South Australia, but on regional grounds Major (1974) considers that the Punkerri Beds overlie the Wright Hill Beds and are overlain by the Wirrildar Beds; all three units forming a structurally conformable sequence. Major cites the presence of pebbles of black oolitic chert in a conglomerate in the Punkerri Beds near the type section, supposedly originating from the underlying Wright Hill Beds, as evidence for an erosional break between these two formations.

Distribution and thickness

In Western Australia, the Punkerri Beds have only definitely been identified in the northeast of WAIGEN, where they are at least 600 m thick. It is likely, however, that they crop out farther west and sandstone ridges in central COOPER, outcrops at the Livesey Range, and sandstone at Axe Hill have tentatively been assigned to this formation. The Livesey Range (central west COOPER) consists of about 40 m of white to brown, very fine to medium-grained quartzitic sandstone, which is commonly thin to medium, parallel-bedded and rarely cross-laminated and ripple-marked. A 3-m interval of finely-laminated dolomitic siltstone and fine-grained sandstone is present near the base of the range. Jackson (1966a) reported float of siltstone with black pisolitic chert in the sand plain surrounding the Livesey Range and suggested that the sandstones are underlain by cherty limestones.

According to Johnson (1963) the outcrops southwest of Skirmish Hill (central COOPER) consist of interbedded white ripple-marked quartzite and green shale with oolitic limestone. These outcrops have not been visited, but on regional grounds have been included in the Punkerri Beds. However, it is possible that they could be part of other formations of similar lithology such as the Wright Hill Beds.

At TALBOT 35 (Axe Hill), about 100 m of quartzitic sandstone crops out. It consists of an alternation of medium to thick-bedded, coarse-grained sandstone with some low-angle cross-bedding, and laminated to thin-bedded, fine-grained sandstone. The sandstone is well sorted and ranges in composition from feldspathic arenite to quartz arenite.

Age

Major (1974) correlates the Punkerri Beds with the Pound Quartzite of the Flinders Ranges (southeastern South Australia) on both lithological and palaeontological grounds, thus implying a Marinoan (latest Proterozoic) age.

Environment of deposition

The presence of the Ediacara fauna indicates a shallow marine environment of deposition. Carbonates containing oolites and beds of coarser-grained to conglomeratic trough cross-stratified sandstone probably indicate very shallow water deposition.

Wirrildar Beds

The name Wirrildar Beds was proposed by Major (1973a) for a sequence of feldspathic and micaceous sandstone, siltstone, and dolomite very poorly exposed in BIRKSGATE and western LINDSAY (SA). No outcrops of this formation are known in Western Australia. Major (1968) showed a 4 km-wide belt of Wirrildar Beds adjacent to the State border in the northwest of BIRKSGATE. As this belt continues into Western Australia in an area containing prominent photo-lineaments in low calcrete mounds between sand dunes, a small area of Wirrildar Beds has been included on the geological map (Plate 1). The Wirrildar Beds overlie the Late Proterozoic Punkerri Beds and are unconformably overlain by the Lower Cambrian Kulyong Volcanics (equivalent to the Table Hill Volcanics). Major (1973a) suggested a ?late Precambrian to ?early

Cambrian age, which seems likely if their tentative correlation with the Clutterbuck and Babbagoola Beds is accepted.

Clutterbuck Beds

The name Clutterbuck Beds was proposed by Lowry & others (1972) for a thick sandstone sequence exposed in the Clutterbuck Hills in the west of COBB. Leslie (1961), Wells (1963), Wilson (1964), and Brown & others (1968) all refer to this range as the Iragana Hills. However, the name Clutterbuck Hills is used on the National Mapping 1:250 000 COBB Topographic Map, so Lowry & others (1972) adopted this name and not Iragana. The unit crops out only in the Clutterbuck Hills (Fig. 10) and in small rises about 28 km north-west of the main range. The type section runs from north to south through the main range (from Grid Reference COBB 428944 to 427938 and 422938 to 422934).

Lithology

The Clutterbuck Beds consist of a uniform sequence of fine to coarse-grained, well-sorted, feldspathic sandstone with thin interbeds of very fine-grained sandstone and siltstone. The formation lacks any marked lithological variations and, although it is over 4500 m thick, it has not been subdivided (Fig. 17).

Mineralogically and texturally the sandstones throughout the whole sequence are very similar; they are well sorted and composed predominantly of sub-angular to well-rounded grains of quartz and feldspar. Although grain size ranges from fine to very coarse, rapid variations in grain size over small vertical intervals are rare. Pebble beds and coarse sandstone containing sparse pebbles or strings of pebbles are present in the upper half of the sequence. In contrast, thin beds of very fine-grained sandstone and siltstone, which commonly weather out to form narrow strike vales, are more common in the lower half of the sequence. Near the base of the sequence Wilson (1964) reported thin, pink calcarenite beds with purple shale and siltstone, and Mack & Herrmann (1965) reported a few thin red dolomite beds.

Cross-stratification, ripple-marks, current lineations, and clay pellet horizons are the most common sedimentary structures. Using sedimentary structures, it is possible to separate the Clutterbuck Beds into upper and lower units, and this distinction is well shown on the aerial photographs (Fig. 10). The lower unit (0-3000 m) is distinctly thin to thick-bedded and cross-bedded. Cross-stratification is dominantly large scale and planar, with sets ranging from about 50 cm up to 3 m (Fig. 18). Beta and gamma cross sets (Allen, 1963) interbedded with thick to very thick, parallel-laminated sets produce the distinctive bedding visible on aerial photographs of the lower part of the sequence. In contrast, the upper part of the sequence (3000-4500 m) is much more massive. It is predominantly indistinctly trough cross-bedded, with sets up to about 10 m thick (gamma or pi type of Allen). Scattered quartzite pebbles up to 10 cm across and massive sandstone beds containing bands of well-rounded quartzite pebbles are common. This type of bedding produces the blocky air photo-pattern which is common in the outcrops to the southwest of the main range (Fig. 10). Wells (1963) referred to the lower parts as *Precambrian sediments* and the upper part as *Undifferentiated Palaeozoic sediments*. As we have used mainly sedimentary structures to characterise these two parts,

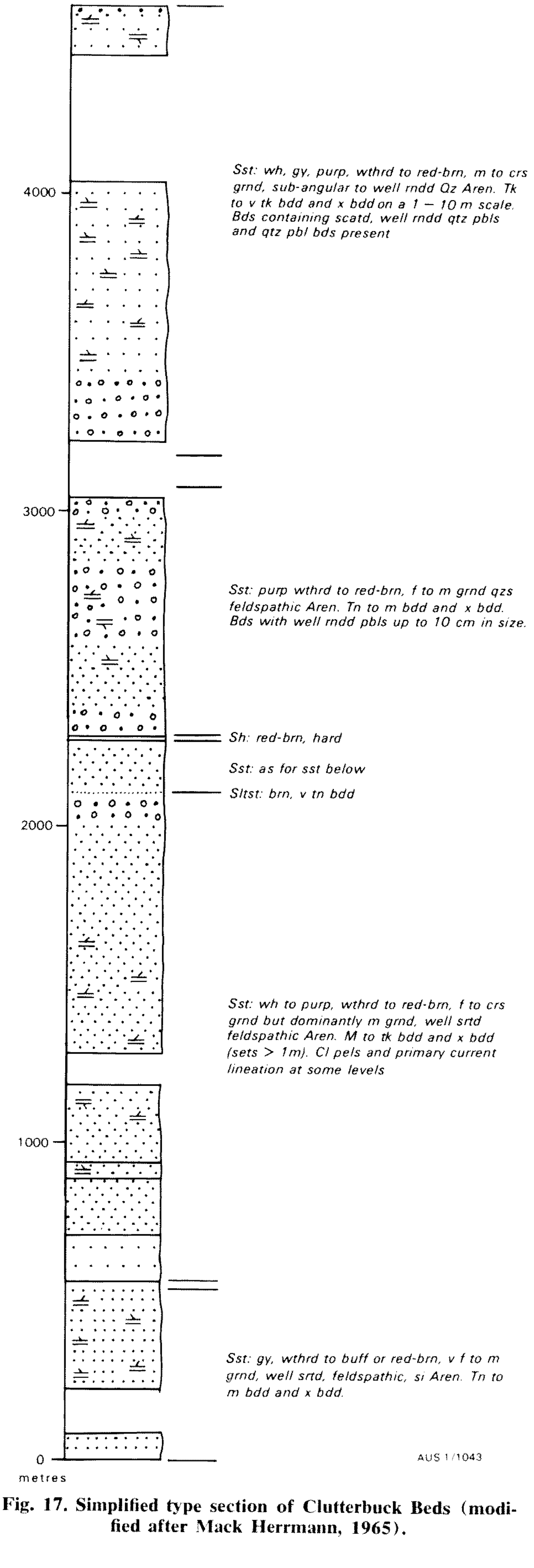


Fig. 17. Simplified type section of Clutterbuck Beds (modified after Mack Herrmann, 1965).

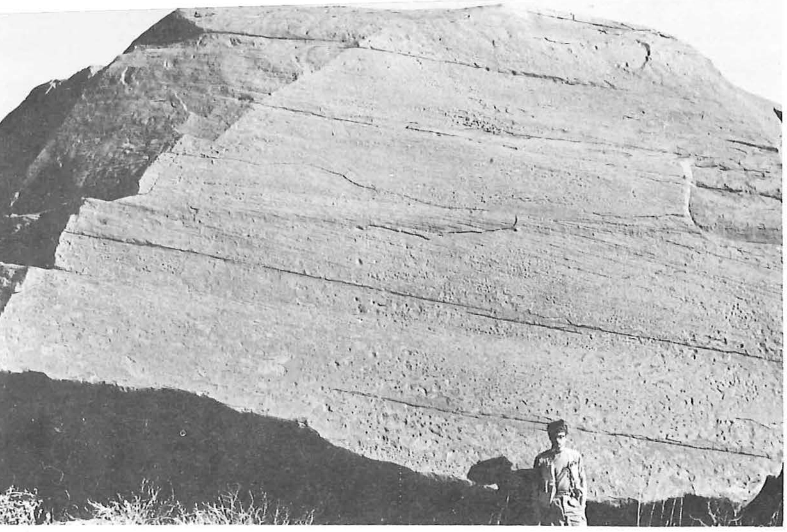


Fig. 18. Large-scale planar cross-stratification typical of the lower part of the Clutterbuck Beds; rare pebbles present (M/1232).

and not a major change in lithology, and as there is no obvious structural break we do not propose a formal subdivision into members.

Stratigraphic relations

The Clutterbuck Beds are exposed in a steeply dipping, partly fault-bounded inlier, surrounded by Permian and younger deposits. Little is known about the stratigraphic relationships of the beds, owing to the isolated position of the inlier, the absence of fossils, the lack of distinction of the lithologies, and the concealment of the upper and lower boundaries of the unit. As discussed in the section on tectonics the COBB area is situated to the north of the Anketell Regional Gravity Ridge (formerly Warri Gravity Ridge), which we use to arbitrarily define the northern boundary of the Officer Basin. Consequently, the Clutterbuck Beds probably represent a western extension of the Amadeus Basin. Wells (1963) noted lithological similarities between the Clutterbuck Beds and upper Proterozoic formations exposed in the RAWLINSON-MACDONALD areas. He tentatively correlated the lower part of the Clutterbuck Hills sequence with the Upper Proterozoic Carnegie Formation, and the upper part of the Clutterbuck Beds with the Maurice Formation and Ellis Sandstone of the Amadeus Basin. The Clutterbuck Beds are also lithologically similar to the Punkerri Beds and Wirrildar Beds, exposed along the southern margin of the Musgrave Block.

Distribution and thickness

The Clutterbuck Beds crop out only in the central western part of COBB, on the upthrown side of the major north-trending Iragana Fault. At the type section the unit is about 4500 m thick, but neither the base nor the top is exposed. In comparison, the Carnegie Formation, Ellis Sandstone and Maurice Formation of the Amadeus Basin have a combined thickness of about 3600 m; the Punkerri and Wirrildar Beds have a similar combined thickness (3900 m).

Age

At the Clutterbuck Hills the Clutterbuck Beds are unconformably overlain by the Paterson Formation, and are therefore pre-Permian. There is no direct evidence to allow a more accurate refinement, but their comparison with the Carnegie Formation, Ellis Sandstone, and Maurice Formation on the one hand, and the Punkerri and Wirrildar Beds on the other, implies a late Proterozoic or early Cambrian age.

Environment of deposition

The uniform lithology and sedimentary structures indicate deposition in a marine sub-littoral environment. A sub-aqueous environment with continuous current activity is indicated by the well-sorted nature of the sandstone, the lack of a clay matrix, the rounding of many of the constituent grains, and the types of cross stratification. Bedding is prominent and composed either of laterally extensive, parallel-laminated sets or distinctly cross-laminated sets, as is common in offshore sand bars and shoals. The presence of ripple marks and primary current lineation is also compatible with the shallow marine environment. The very large scale of some sets indicates deposition in large bedforms, such as megaripples. The very well-rounded nature of the pebbles and their inclusion within well-sorted medium-grained sandstone suggest that they are not in their first cycle of erosion and deposition, and therefore originated from conglomeratic source rocks.

The good sorting, lack of clay matrix, and rounded grains indicate a reasonable amount of reworking in the environment. However, the detritus must have been rapidly buried, as some of the feldspar has not been destroyed. As the whole sequence is lithologically monotonous, a delicate balance between sediment supply, deposition, and subsidence must have been maintained for the whole of the sequence.

Babbagoola Beds

The name *Babbagoola Formation* was first used by Jackson (1966b) for rocks intersected in Hunt Oil-Placid Oil well Yowalga 2, and was published by Peers & Trendhall (1968) and Peers (1969) without adequate definition; Lowry & others (1972) modified the name to Babbagoola Beds. Since then, these rocks have been intersected in a second drill hole, BMR Throssell 1 (Jackson & others, 1976), but they have not been seen at the surface. The name is derived from the Babbagoola Rock Hole (26°26′S, 126°11′E) in the TALBOT area.

Lithology

The interval from 846 m to 989 m (2775-3246 ft) in Yowalga 2 (Appendix 1) is designated the type section. The following description is based on that supplied by Jackson (1966b). He described three separate units within the Babbagoola Beds (in descending stratigraphic order):

Unit A 846-887 m: interbedded sandstone and shale with anhydrite and gypsum along fractures and as vein fillings. The sandstones are hard buff to dark brown, fine to very coarse-grained, poorly sorted, subrounded to well rounded, pebbly and micaceous with scattered lithic fragments. The shale is hard, dark reddish brown, slightly fissile and micaceous.

Unit B 887-893 m: fine-grained dolomite with anhydrite and gypsum along fractures and as vein fillings. The dolomite is very hard, dark grey to brown, silicified and anhydritic, very fine-grained to cryptocrystalline. The dolomite is finely banded and micro-brecciated in the upper part.

Unit C 893-989 m: interbedded shale and siltstone. The shale is soft, light greyish-green and maroon in upper part grading to dark grey, micaceous, silty and fissile. The siltstone is light grey to white, micaceous and sandy.'

Detailed descriptions of selected core samples are given by Glover (*in* Jackson, 1966b).

A very similar sequence was intersected in BMR Throssell 1, which was drilled 200 km southwest of Yowalga 2. Geological logs of the two drill holes are included in Appendix 1.

Stratigraphic relations

In Hunt Oil Yowalga 2 the Babbagoola Beds unconformably underlie the Early Cambrian Table Hill Volcanics. The base of the beds is not known, but seismic information in this area indicates that the 143 m intersected by the drill hole is part of a gently folded sequence that is up to about 5000 m thick; this sequence is shown as *Younger Proterozoic* on the cross-sections on Plate 1.

In BMR Throssell 1 the Babbagoola Beds underlie a lacustrine claystone sequence of probable Tertiary age, and form part of a thin wedge of the Younger Proterozoic rocks, which thin out to nothing about 8 km to the west of the drillsite. It is therefore likely that in this area the Babbagoola Beds may directly overlie the Robert Beds, which form the base of the Younger Proterozoic sequence. The results of recent micropalaeontological work (see below) indicate an Early Cambrian age, and a correlation with the Wirrildar Beds seems most likely. Therefore, in this southwestern part of the basin a large part of the Younger Proterozoic sequence (namely, Lefroy, Lupton, Wright Hill Beds or equivalents) could be missing.

Distribution and thickness

In Hunt Oil Yowalga 2 the Babbagoola Beds have a minimum thickness of 143 m; in BMR Throssell 1, about 200 km to the southwest, they are at least 97 m thick. A lithologically similar sequence of rocks about 700 m thick, called the Observatory Hill Beds, was intersected in SADME Wilkinson 1, located 700 km southeast of Yowalga 2. If the correlation with the Wirrildar Beds and Observatory Hill Beds is correct they are probably widely distributed in the Officer Basin.

Age

A Precambrian age was orginally suggested (Lowry & others, 1972), as the overlying Table Hill Volcanics were thought to be about 1000 m.y. old and because of sparse palaeontological evidence. Balme (*in* Jackson, 1966b) examined the Yowalga core material for microfossils and reported that all cores in the interval 887 m to 989 m yielded simple but well preserved leiospheres, and he also tentatively identified the acritarch genus *Michrystridium*, all of which he interpreted as indicating a Riphean age (late Proterozoic). Recently, however, Jackson & Muir (1981) have examined samples of grey shale from Hunt Yowalga 2 which indicate an oldest Cambrian age. They recognised the following new forms: Form B Bliss 1977; cf *Michrystridium lanatum* Volkova 1969; *Granomarginata squamacea* Naumova 1961; *Plicatosphaera elementaria* Potter 1974; cf *Alliumella* Bliss 1977; *Leiospheridia* Type 3 Bliss 1977; *Leiospheridia* Type 4 Bliss 1977; *Leiospheridia* spp; unsegmented straight filaments; twisted segmented filaments: which overall indicate an earliest Cambrian age. This concurs well with the correlation of the Babbagoola Beds with the Wirrildar Beds, which are probably of early Cambrian age (Major, 1973a) and with the Observatory Hill Beds in Wilkinson 1, which contain a similar microfossil assemblage (Muir, pers comm) and the trilobite Protolenus (J. Jago, pers comm).

Environment of deposition

Petrographic examination of thin sections cut from cores from both Hunt Oil Yowalga 2 (Glover *in* Jackson, 1966b) and BMR Throssell 1 (Jackson & others, 1976) indicate that the sandstones in Unit A are poorly sorted somewhat immature clastic sediments that were deposited in an evaporitic environment under oxidising conditions. Very well-rounded, frosted quartz grains may have originated in an aeolian environment. The dolomite, anhydrite, and dolomitic sandstones in Unit B form a mineral association indicative of an evaporitic environment. The textures and fabrics visible in thin section indicate a complex sequence of post-depositional diagenetic changes, which mask the original depositional characteristics. Underlying Unit B is a well-indurated, silicified, partly dolomitic sequence of mainly grey and green fine-grained sandstone and interbedded fissile siltstone and claystone. Flame structures and load casts in some beds disrupt what is otherwise a distinctly parallel-laminated sequence. A low-energy, shallow marine depositional environment is envisaged.

The results of seismic surveys along the road from Warburton to Laverton show that the Babbagoola Beds are part of a gently folded layered sequence. As the two drill holes are over 200 km apart and as they record a similar sequence of events, an extensive evaporitic environment must have been prevalent at the time of their deposition.

Woolnough Beds & Madley Beds

The names Woolnough Beds and Madley Beds are here proposed for the sequence of Proterozoic rocks cropping out only in the Woolnough Hills and Madley diapiric structures (WARRI and MADLEY), where cores of gypsum, Madley Beds (P*on*), are partly or wholly surrounded by sequences of dolomite, silicified dolomite, dolomitic limestone, siltstone and sandstone, Woolnough Beds (P*oo*). The sequence exposed at Woolnough Hills was described by Veevers & Wells (1959a, b) and Leslie (1961), and, together with the deposits at the Madley diapirs, by Wells (1963), Wilson (1964, 1967) and Mack & Herrmann (1965). The thickest sequence is exposed in the Woolnough Hills diapir, but in Madley diapir no. 2, about 20 km to the southwest, the sequence contains about 150 m of sandstone which was not seen at Woolnough Hills.

Lithology

The Madley Beds, which form the surface of the diapiric core at the Woolnough Hills and Madley diapirs are gypsum caprock which overlies dolomite, anhydrite, and halite at depth (Fig. 19). The caprock contains numerous blocks of dolomite and sandstone. Some of these blocks, which are up to several tens of metres across, are intensely brecciated, whereas others are virtually undeformed. The gypsum caprock itself, where not surficially weathered, has a strongly sheared gneissose appearance.

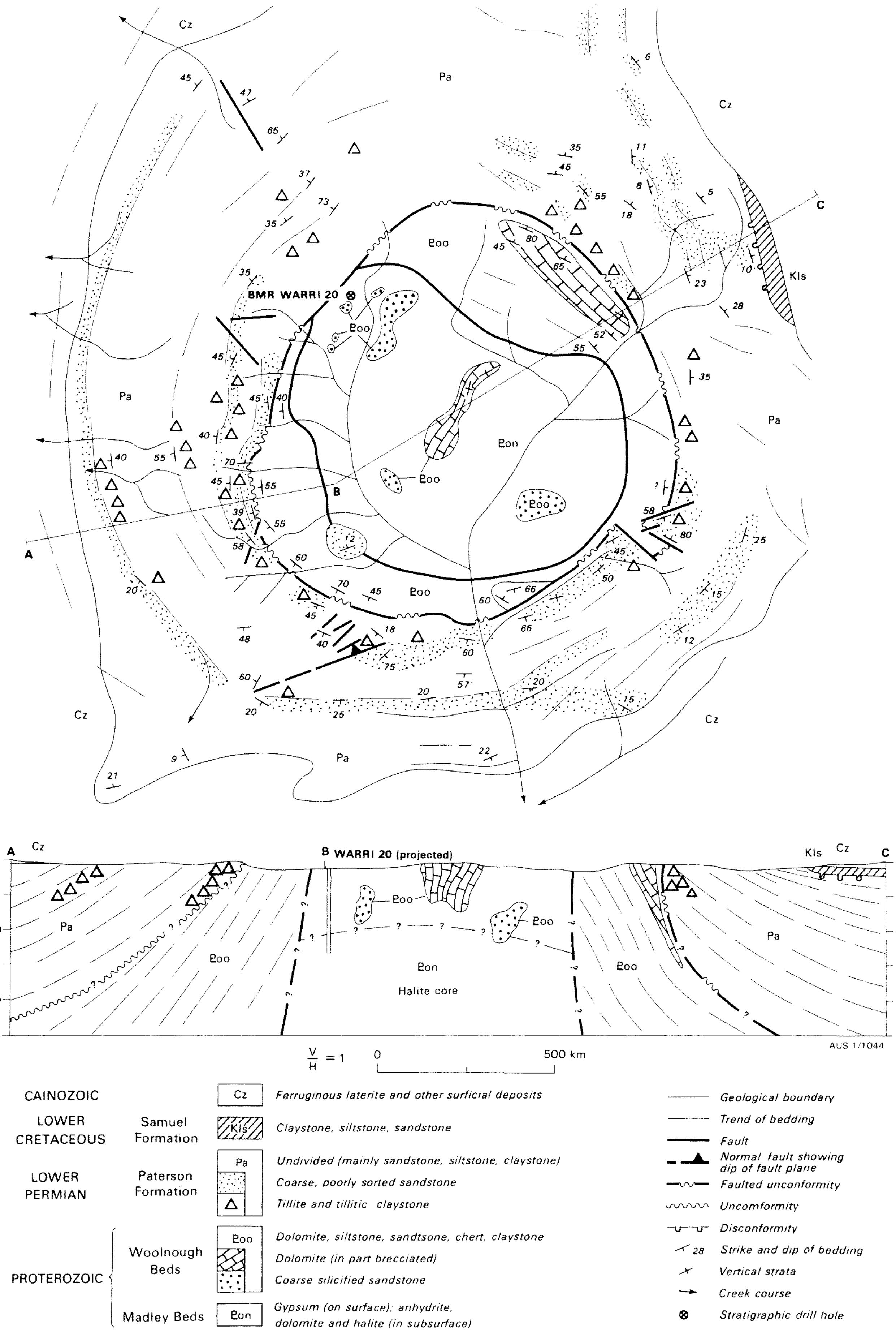


Fig. 19. Simplified geological map and cross-section of Woolnough Hills diapir.

Some dolomite blocks within the core at Woolnough Hills are identical to the dolomite present in the surrounding rim, but the sandstone blocks, which consist of silicified, medium to coarse-grained, poorly sorted quartz arenite are dissimilar to any of the rim rocks. They are, however, somewhat similar to the sandstone sequence in the Woolnough Beds exposed in Madley diapir no. 2.

At Woolnough Hills diapir the core material is surrounded by a poorly exposed rim sequence, here called Woolnough Beds, which was described in detail by Wilson (1964, 1967) and Mack & Herrmann (1965). This sequence consists of a predominatly siliciclastic lower part with interbedded siltstone, dolomite, and minor limestone, and an upper part consisting of dolomite, silicified dolomite, and minor limestones (Fig. 20). Beds with pseudomorphs after halite and gypsum are present in the siltstone interval. In thin section the pseudomorphs consist of length-slow chalcedony, indicating replacement of evaporitic minerals (Folk & Stuart Pittman, 1971), and euhedral quartz with gypsum crystal shapes (Fig. 21).

The carbonates in the upper part of the Woolnough Beds occur in discrete lenticular bodies, which grade laterally into well-bedded siltstones (cf. Fig. 19 with 20). The siltstone has very continuous but wrinkly laminations which in thin section can be seen to consist of porous finely crystalline chert with irregular remnants of carbonate, indicating that this siltstone was probably originally dolomite. This implies that the present lenticular form of the dolomite bodies is at least in part due to diagnetic effects, although faulting may also have played a role.

The carbonates in the Woolnough Beds exposed in the Madley diapirs are similar to those described above, with grey to black, partly silicified, fine-grained limestone dominant. Well-sorted, fine to medium-grained, lithic quartz sandstone and siltstone crop out around three of the domes, but, owing to poor outcrop and structural complexities produced by the diapiric intrusion, the stratigraphic relations between the carbonates and sandstones are not clear.

Stratigraphic relations

On the western side of the Woolnough Hills diapir the Woolnough Beds are unconformably overlain by the Permian Paterson Formation. Owing to the isolated occurrence of these diapirs little more can be said about the stratigraphic relationships of the exposed Proterozoic rocks. The contact between the central evaporite core of Madley Beds and surrounding rim rocks (Woolnough Beds) is faulted, indicating that the Madley Beds are older. As diapirs ordinarily require an overburden of a few thousand metres for the salt to be mobilised the Madley Beds may be much older than the Woolnough Beds; in fact, these units show strong lithological and structural similarities to the Browne Beds and Babbagoola Beds, respectively (cf. section A-D, Plate 1), and a tentative correlation is suggested. The Madley and Woolnough Beds would both form part of the younger Proterozoic to earliest Cambrian fill of the area.

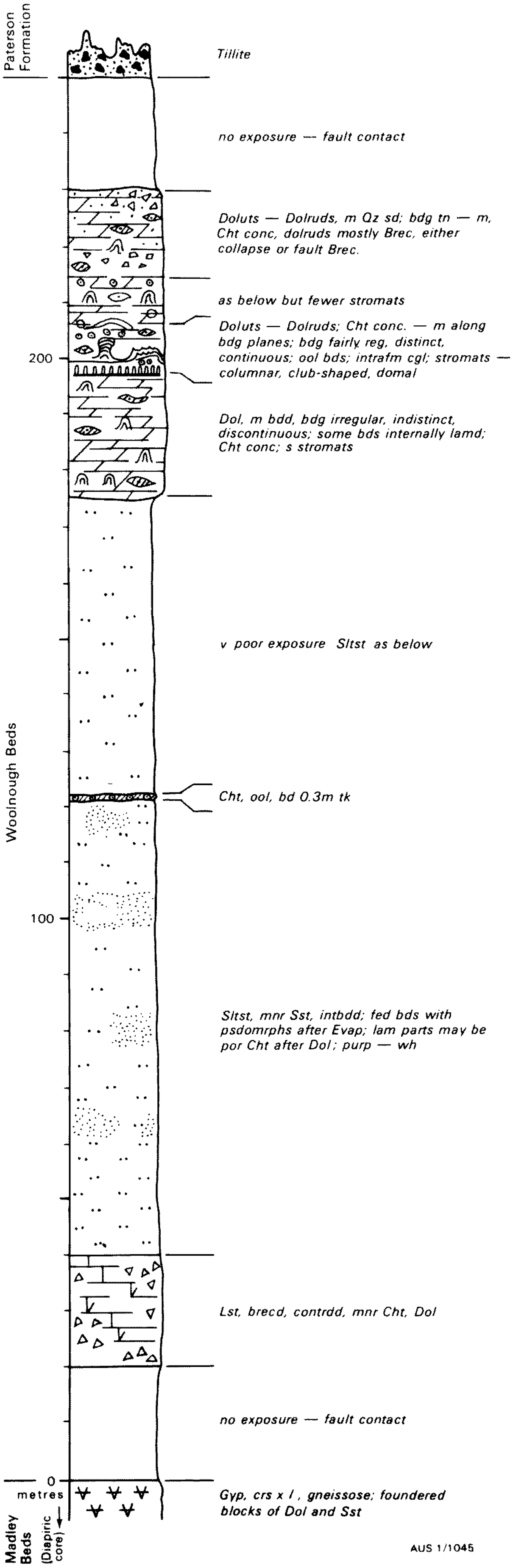


Fig. 20. Measured section of Woolnough Beds.

Distribution and thickness

The two formations are only known at the Woolnough Hills and Madley diapirs, and little subsurface information is available. Maximum thickness of the Woolnough Beds at Woolnough Hills is abut 220 m, but in Madley diapir no. 2 about 150 m of sandstone is also present. If the correlation with the Babbagoola and Browne Beds is accepted, these deposits form parts of thick and widespread late Proterozoic evaporite and carbonate sequences, also recognised in the Amadeus and Ngalia Basins.

Age

The Woolnough Beds contain the stromatolite *Acaciella*; identifiable at group level only. The stromatolite group Acaciella has been previously recorded from the Adelaidean to Early Cambrian. This is in accordance with the correlation of the Woolnough Beds with the Babbagoola Beds which are of possible earliest Cambrian age.

Black cherts collected from a large block of dolomite within the Madley Beds of Madley diapir no. 1 contain abundant microfossils. The assemblage has been divided into 8 taxa: *Melasmatophaera media* Hofmann, *Sphaerophycus parvum* Schopf, *Myxococcoides minor* Schopf, *Eosynechococcus moorei* Hofmann, cf. *Eomycotopsis filiformis* Schopf, *Siphonophycus kestron* Schopf, an unnamed multitrichomate filamentous cyanophyte, and an unnamed smooth sheath of a cyanophyte (Walter, 1978, written communication). The microbiota can be used to elucidate accurately the depositional environment (see below), but cannot be used to provide unequivocable biostratigraphic data. However, the microbiota and its type of preservation are most like that of the Bitter Springs Formation of the Amadeus Basin.

This strengthens our correlation (on lithological and regional grounds) of the Lefroy Beds, Browne Beds and Madley Beds with the Bitter Springs Formation of the Amadeus Basin. It also proves that the core rocks are distinctly older than the rim rocks, as suggested above.

Environment of deposition

The presence of halite and anhydrite in the Madley Beds obviously indicates a strongly evaporitic environment for the source bed of the diapiric material. The microbiota from the cherty dolomite at Madley diapir no. 1 have been interpreted by Walter (written communication) to represent marine peritidal, and probably intertidal, environments.

The siltstone, sandstone and dolomite sequence of the Woolnough Beds, although distinctly younger, is interpreted as being deposited within a similar environment. The oolitic layers, the intraformational conglomerates, and the stromatolites indicate a shallow marine to intertidal environment. The presence of pseudomorphs after evaporite minerals probably indicates a marine sabkha to shallow marine deposit (Kinsman, 1969).

LOWER PALAEOZOIC

Table Hill Volcanics

The name Table Hill Volcanics was first used by Peers (1969) to describe basalts that crop out at Table Hill in TALBOT. In the same publication she also used the term Officer Volcanics; a name originally coined in unpublished reports by P. Jackson (1966a, b) to describe basalts intersected in Hunt Oil Yowalga 1 and 2. We now consider all the isolated outcrops of basalt to be part of the same unit, so they are all called the Table Hill Volcanics. The name Kulyong Volcanics is the valid published name for equivalent basalts in South Australia (Major & Teluk, 1967).

The section on the east side of Table Hill (26°28′S, 126°53′E) is nominated as the type section. A continuously cored drill hole, BMR Westwood 1 (210 km southeast of Table Hill), is nominated as a reference section, as it is the only place where the whole formation has been intersected, and the core material is available for reference (Appendix 1).

Lithology and chemistry

The type section at Table Hill consists of 26 m of finely crystalline greyish-green to dark-grey basalt, with 2 m of very fine to medium-grained, micaceous sandstone in the middle. The basalt is overlain unconformably by 5 m of highly ferruginised conglomeratic sandstone of the Permian Paterson Formation. Basalt with interbedded sandstone also occurs in the northeast of ROBERT, between Mount Smith and the Herbert Wash. Here, two distinct basalt layers exhibiting features characteristic of subaerial lava flows are separated by a one-metre thick bed of sandstone. The lower flow is massive, except near the top, where it is scoriaceous and contains vesicles of quartz and agate. It is overlain by a thin bed of cross-laminated sandstone, which is overlain by the succeeding lava flow, which is four metres thick and has a base that is markedly chilled, crumbly, and weathered.

Peers (1969) provided detailed petrological descriptions of basalts from Table Hill, Hunt Oil Yowalga 2, and South Australia, based largely on the descriptions by Glover (*in* Jackson, 1966b). She divided the volcanics into two groups: altered amygdaloidal basalts, and unaltered basalts. All the volcanics collected during regional mapping can conveniently be referred to either of these groups.

The *altered amygdaloidal basalts* are composed of numerous rounded amygdales of mainly chorite, hematite, muscovite and calcite, but they also contain rare phenocrysts of altered feldspar in a fine-grained groundmass. The *unaltered basalts* are commonly fine to medium-grained, dark grey, reddish-brown or brownish green, and composed of an interlocking mesh-work of plagioclase and pyroxene crystals with rare phenocrysts of plagioclase. The interstitial material in these fine-grained basalts is largely potassium feldspar, which is either devitrified glass or the product of crystallisation of residual magma. Some of the interstitial areas are filled with chlorite, prehnite, and chalcedony, but none of these are well enough developed to be described as amygdales.

In BMR Westwood 1 there are also two distinct flows separated by a thin bed of sandstone. Both flows have slightly altered interiors grading upwards into vesicular, amygdaloidal, altered tops. Representative samples of these zones from both flows, together with selected surface samples, were chemically analysed (Table 2) and the variation of the major oxides within the unit is shown in Figure 22. There is no great difference in the composition of the two flows, but the upper flow

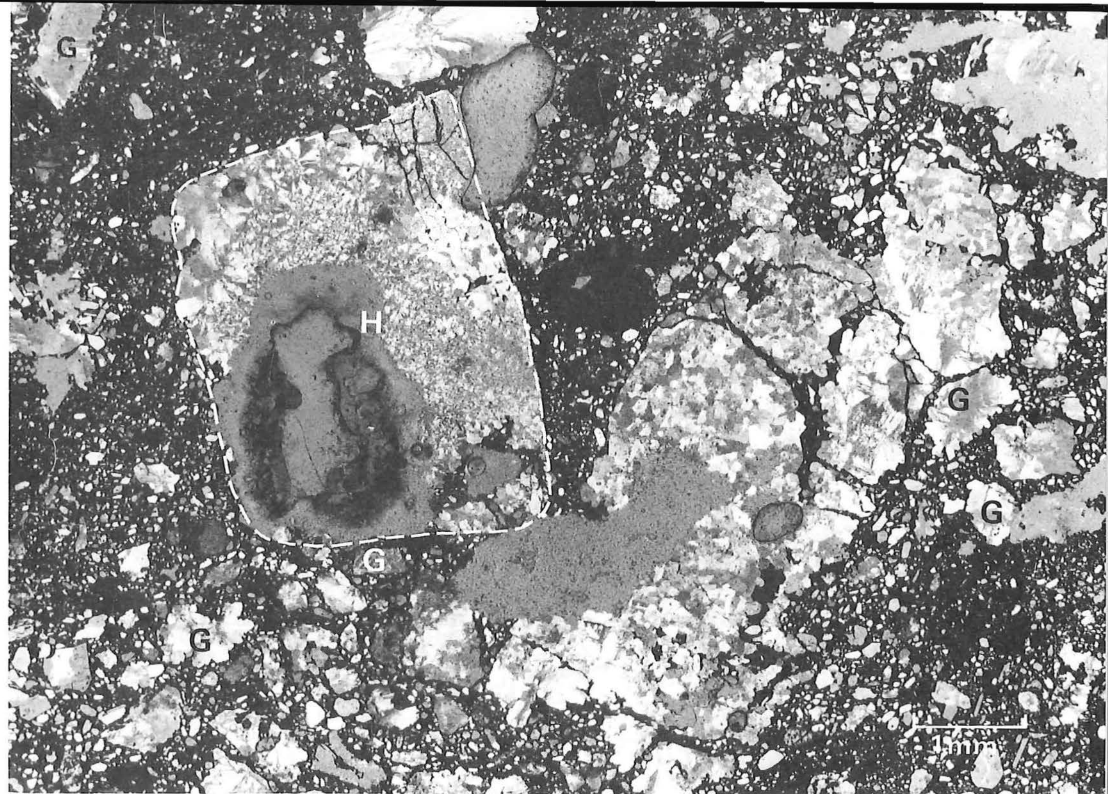


Fig. 21. Length-slow chalcedony and quartz forming pseudomorphs probably after halite (H) and gypsum (G) in siltstone of Woolnough Beds (GSWA thin section 4331).

has, on average, slightly less Na_2O and slightly more TiO_2 than the lower flow. The interior (30-70 m) of the lower flow has a uniform chemical composition, but shows a slight decrease in SiO_2 and CaO and slight increase in Na_2O and K_2O in its upper part (30-55 m). Marked variation in all oxides occurs in altered amygdaloidal lavas at the top and bottom of both flows. Table 3 compares the average for the freshest five specimens of Table Hill Volcanics from BMR Westwood 1, with an average for the Antrim Plateau Volcanics (Bultitude, written communication) and the world average for tholeiitic basalt (Hess & Poldervaart, 1967), and shows that the Table Hill Volcanics are tholeiitic.

Stratigraphic relations

The Table Hill Volcanics unconformably overlie the Babbagoola Beds in Yowalga 2 and a sandstone of assumed Proterozoic age in BMR Westwood 1. Except at the Herbert Wash, the base of the volcanics has not been seen in outcrop. At the Herbert Wash, a 3-m thick vesicular basalt flow rests with angular unconformity on a gently folded quartzitic sandstone of unknown age. As none of the Phanerozoic in the Officer Basin is folded, except where associated with diapiric structures, the quartzite at the Herbert Wash is probably Proterozoic, and its location in the northeast of ROBERT suggests a correlation with the Robert Beds. In Yowalga 2, Lennis 1, and outcrops in TALBOT, COOPER, LENNIS, and WAIGEN, the Table Hill Volcanics are overlain by the Lennis Sandstone. At Herbert Wash the volcanics are unconformably overlain by conglomerates of the Permian Paterson Formation. Elsewhere, the volcanics are either overlain by the Paterson Formation or the top is eroded.

Distribution and thickness

In the vicinity of Table Hill the volcanics crop out over an area of about 35 square kilometres; they are well exposed at Table Hill itself, in a creek that is deeply incised into a 30-m high mesa. Elsewhere, the unit crops out either in low escarpments or as rounded rubble-strewn rises. The rubble produced by the weathering of the basalts is composed predominantly of rounded core-stones of basalt and it is this material that gives the unit a distinctive smooth light-grey tone on aerial photographs.

The distribution of outcrops of Table Hill Volcanics, together with drillholes that have intersected them and structure contours based on the seismic surveys are shown in Figure 23. In South Australia the volcanics have only been found in the western half of BIRKSGATE, so it appears they do not continue very far east of the area shown. Their northern extent is unknown, but they are unlikely to be present north of about 24°S, as volcanics of this age are not known in the Canning Basin.

In BMR Westwood 1 the volcanics are 71 m thick; in Hunt Yowalga 2 they are 116 m thick. The thickest exposed sequence is at Table Hill, where at least 26 m is preserved. At these localities and at the Herbert Wash the Table Hill Volcanics consists of two distinct flows separated by a thin sandstone unit.

Age

A detailed discussion of the age of the Table Hill Volcanics has been provided by Compston (1974): a summary of the more pertinent data is provided here. Initially, Rb-Sr model ages of total rock samples from Yowalga 2 suggested a Proterozoic age of about 1100 m.y. (Jackson, 1966b). The regional mapping in 1971 and 1972, however, indicated that the volcanics were more likely to be very late Precambrian or younger, and this younger age was supported by discordant K-Ar ages, 330-445 m.y., that had been discounted by Jackson (1966a). Consequently, additional dating was done on specimens from Yowalga 2 and from WAIGEN 10 (Compston, 1974). The new total rock analyses tended to confirm the original Rb-Sr Proterozoic age. Analyses of individual minerals, however, did not confirm the low value for the initial $^{87}Sr/^{86}Sr$ that had been assumed to calculate the 1100 m.y. model age. Using a higher $^{87}Sr/^{86}Sr$ ratio, the mineral ages, used in the context of the field controls, suggest an apparent age of 575 ± 40 m.y. Compston suggested that the problems

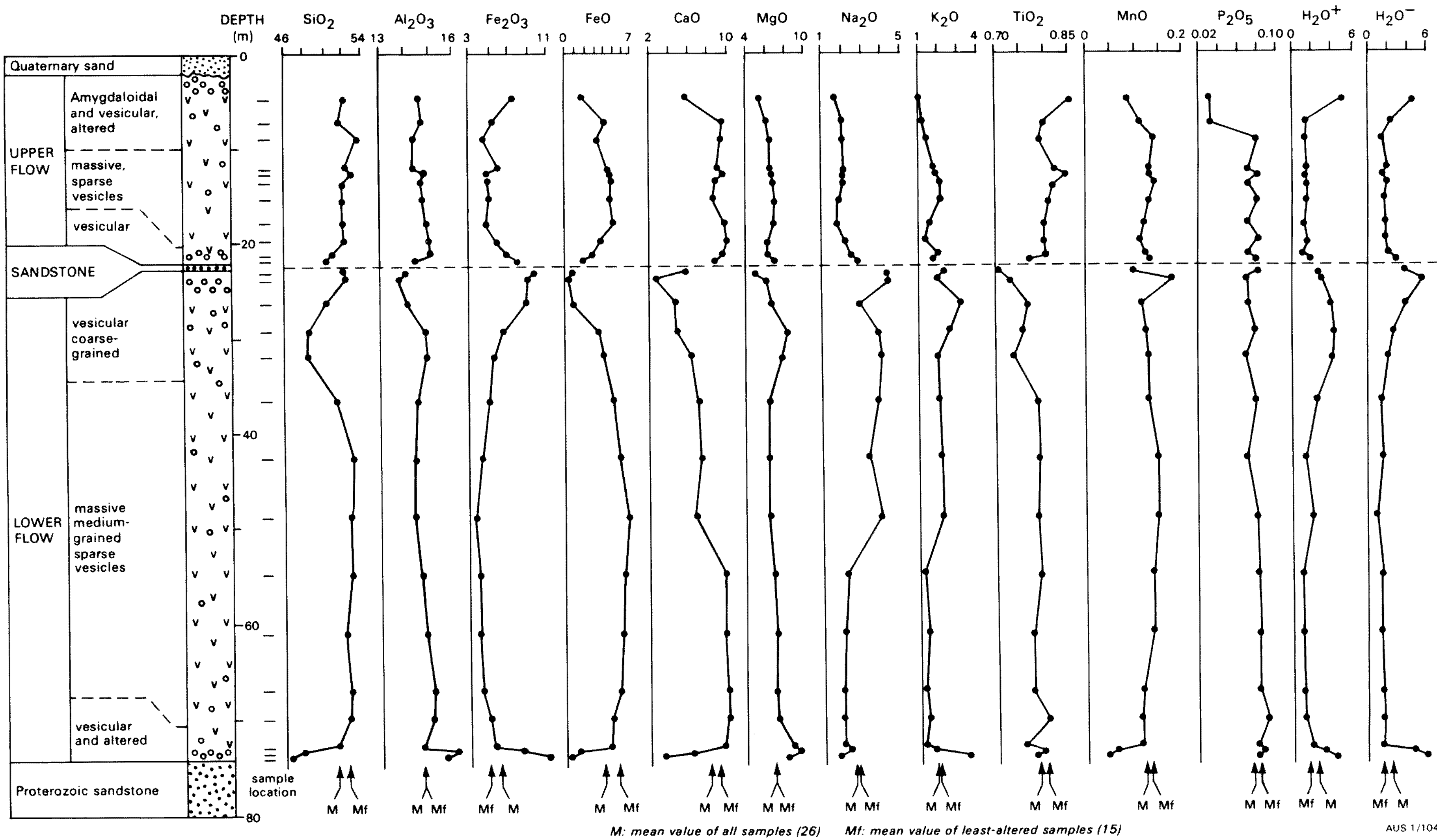


Fig. 22. Variation of major oxides in Table Hill Volcanics in BMR Westwood 1.

TABLE 2. CHEMICAL ANALYSES OF TABLE HILL VOLCANICS FROM BMR WESTWOOD 1 AND SELECTED SURFACE OUTCROPS

Location in flow, based on hand specimen	*UPPER FLOW*												
	White band	*Amygdaloidal upper part*			*Massive middle part*				*Intrusive vein*	*Massive middle part*		*Amygdaloidal lower part*	
Registered Number	282	297	295	293	288	287	289	291	299	292	283	285	302
SiO_2	48.0	51.80	51.47	53.52	52.08	52.59	51.93	51.76	74.5	51.68	51.99	50.71	50.29
Al_2O_3	34.0	14.60	14.70	14.35	14.43	14.79	14.68	14.70	6.6	14.88	15.04	14.99	14.52
Fe_2O_3		7.46	5.44	4.37	5.70	4.88	4.99	5.11		4.83	5.71	7.08	8.02
	0.5								4.8				
FeO		1.95	4.30	5.34	4.37	4.85	4.85	4.56		4.97	3.82	2.96	1.95
CaO	0.2	6.36	9.80	9.63	9.29	9.48	9.07	8.80	1.0	9.99	10.2	9.55	8.28
MgO	0.52	5.14	5.82	6.26	6.21	6.59	6.57	6.83	1.3	6.70	5.99	6.32	6.73
Na_2O	0.10	1.55	1.97	2.00	2.10	2.05	1.97	1.81	0.95	1.87	2.15	2.40	2.90
K_2O	0.2	0.95	0.89	1.20	1.58	1.56	1.96	2.12	2.0	1.42	1.22	2.00	1.91
TiO_2		0.86	0.80	0.79	0.82	0.84	0.82	0.81		0.80	0.80	0.80	0.77
MnO		0.08	0.11	0.14	0.13	0.13	0.14	0.13		0.12	0.11	0.12	0.13
P_2O_5		0.03	0.03	0.08	0.07	0.08	0.07	0.08		0.07	0.08	0.07	0.08
H_2O+		5.09	1.64	1.10	1.28	1.22	1.31	1.45		1.07	1.40	1.21	1.65
H_2O-		4.59	2.54	1.22	1.86	1.50	1.59	1.87		1.73	1.92	1.95	2.67
TOTAL		100.45	99.50	99.99	99.91	100.56	99.95	100.04		100.11	100.24	100.15	99.90
Depth (m)	4.67	4.88	7.32	9.07	12.19	12.80	13.72	15.54	18.29	17.98	19.81	21.34	21.79

Specimens analysed at Australian Mineral Development Laboratories, Adelaide. (Values expressed in weight per cent) Specimens 282, 299, and 334 were analysed using computer-controlled direct reading emission spectroscopy methods (accuracy ± 10% relative); in all other specmens the major components were determined by XRF methods, the minor components by wet chemical methods. (Specimen 334 is a direct repeat of 308, for comparison).

	LOWER FLOW												
	Amygdaloidal and vesicular upper part						*Massive medium-grained basalt, middle part*						
	286	305	303	306	308	334	310	312	314	316	318	320	321
SiO_2	52.14	52.13	50.01	48.41	48.12	48.7	51.27	52.89	52.64	52.79	52.23	52.58	52.40
Al_2O_3	13.95	13.70	14.05	14.78	14.86	13.4	14.48	14.38	14.29	14.72	14.75	15.05	15.03
Fe_2O_3	9.65	9.33	8.94	6.28	5.39		4.82	4.19	3.41	3.81	3.87	4.07	4.98
						8.6							
FeO	0.30	0.03	0.85	3.50	3.95		5.11	5.82	6.47	6.23	6.10	5.60	4.78
CaO	5.37	2.19	4.69	5.07	6.47	5.9	7.22	7.62	6.84	9.95	9.74	10.12	10.10
MgO	4.78	5.93	6.73	8.04	7.47	8.5	6.53	6.40	6.30	6.64	6.62	6.82	6.73
Na_2O	4.25	4.45	2.90	3.80	4.00	3.4	3.90	3.30	4.00	2.20	2.00	2.00	2.10
K_2O	2.27	1.95	2.98	2.45	1.97	2.0	2.08	2.07	2.18	1.19	1.27	1.11	1.16
TiO_2	0.70	0.73	0.77	0.76	0.74		0.79	0.79	0.79	0.79	0.78	0.78	0.81
MnO	0.10	0.18	0.12	0.13	0.13		0.13	0.15	0.15	0.14	0.14	0.12	0.11
P_2O_5	0.08	0.07	0.07	0.08	0.07		0.08	0.07	0.08	0.08	0.08	0.08	0.09
H_2O+	2.68	3.09	3.91	4.31	4.25		2.53	1.25	2.16	0.84	0.82	0.77	0.80
H_2O-	3.68	5.63	4.13	2.61	1.93		1.33	1.49	0.48	1.14	1.20	1.19	1.34
TOTAL	99.96	99.40	100.14	100.22	99.35		100.27	100.42	99.78	100.17	99.60	100.29	100.43
Depth (m)	23.16	24.08	26.37	29.26	32.00	32.00	36.58	42.67	48.77	54.86	60.96	67.06	70.10

	LOWER FLOW			*SELECTED SURFACE OUTCROPS*							
	Amygdaloidal lower part			*Mt Smith area*		*ROBERT*	*WAIGEN 10*	*KULYONG*	*BIRKS-GATE*	*TABLE HILL*	*TALBOT*
	323	325	327	7188 0001	7188 0002	7188 0003	7188 0008	7188 0009	7188 0010	7188 0011	7188 0012
SiO_2	50.98	47.60	46.35	52.8	52.7	52.6	54.3	53.9	53.9	55.7	54.8
Al_2O_3	14.60	16.07	15.62	13.8	13.7	13.6	14.5	14.4	14.5	14.2	14.2
Fe_2O_3	5.40	7.63	11.24	1.93	2.15	1.92	2.80	4.65	4.65	5.05	4.25
FeO	4.73	1.13	0.10	10.8	10.7	11.0	7.60	5.95	5.70	5.30	5.95
CaO	9.45	6.18	3.15	8.20	8.15	8.30	6.30	5.90	6.20	4.50	5.15
MgO	8.33	8.87	7.67	5.20	5.30	5.10	5.20	5.10	5.10	4.35	4.75
Na_2O	2.00	2.15	1.72	2.10	2.15	2.15	4.70	4.65	4.65	3.25	2.25
K_2O	1.08	1.26	3.44	1.31	1.40	1.35	1.35	1.69	1.69	4.00	5.35
TiO_2	0.76	0.80	0.79	1.91	1.95	1.96	0.95	0.99	0.99	0.97	0.94
MnO	0.12	0.06	0.04	0.19	0.19	0.19	0.17	0.18	0.16	0.18	0.17
P_2O_5	0.08	0.08	0.08	0.21	0.21	0.21	0.08	0.08	0.07	0.08	0.08
H_2O+	1.58	3.19	4.31	1.03	0.83	1.07	1.59	1.43	1.73	1.23	1.22
H_2O-	1.12	4.51	5.33	0.17	0.31	0.13	0.45	0.73	0.61	0.67	0.60
CO_2				0.05	0.07	0.13	0.05	0.13	0.09	0.09	0.06
	100.23	99.53	99.84	99.70	99.81	99.71	100.04	99.78	100.04	99.57	99.77
	72.85	73.46	74.07								

TABLE 3. COMPARISON OF TABLE HILL VOLCANICS WITH OTHER BASALTS

	Table Hill Volcanics[1]	*Antrim Plateau*[2]	*World Average*[3]
SiO_2	52.5	52.8	51.1
TiO_2	0.8	1.1	1.6
Al_2O_3	14.8	14.6	16.2
Fe_2O_3	4.0	3.41	3.1
FeO	5.8	6.76	7.6
MnO	0.13	0.17	0.17
MgO	6.6	6.04	6.2
CaO	9.8	8.12	9.9
Na_2O	2.5	2.99	2.5
K_2O	1.4	1.72	0.7
P_2O_5	0.08	0.12	0.22
H_2O+	1.1	1.33	0.7
H_2O-	1.1	0.63	—
CO_2	—	0.15	—
TOTAL	100.61	99.94	99.99

[1] freshest five specimens from BMR Westwood 1 (Jackson & others, 1976)
[2] average of 45 analyses (Bultitude, written communication)
[3] 897 analyses (Manson, V., p. 227 *in* Hess & Poldervaart, 1967)

of age dating are due to contamination of the magma by radiogenic strontium and alkalis from Precambrian crustal material. The age, chemical, and petrological similarities indicate that the Table Hill Volcanics were coeval with the Antrim Plateau Volcanics of Northern Australia (Bultitude, 1976).

Mode of formation

The flow-banding, vesicular amygdaloidal and scoriaceous tops, and the lack of features diagnostic of submarine flows indicate that the Table Hill Volcanics were extruded subaerially. At four widely separated localities —Mt Smith, BMR Westwood 1, Hunt Yowalga 2 and Table Hill (Fig. 23)—the Table Hill Volcanics consist of two flows separated by a thin sandstone bed; therefore, their extrusion must have been uniform throughout a wide area. In size and thickness the Table Hill Volcanics compare closely with the Columbia River Volcanics of British Columbia, where individual flows are commonly 15-30 m thick (but in some places reach 80 m) and cover comparable areas (McDonald, 1967, *in* Hess & Poldervaart). In his description of the various types of lava flows, McDonald notes that vesicles of pahoehoe flows are characteristically spherical or spheroidal, in contrast to the vesicles of aa and blocky flows which are very irregular, twisted, and deformed. In the Table Hill Volcanics the vesicular and amygdaloidal tops of the flows are characterised by well-rounded, even, spheroidal, undistorted amygdales (Fig. 24). It therefore seems likely that the eruption of the Table Hill Volcanics was of pahoehoe type. Also characteristic of pahoehoe flows are gently undulating or hummocky surfaces. Although the Table Hill Vol-

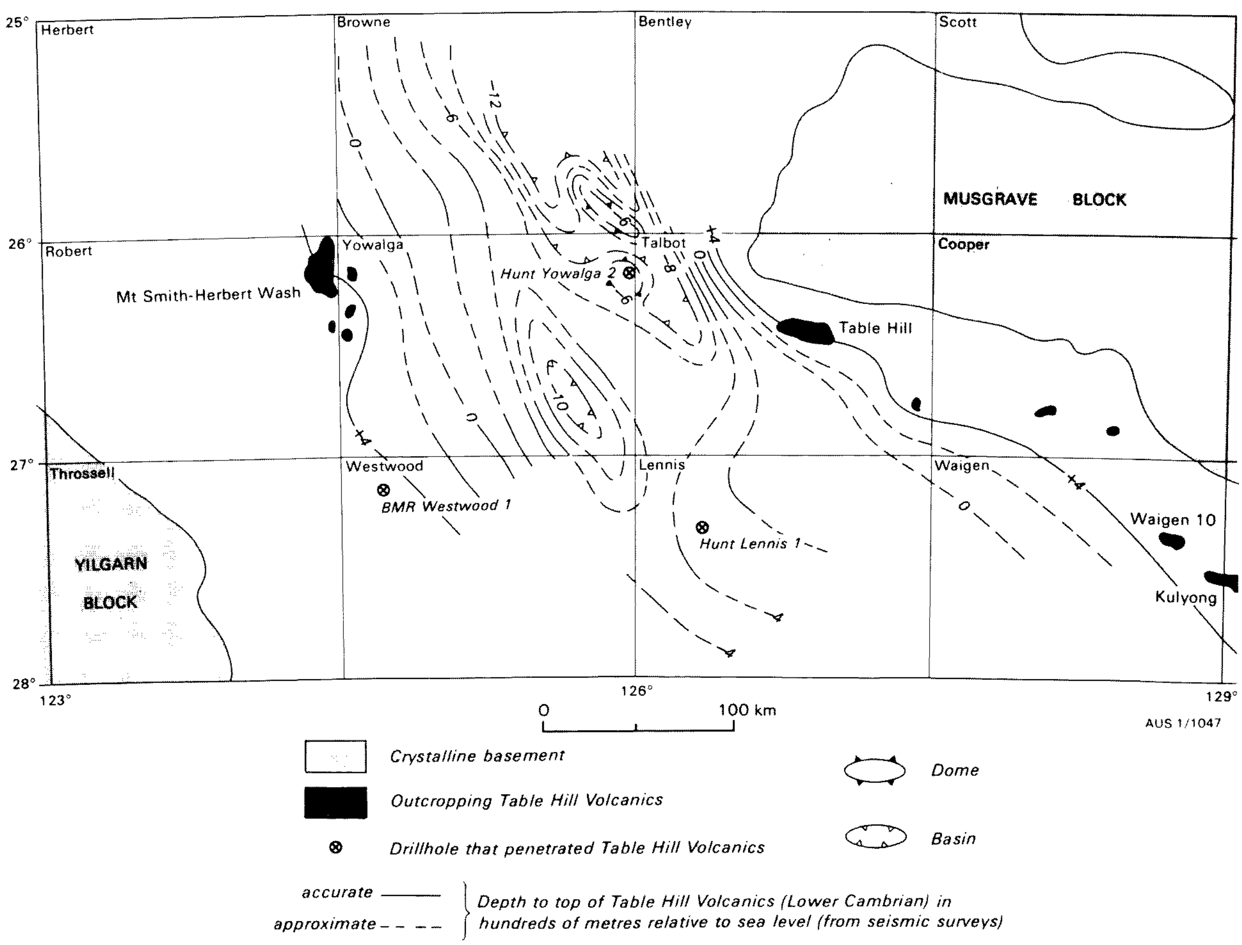


Fig. 23. Distribution of outcrops of Table Hill Volcanics and structure contours of Horizon 'A' in central part of basin.

canics exposed at Mount Smith crop out only over a small area, the lower flow has a fairly smooth undulating top.

Lennis Sandstone

The name Lennis Sandstone was first used in an unpublished report by P. Jackson (1966a). He did not nominate a type section, and only described the unit from Hunt Oil Lennis 1 and Yowalga 2. Peers & Trendall (1968) published the name, but without an adequate description; Lowry & others (1972) provided a full description and definition. They also designated the interval 407-728 m in Hunt Oil Yowalga 2 as the type section and exposures at grid reference 552623, (LENNIS 10) as the reference section (Fig. 25). The unit was first encountered in Hunt Oil Lennis 1 and the name is taken from the 1:250 000 Sheet area in which the hole is located.

Lithology

The Lennis Sandstone consists of red to reddish-brown, fine to medium-grained, sub-angular to sub-rounded, moderate to well-sorted, feldspathic micaceous sandstone. Red micaceous siltstone beds up to 3 m thick are interbedded with the sandstone in the northeast of LENNIS. Bedding ranges from laminated to very thick, but medium to thick bedding is dominant. The medium to thick beds are commonly internally laminated or cross-laminated. Tabular red siltstone clasts up to a few centimetres in size are also present.

Well-developed large-scale cross-stratification is a ubiquitous feature of the formation. It is well exposed in the mesas and buttes in the northeast of the basin, but highly variable dipmeter results in Yowalga 2 indicate that large-scale cross-bedding is also present in this area.

The following detailed descriptions refer only to the measured sections in the northeast of LENNIS (Fig. 25) where part of the formation is well exposed. Well-sorted cross-stratified quartz and feldspathic arenite dominate. Cross sets are commonly 40-60 cm thick, but range up to a maximum of 2 m. They are grouped into co-sets between 2 and 4 m thick. Foreset dips range between 15 and 35 degrees. The most common type of cross-bedding is the omikron and pi types of Allen (1963) although xi types are also present. The cross-stratification in the section measured at Sulphur Knob (LENNIS 38) is distinctly smaller scale (sets 5-20 cm thick) than that seen at the other sections, but it is also composed of grouped sets with scooped bases. Near the top of the bluff several sets infilled a 15-m wide channel which is cut into the underlying siltstone bed.

In all detailed sections measured the co-sets of cross-stratified sandstone were separated from each other by thin beds of laterally extensive siltstone or fine-grained silty sandstone which weather out to form prominent benches in the sides of the mesas. Most siltstone beds are highly micaceous and in many places have a well-developed bedding fissility. At most outcrops isolated tabular to oblate clasts of red siltstone with leached surrounds are common on the foresets, indicating early reworking of weakly consolidated siltstone. Although somewhat obscured by intense weathering, in situ brecciation of siltstone beds is present at LENNIS 10, 18 and 38. The brecciation appears to be due to early post-depositional slumping.

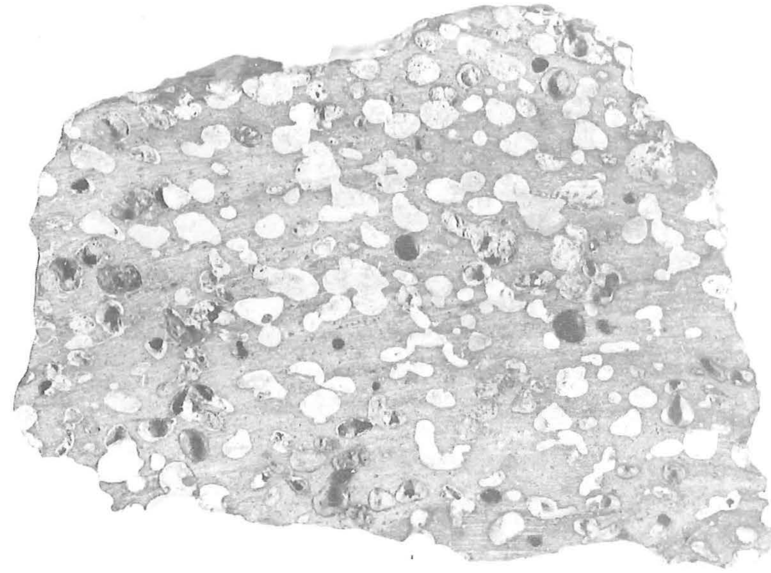


Fig. 24. Spheroidal quartz and chalcedony-filled amygdales from top of lower flow of Table Hill Volcanics at Mount Smith.

In cores 3 and 4 from BMR Neale 1 (Appendix 1), the Lennis Sandstone contains small patches of a calcareous matrix; however, as many of the intergranular areas are now voids, it is possible that the rock originally contained much more calcareous matrix. Except for the above-mentioned cases, all specimens, both surface and sub-surface, have a large intergranular porosity partly filled with a submicroscopic matrix that is now mostly hematite and limonite. The characteristic red to reddish-brown colour of the formation appears to be caused mainly by the iron oxide staining or replacing the matrix. Although the medium-grained sandstones are commonly well-sorted and are composed of sub-angular to sub-rounded grains, the finer-grained sandstones and siltstones are composed of sub-angular to angular grains of quartz and feldspar and numerous thin slivers of muscovite. Micro-cross-laminae containing coarse to very coarse spherical quartz grains with surface frosting are present in core 3, and were also seen in outcrop.

Stratigraphic relations

The Lennis Sandstone unconformably overlies the Table Hill Volcanics in Hunt Oil Lennis 1 and Yowalga 2. At the only outcrop where these two units were found together (south-central COOPER) the Lennis Sandstone overlies the volcanics with a sharp contact. The actual contact is hidden by 2 m of scree, but weathered vesicular and amygdaloidal basalt containing agate and quartz-filled geodes is overlain by red, medium to thick cross-bedded, micaceous and feldspathic sandstone. In Yowalga 2 and Lennis 1 the Lennis Sandstone is unconformably overlain by the Paterson Formation, but in BMR Neale 1 it is conformably overlain by the Wanna Beds. In WANNA, WAIGEN, COOPER and LENNIS the inferred distribution of both units (solid geology inset, Plate 1) suggests that the Lennis Sandstone is overlain disconformably or unconformably by the Wanna Beds.

Regional correlations

The closest lithologically similar rocks are the Cambro-Ordovician clastics (especially the Trainor Hill Sandstone) in the eastern Officer Basin (Kreig & others, 1976) 300 km to the east.

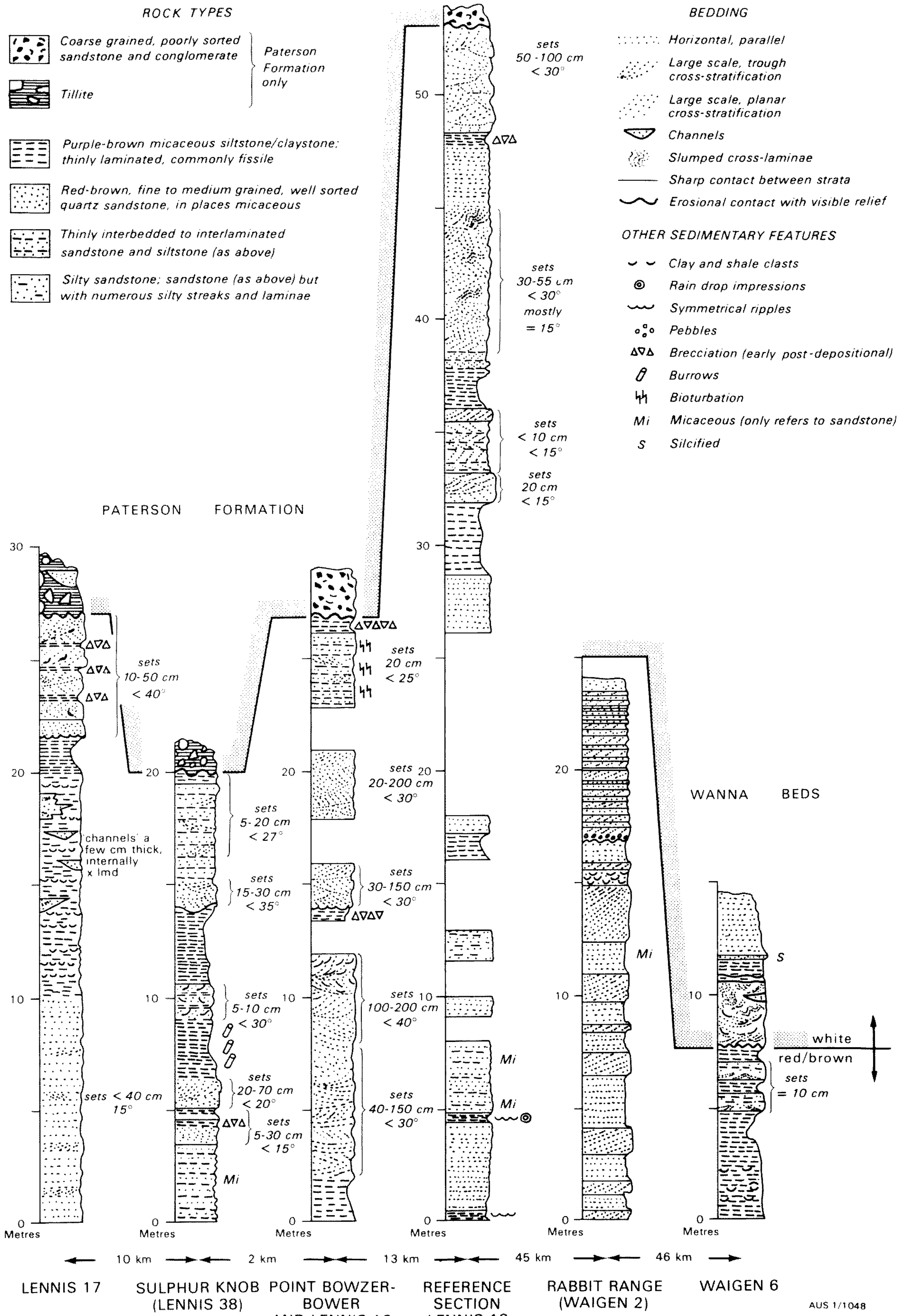


Fig. 25. Measured sections of Lennis Sandstone.

Distribution and thickness

The Lennis Sandstone crops out in the east and northeast of the Officer Basin in Western Australia (Plate 1). A small isolated outcrop on the western margin of the basin (northeast ROBERT) has also been tentatively identified as Lennis Sandstone. The Lennis Sandstone shown at Madley 14 (Kennewell, 1975) is now regarded as part of the Bangemall Group. We consider that the Lennis Sandstone probably has a similar subsurface distribution to that of the Table Hill Volcanics (Fig. 23).

In Hunt Lennis 1 the formation is 425 m thick, in Hunt Yowalga 2 it is 301 m thick, and in Continental Oil Birksgate 1 it is 342 m thick. The upper part of the Lennis Sandstone was also intersected between 140 m and 205.74 m (T.D.) in BMR Neale 1, so here it is at least 66 m thick.

The thickest known section on the surface is at the reference section (Fig. 25), where just over 52 m is exposed. Major (1968) mentioned red micaceous and feldspathic sandstone with some siltstone in the southwest of BIRKSGATE and considered them to be of probable Palaeozoic-Mesozoic age. We consider these outcrops to be Lennis Sandstone.

Age

The age of the Lennis Sandstone is in the range early Cambrian to early Permian, as it overlies the Table Hill Volcanics and is overlain by the Paterson Formation.

Environment of deposition

Jackson (1966a) suggested an oxidising non-marine environment, based mainly on the red colour of the formation, but Lowry & others (1972) preferred a shallow marine interpretation. We prefer a shallow marine environment for most of the formation, but there are indications of subaerial exposure in some outcrops.

In the Rabbit Range (central WAIGEN) the formation was probably deposited in a shallow marine environment. Here, it consists of alternating beds of cross-laminated and parallel-laminated sandstone (Fig. 25). The bedding is distinctive, and individual beds are continuous throughout the outcrop (some 200 m long). In the lower part of the outcrop, thin to thick parallel-laminated sandstone alternates with thin to very thick beds of cross-laminated sandstone (alpha or beta-type) with the cross laminae dipping up to 20°. The upper part of the outcrop is composed of a similar sequence of alternating parallel and cross-bedded sets, except that the bedding is thin to medium throughout. Although this sequence of cross-bedded and parallel bedded sandstone could originate in, say, an extensive low-gradient alluvial environment, the very good sorting and rounding of the grains, the common presence of mica, the lateral continuity of the beds throughout the outcrop, and a lack of obvious channels suggest a shallow marine environment with migrating low bars.

The only unequivocal evidence of subaerial exposure was found near the base of the reference section (LENNIS 10) where specimens of claystone with mudcracks and one with rain-drop impressions were found in float. The remainder of the reference section is probably subaqueous, with good evidence for such near the top of the section where cross-sets with over-

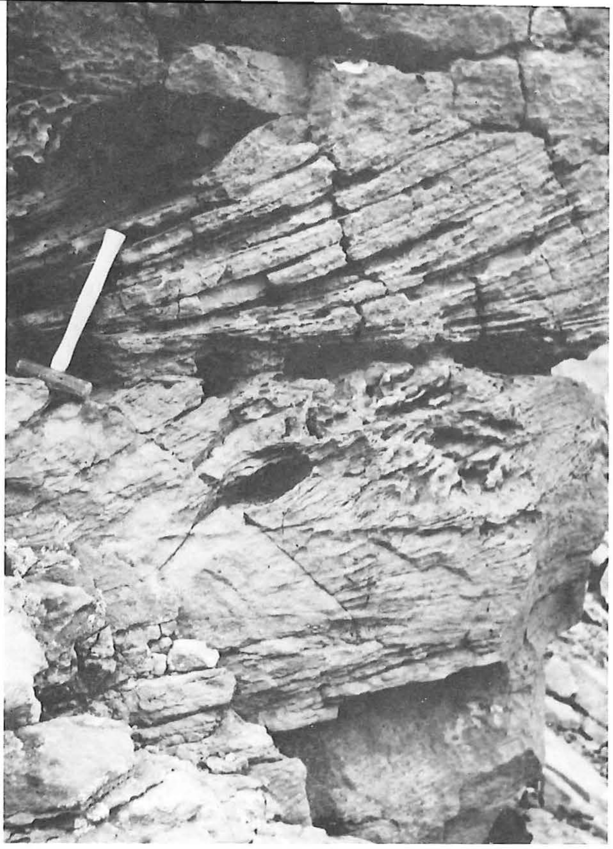


Fig. 26. Two sets of scoop cross-stratified Lennis Sandstone with slumping of cross-laminae in upper part of lower set; LENNIS 10 measured section (GB/2087).

steepened and slumped cross-laminae (Fig. 26) similar to those described by Allen & Banks (1972) occur. They interpret these structures as having been formed by deformation of a liquefied sand by current drag, following an event such as an earthquake shock. It is noteworthy that laterally extensive (tens of kilometres) brecciated siltstone beds at the same level as these slumped sands occur in several outcrops in the northeast of LENNIS. The common presence of large spherical sand grains with frosted surfaces in some of the finer sands may indicate an aeolian origin for some of the detritus.

Wanna Beds

The name Wanna Beds was proposed by Lowry & others (1972) for a unit of white-weathering sandstone with minor claystone, with common large-scale cross-stratification. The unit crops out in the southeastern part of the area, and was named after the nearby Wanna Lakes. The type section is located at 28°49′S, 128°16′E (WANNA 3) where about 10 m is exposed. In BMR Neale 1 the formation was penetrated between 58 and 138 m. As this is the thickest and most complete section known in W.A., it is here designated as a reference section (Appendix 1).

Lithology

In the main outcrop area the Wanna Beds consist of white to pale green, fine to very fine-grained, well-sorted to bimodally sorted, slightly micaceous sandstone. Locally, the unit is partly red, like the Lennis Sandstone. Bedding is mostly distinct and continuous, and ranges from thinly laminated to very thickly bedded.

Cross-stratification up to 6 m thick, but mostly not thicker than about 1.5 m, is diagnostic (Fig. 27). Cross-stratification is mostly of the trough type (pi type of

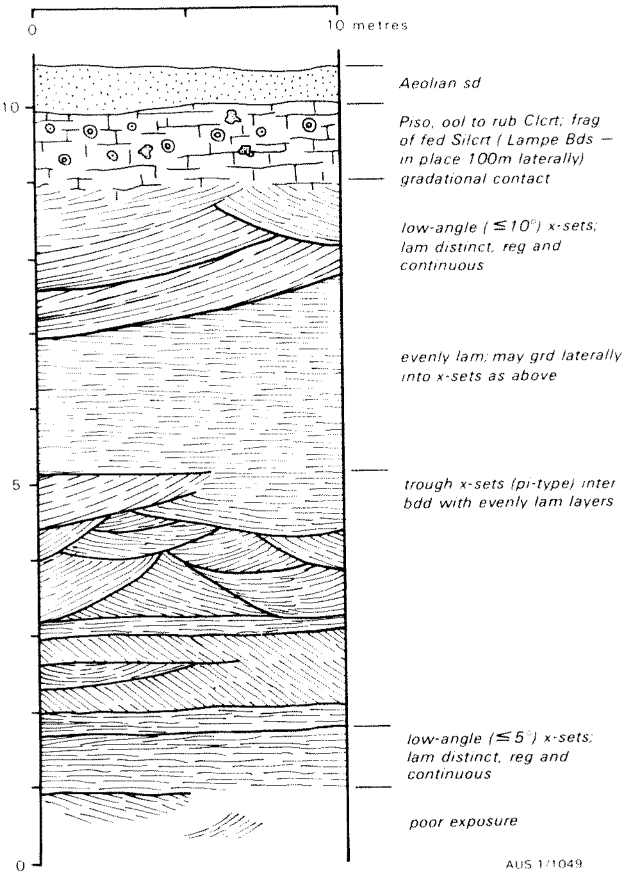


Fig. 27. Wanna Beds type section at WANNA 3.

Allen, 1963) but beta type cross-sets and planar cross-stratification of types described by McKee (1966) also occur. The troughs have a maximum width of about 10 m, and in the down-current direction individual trough cross-sets have been traced for over 60 metres. The cross-sets are laminated to thinly bedded. The foresets of the cross-sets are normally concave upwards. Towards the base, the foreset beds flatten tangentially and can commonly be traced laterally into horizontally bedded strata, and transitions from pi cross-sets with clearly erosional bases to parallel-bedded sandstone are common.

At WANNA 7 there is an exposure of large-scale, straight cross-stratification. The preserved height of this cross-set is 5.3 m, and it can be traced for several

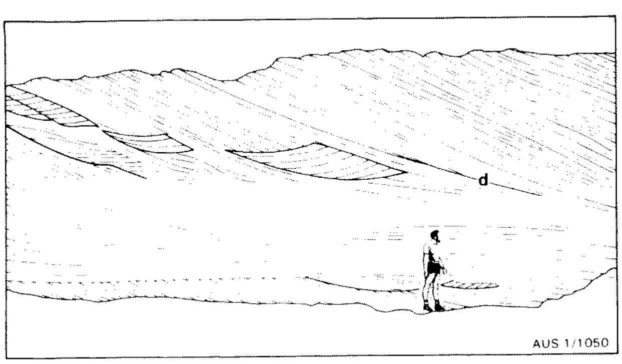


Fig. 28. Large-scale trough cross-stratification in Wanna Beds at WANNA 7.
Note cross-sets with opposing dips and discontinuity plane (d). (Sketched from GSWA photo).

hundred metres in the current direction. Along the strike of the foresets the cross-set can be traced for over 150 m. Superimposed on, and alternating with, the steeply dipping (up to 25°) foresets are some medium-scale cross-sets which indicate a direction of transport diametrically opposite to that of the bigger set (Fig. 28).

These superimposed, opposing cross-sets which are up to 0.8 m thick, are present only in the upper part of the larger cross-set over a distance of about 10 m. Small-scale opposing cross-sets (5-10 cm thick), at the base of the large-scale cross-bedding, are present in a different part of the outcrop.

The medium-scale, opposing cross-sets have an erosional base and are in turn covered, with an erosional contact, by the main cross-set. The foresets of the large-scale cross-bedding and those of the opposing cross-sets do not interfinger.

Although the large-scale cross-bedding, where not modified by opposing cross-sets, has a regular appearance, several discontinuities are present (Fig. 28). Such discontinuities have also been noted in other outcrops of the Wanna Beds.

In the main outcrop area of the Wanna Beds, thin claystone layers are locally present, but further west, in NEALE, claystone is more common (NEALE 7, BMR Neale 1). Locally, claystone clasts up to 10 cm long occur along the scoured bases of the cross-sets and along the foresets.

Rare burrows are present, but fossil organisms have not been found. The sandstones are well sorted, very fine to medium-grained feldspathic arenites (arkoses), with minor lithic fragments and, commonly, with a clay matrix or cement. The grains are generally sub-rounded to rounded, but over-growth with quartz and/or feldspar during diagenesis has often obliterated the original shape. The feldspars are mostly altered, and kaolinite-type clay generally occurs in discrete aggregates as a cement or matrix, indicating that the high-clay matrix is due to decomposition of feldspar and the formation of clay minerals during diagenesis and/or weathering.

The red colour of parts of the Wanna Beds is due, as in the case of the Lennis Sandstone, to an iron-rich coating (?hematite) on some grains. This iron-rich coating occurs predominantly on feldspar grains, and predates the feldspar or quartz overgrowth rim present on many detrital grains (Fig. 29). The coating is therefore a syndepositional or early diagenetic feature of these sediments.

Stratigraphic relations

The Wanna Beds conformably overlie the Lennis Sandstone with a transitional contact at WAIGEN 6, and in BMR Neale 1. In contrast, the distribution of Lennis Sandstone and Wanna Beds in WAIGEN and COOPER (solid geology inset on Plate 1) suggests that the relationship in that area is disconformable or unconformable. Petrographically, the main distinction between the two units is the texturally more mature character of the Wanna Beds (better rounding of grains, combined with fewer lithic clasts), but there is not enough information to determine whether there is an abrupt or a gradational increase in maturity at the boundary between the two units.

On MASON the Wanna Beds may unconformably overlie the Precambrian Ilma Beds, but the contact is not exposed.

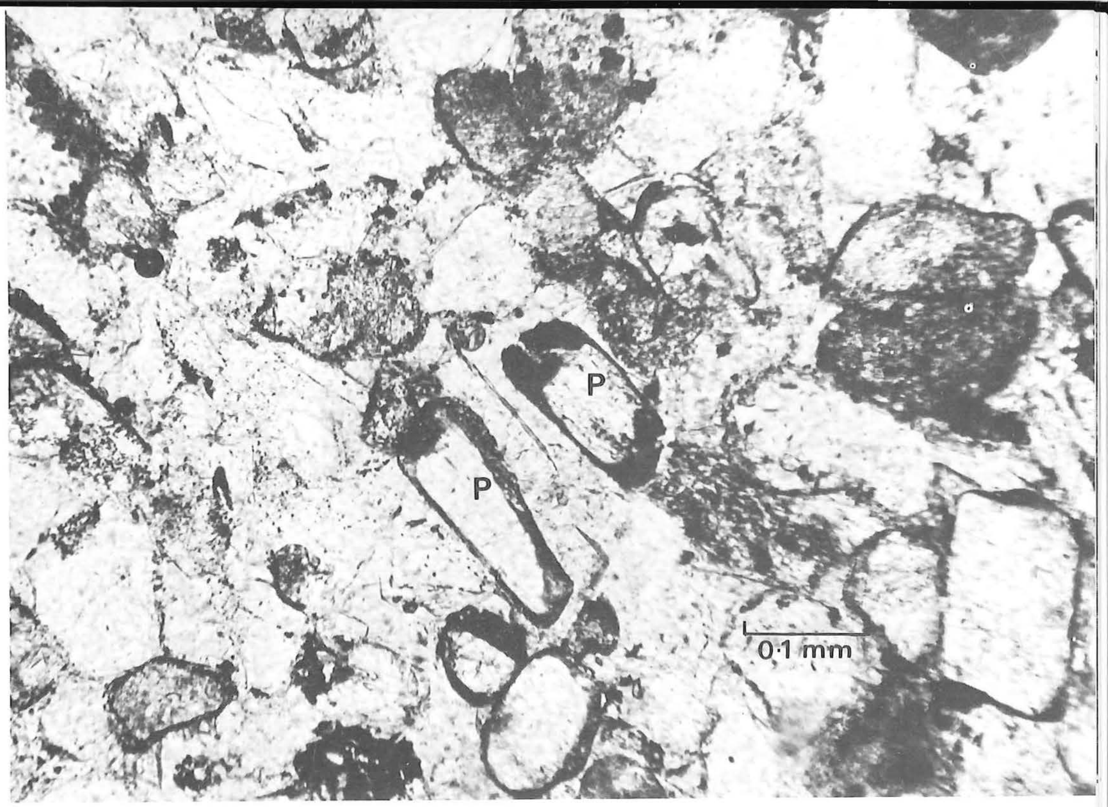


Fig. 29. Subrounded plagioclase grains (P) with reddish-brown, iron-rich coating and feldspar overgrowth; Wanna beds at NEALE 7 (GSWA thin section 29180).

The Paterson Formation unconformably to disconformably overlies the Wanna Beds over most of their extent, but in the southeast the unit is disconformably overlain by the Cretaceous to Tertiary Lampe Beds or by Tertiary sediments of the Eucla Basin.

No definite correlatives of the Wanna Beds are known. This is due to a lack of dates for the formation, as well as to the generally poor exposure in the Great Victoria Desert. Possible correlatives are the ?Cambrian Observatory Hill Beds, the ?Ordovician Mount Chandler Sandstone, Indulkana Shale, Blue Hills Sandstone, and Cartu Beds, or the ?Siluro-Devonian Mintabie Sandstone, all in the South Australian part of the Officer Basin (Krieg, 1972).

Distribution and thickness

The Wanna Beds underlie much of the area south of 27°S and crop out on MASON, WANNA, WAIGEN, COOPER, NEALE, and LENNIS. In the subsurface, the Wanna Beds are known from BMR Westwood 2 (43-101.5 m, T.D.), BMR Neale 1 (58-138.5 m), and they may form part of the Palaeozoic sequence which seismic data indicate is present in the subsurface of BROWNE (Jackson, 1976).

The Wanna Beds extend into NOORINA and WYOLA in South Australia, and have been tentatively interpreted, on the basis of descriptions by Henderson & Tauer (1967), to occur in Birksgate 1 in the interval 32.5 m-158.5 m.

The exposed thickness at the type locality is about 10 m, and it is unlikely that this is greatly exceeded at any other outcrop. The borehole data in W.A. indicate thickness ranges from 58.5 m to at least 80.5 m. If the interpretation of the sequence in Birksgate 1 is correct, the unit thickens eastwards as it is 136 m thick in Birksgate 1.

Age

No fossils have been found in the Wanna Beds. Therefore the age of the unit is in the range Early Cambrian to Early Permian.

Environment of deposition

The types of cross-bedding, the presence of burrows and clay clasts, the textural maturity, and the uniform rock types over a large area indicate a current-swept, shallow marine environment of deposition for most of the exposed Wanna Beds.

The beta cross-set more than 5 m high, containing medium to large-scale, opposing cross-sets, that is present at WANNA 7 (Fig. 28) allows a detailed interpretation of the environment to be made. The opposing cross-sets occur in the middle and upper part of the main cross-set and do not interfinger with it. Therefore, they were not formed by ripples caused by counter current eddies, but instead form conclusive evidence of an independent current directly opposing the one that formed the very large-scale cross-set. Such opposing current directions are characteristic of tidal currents, and an offshore subtidal environment, such as the present southern North Sea, which is characterised by tidal-current ridges and mega-ripples (Houbolt, 1968), is interpreted for the Wanna Beds on WANNA and MASON (van de Graaff, 1972).

At the other exposures visited no such clear evidence of opposing tidal currents was observed. The current directions as deduced from various types of cross-bedding are shown in Figure 30.

The presence of the various large-scale cross-sets and the relatively high current velocities they imply, make it unlikely that the clayey matrix present in the sandstones was deposited simultaneously with the sand-sized grains. The general rareness of clay drapes suggests that, even during periods of negligible water flow, little clay was deposited. This reinforces the argument that the clayey matrix is a diagenetic and/or weathering product. An alternative interpretation is that the clay matrix is a post-depositional infiltrate. Such post-depositional precipitation and/or infiltration of clay matrix in originally well-sorted porous sandstone is increasingly being recognised (e.g. Walker & others, 1978).

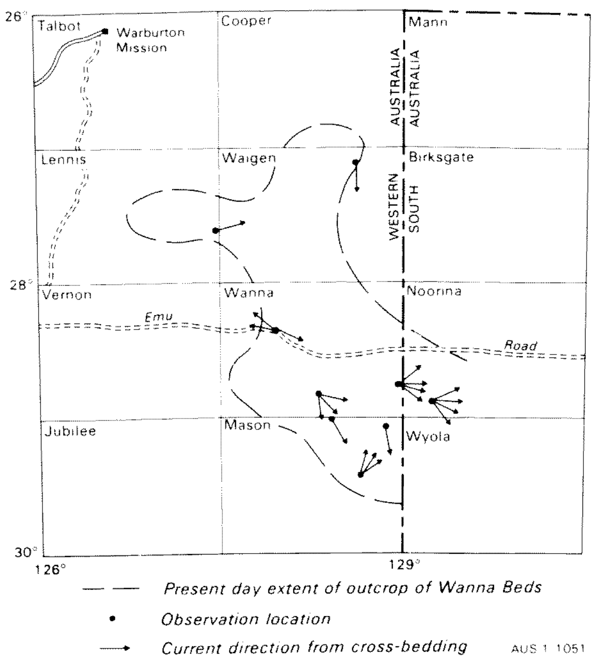


Fig. 30. Palaeocurrent directions from Wanna Beds, south-eastern part of the basin.

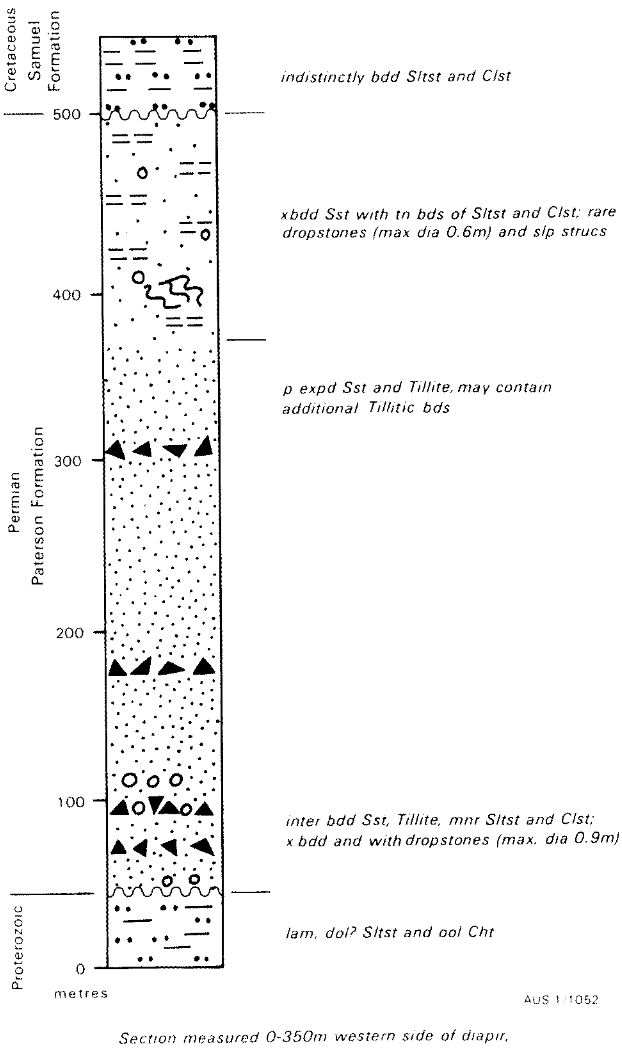


Fig. 31. Composite stratigraphic section through Paterson Formation at Woolnough Hills diapir.

The red colour of part of the Wanna Beds is caused, as in the case of the Lennis Sandstone, by an iron-rich coating on feldspar grains. It is improbable that this coating could have been acquired by the grains before final deposition, as the continual reworking of the sand would have removed the thin coating. The coating is therefore a diagenetic phenomenon which must have originated in an oxidising environment.

UPPER PALAEOZOIC AND YOUNGER

Paterson Formation

Traves & others (1956) amended the name Paterson Range Series (Talbot, 1920) to Paterson Formation when describing a highly varied unit of claystone, siltstone, sandstone, and diamictite that crops out in the Canning Basin. At the type locality, in the Paterson Range (Lat. 21°45′S, Long. 122°10′E), the formation unconformably overlies Precambrian metamorphics, and consists of about 30 m of diamictite and sandstone.

Lithologically similar deposits in the Officer Basin area have previously been referred to as 'Wilkinson Range Beds' (Talbot & Clarke, 1917; McWhae & others, 1958, and a number of other workers), or as 'Wilkinson Range Series' (Talbot & Clarke, 1918). To simplify stratigraphic nomenclature, Lowry & others (1972) used the name Paterson Formation.

The name 'Yowalga Sandstone', which was used by Jackson (1966a, 1966b) for these rocks where intersected in drillholes, was never formalised, and the sediments referred to are here considered to be part of the Paterson Formation.

As only an incomplete and thin sequence is exposed in the type area, the more complete section at Woolnough Hills diapir is here proposed as a reference section (Fig. 31).

Lithology

The Paterson Formation consists of diamictite, cross-bedded, coarse-grained pebbly sandstone, and well-bedded claystone, siltstone, and fine-grained sandstone. These rock types form three main facies which to a minor extent grade into each other. A fourth facies, consisting of calcareous and carbonaceous clayey sandstone is only known in the subsurface in BMR Wanna 1. During mapping, the Paterson Formation was subdivided into these facies wherever possible and the detailed subdivisions are shown on the 1:250 000 geological maps. For the purpose of this Bulletin, however, the Paterson Formation on the accompanying map (Plate 1) has not been subdivided.

The first facies is an unbedded, homogeneous, very poorly sorted, conglomerate to pebbly mudstone (diamictite) (Fig. 32). Compositionally, this facies is mostly a lithic wacke to mudstone. It usually occurs in laterally extensive beds ranging in thickness from a few decimetres to over 40 m (ROBERT 69—Parson's Bluff). At any locality a great variety of angular and rounded clasts, ranging in size from a few millimetres to more than 4 m, of igneous, sedimentary, and metamorphic rocks are present. Commonly, there is a complete gradation from clay-sized matrix to cobble or boulder clasts. Some of the clasts are facetted and and striated (Fig. 33), but in general these are rare. The facets and striations are most easily seen on weathered-out clasts on scree slopes and, therefore, are mostly observed on clasts of fine-grained quartzose rocks, which are resistant to weathering.

In areas close to basement the clasts can be matched with rock types within the basement. Elsewhere, transport up to several hundred kilometres must be inferred for boulders up to about 1 m diameter.

The second facies consists of moderately to poorly sorted, subangular to subrounded, medium to coarse-grained sandstone, grading to pebble and minor cobble conglomerate, with rare, isolated boulders. Minor intercalations of claystone, siltstone, and fine-grained sandstone are also present. Compositionally, the sandstones are mostly quartz arenites to feldspathic arenites grading to wackes.

Few of the lithic clasts that are so characteristic of the diamictites are present in this facies. Bedding is generally on a medium to thick scale, and is mostly distinct, but discontinuous and irregular. The discontinuous and irregular aspect is largely due to the common presence of medium and large-scale cross-bedding, of planar or trough type. Complete cross-sets have only rarely been preserved, but at CUNDEELEE 3 only slightly modified large-scale mega-ripples of medium to coarse-grained sandstone are preserved in fine-grained sandstone to siltstone. The biggest mega-ripple is at least 1.8 m high and over 70 m wide.

Exceptionally large-scale, channel-type cross-stratification is exposed at NEALE 7 (width of channel approximately 65 m; depth 6 m; Fig. 34). Rare fining-upward sequences, were recognised at COBB 12 and 26.

The third facies comprises claystone, siltstone, and fine to medium-grained sandstone, which is generally distinctly, regularly and continuously stratified (Fig. 35) in the range of laminated to medium-bedded. Small-scale cross-stratification is most common in siltstone and sandstone, but low-angle medium to large-scale cross-stratification is locally present. Bedding is in places disturbed by burrows and bioturbation can be so intense that virtually all bedding features are destroyed. Intense slump folding has locally affected claystone-siltstone sequences up to 10 m thick (e.g. WESTWOOD 9) and, less commonly, sandy deposits. At

Fig. 32. Hand specimen of tillite from Paterson Formation at Woolnough Hills diapir (GSWA sample 4341).

Fig. 33. Glacially facetted and striated, subrounded sandstone cobble from Paterson Formation tillite at Woolnough Hills.

Fig. 34. Large-scale channel cross-stratification in fluviatile Paterson Formation at NEALE 7.

RASON 12, a 0.5-m thick layer of poorly sorted coarse-grained sandstone is intricately deformed (Fig. 36), probably as a result of very irregular loadcasting, with multi-directional injection features in the upper part of the bed.

In these generally well-bedded fine-grained sediments, sparse isolated subrounded to subangular clasts up to 1.2 m diameter of mostly resistant rock types are present (Fig. 37) but finer-grained debris also occurs.

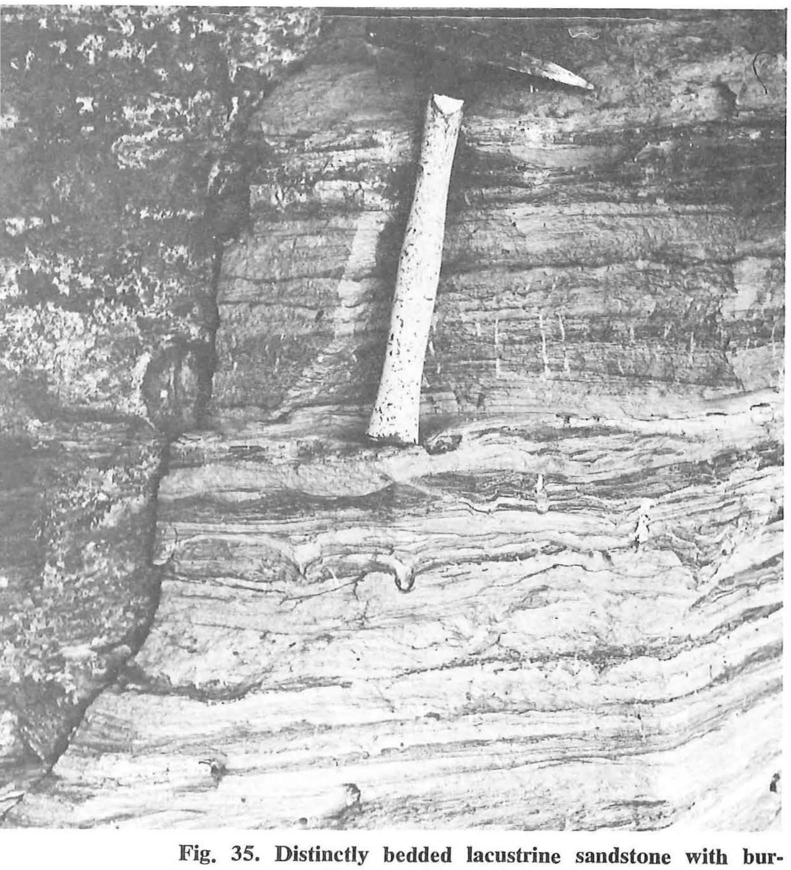


Fig. 35. Distinctly bedded lacustrine sandstone with burrows; Paterson Formation at RASON 11.

Several sub-facies can be distinguished in this group of fine-grained sediments. The most important of these are graded siltstone and claystone, and coarsening-upward sequences. The graded siltstone and claystone sub-facies (Figs. 38 & 39; cf. Flint, 1971, fig. 15-4) is distinctly, very regularly, and continuously bedded on a centimetre scale, and contains beds with sharp bases and isolated large clasts.

Two types of coarsening-upward sequences, which can be up to 20 m thick, have been recognised. The lower part of both types consists of interlaminated to interbedded claystone, siltstone, and minor sandstone, in which the bedding is partly or completely destroyed by bioturbation. In the first type of coarsening-upward sequence this lithology grades upward into well-sorted, fine to medium-grained sandstone with low-angle cross-bedding and rare symmetrical ripples. The second type of sequence consists of coarse-grained, cross-bedded conglomeratic sandstone commonly with an erosional base. Occasionally, the two types of coarsening-upward sequence are superimposed (COBB 24; WESTWOOD 22, 23).

The fourth facies, which is only known from BMR Wanna 1, differs from the other fine-grained deposits in being calcareous and carbonaceous. It is a 120-m thick, lithologically uniform sequence of brownish-grey, silty, fine to medium-grained, carbonaceous and calcareous wacke with numerous well-rounded quartz grains.

Little is known about regional facies relationships in the Paterson Formation, as exposures are generally thin and scattered, and few holes have been drilled through the unit. No order of facies has been established, except that where they are present the diamictites tend to occur near the base of the formation (e.g. BMR Rason 1 & 2, BMR Neale 1, NEALE 7, Woolnough Hills, and numerous outcrops in the western part of the area). A notable exception, however, occurs at LENNIS 25 (7.5 km east-southeast of Hunt Oil Lennis 1), where a diamictite is present in a sequence of cross-bedded coarse-grained sandstone a few tens of metres below the contact with the Cretaceous Samuel Formation. Lennis 1, which was spudded topographically lower than the outcrop at LENNIS 25, penetrated 187

Fig. 36. Involutions (cryoturbations in fluviolacustrine Paterson Formation at RASON 12.
Involutions indicate subaerial periglacial conditions.

m of Paterson Formation, consisting mainly of sandstone with lesser amounts of siltstone and claystone. A poor core sample indicates that another diamictite is present at a depth of approximately 135 m. Sequences with more than one diamictite have also been observed at Woolnough Hills (Fig. 31), and at CUNDEELEE 1, where several thin layers of diamictite are interbedded with graded sandstone beds containing isolated clasts. This sequence is partly deformed by minor slump folding and synsedimentary faulting.

The uppermost part of the Paterson Formation is mostly fine-grained (Hunt Lennis 1 area, Browne diapir, Woolnough Hills diapir). The middle part of the formation consists of alternating coarse and fine-grained rock types with lesser amounts of diamictite. Lateral facies changes are locally abrupt. The absence of marker beds and the wide spacing of wells and outcrops precludes regional subdivision of the formation.

Stratigraphic relations

The Paterson Formation disconformably to unconformably overlies older units. The nature of the contact changes from a disconformity in the central parts of the basin, where the formation overlies flat-lying older

Fig. 37. Rounded quartzite dropstone in lacustrine claystone; Paterson Formation at ROBERT 32.

Fig. 38. Varved siltstone and claystone overlying tillite in Paterson Formation at NEALE 7a.
Note irregular upper surface of tillite next to hammer.

Fig. 39. Siltstone to claystone grading in varves; Paterson Formation at NEALE 7a (GSWA sample 29179).

Palaeozoic strata, to a pronounced unconformity or nonconformity at the basin margins, where it overlies Proterozoic and Archaean rocks.

The Paterson Formation is overlain by the Samuel Formation in the central and northern parts of the area, by the Bejah Claystone in the west, and by the Loongana Sandstone and the Madura Formation in NEALE.

In the northern part of the Eucla Basin the Paterson Formation is disconformably overlain by Tertiary marine sediments.

Lateral equivalents of the Paterson Formation are the Buck Formation in the western part of the Amadeus Basin (Wells & others, 1970), and parts of the Grant Group of the Canning Basin (Crowe & Towner, 1976). These correlations are based on lithological similarities and on sparse palynological information from the Grant Group and the Paterson Formation.

Distinction of Paterson Formation from overlying units

As the upper part of the Paterson Formation consists of predominantly fine-grained sediments and is overlain by lithologically similar Cretaceous rocks, it is often very difficult to map the boundary between these units. However, the presence of scattered pebbles and cobbles or poorly sorted coarse-grained intercalations is generally characteristic of the Paterson Formation. At Browne diapir, rhizocorallid burrows (Fig. 40) are pre-

Fig. 40. Rhizocorallid burrow, basal Samuel Formation; LENNIS 25 (GSWA sample 29185).

sent at about the contact between the Paterson Formation and the Samuel Formation. As these trace fossils probably formed in a marine environment, they are likely to belong to the Early Cretaceous transgression sequence.

At LENNIS 39 (Hann's Tabletop Hill) the Samuel Formation consists of a transgressive fining-upward sequence with rhizocorallid burrows at the base, but with a few small pebbles (< 5 cm diameter) higher up. But for the presence of the marine trace fossil, this sequence could have been mapped as Paterson Formation, because of the supposed glacial pebbles in the lowermost part of the sequence. This outcrop exemplified the difficulty of distinguishing the two units and mapping their boundary, especially as both rhizocorallid burrows and pebbles are not abundant.

The Bejah Claystone, where developed in typical radiolarite facies, is easily distinguished from the Paterson Formation, because of its low density and extensive near-surface porcellanisation. In more clayey or silty development, however, it is more difficult to distinguish the Bejah Claystone from thick claystone intervals in the upper part of the Paterson Formation (ROBERT, HERBERT).

The Loongana Sandstone, though similar in appearance to the coarse-grained sandstone facies in the Paterson Formation, is characterised by the presence of silicified sponges.

In the northern part of the study area, previous workers (Leslie, 1961; Wells, 1963; Wilson, 1964, 1967) mapped a number of units which are all now included in the Paterson Formation. The formation as now mapped includes units mapped by Leslie (1961) as *?Jurassic*, by Wells (1963) as *Undifferentiated Mesozoic*, and by Wilson (1964, 1967) as *Jurassic*. These units, which partly or wholly correspond to each other, were examined principally at the Woolnough Hills diapir. Detailed mapping of the diapir (Fig. 19) showed, however, that the supposed Mesozoic sequence contains diamictite, and we have therefore mapped it as Paterson Formation. At the Madley diapirs, identical rock types are present, which are also reinterpreted as Paterson Formation.

In COBB the abovementioned Mesozoic units have previously been mapped in the Iragana Fault zone and at a number of other localities. Although diamictites have not been found in the areas of COBB the lithologies are identical to those seen elsewhere in the Paterson Formation. An alternative interpretation for outcrops in this part of COBB was given by Veevers & Wells (1961, p. 99). They considered the fine-grained sequence at Hickey Hills as probable Lightjack Formation (Liveringa Group). However, no datable fossils have been found in these sediments, and without palaeontological information to the contrary, we see no reason why they should not be included in the Paterson Formation.

Distribution and thickness

The Paterson Formation is present throughout most of the area (Fig. 41), and outliers of it are known from widely scattered localities on the Yilgarn Block, indicating that the formation may have covered extensive areas of the Precambrian terrain that adjoins the Officer Basin. The correlation with the Grant Group and Buck Formation in the Canning and Amadeus Basins, respectively, also implies a wide distribution to the north and northeast.

The preserved thickness of the Paterson Formation ranges up to a known maximum of about 450 m. As very few complete sections of the preserved part of the formation are known, little can be said about thickness distributions, except that preserved thickness is determined by the following factors: relief of the sub-Paterson Formation unconformity; pre-Cretaceous erosion; post-Cretaceous erosion. It seems likely that the original thickness was greatest in the axial part of the basin, and the thicknesses determined at Lennis 1, Yowalga 2, and Woolnough Hills diapir (200 m, 340 m, and 450 m, respectively) are but minimum figures (Fig. 41). The low value of 110 m at Browne diapir is considered to be due to the structural setting of that section, and pre-Cretaceous movement of the diapir is thought to have caused erosion of the Permian sequence.

Along the basin margins the original variations in thickness due to the relief of the sub-Paterson Formation unconformity were probably considerable. Slopes of about 3°-5° have been observed on the unconformity (e.g. RASON 11). Near CUNDEELEE 4, combined borehole and outcrop data suggest relief on the unconformity of the order of at least 280 m over a horizontal distance of 11 km, giving an average slope of one and a half degrees.

Fossils and age

Apart from simple types of trace fossils and a few fragments of fossil wood, no macrofossils were found in the Paterson Formation during the mapping. The only trace fossil described is from probable Paterson Formation at COBB 20; it belongs to the genus *Tasselia*. Babin & others (1971) consider *Tasselia* to be a biogenic structure ('mud muffs') formed by polychaete worms of the family Maldanidae. Present-day members of the Maldanidae are marine, and the known stratigraphic range of the group is Ordovician to Holocene.

Diverse palynomorph assemblages have been found in fresh subsurface samples. Evans (*in* Wells, 1963) first established the Permian age of the Paterson Formation in the study area, when he recognised the Early Permian 'Nuskoisporites' assemblage, and Balme (*in* Jackson, 1966b) confirmed this dating.

Kemp (1976) examined material from BMR Wanna 1, Neale 2, Rason 2, and re-examined material from Hunt Oil Browne 1 & 2 and Yowalga 1 & 2, and a seismic shothole near NMF 23 (north BROWNE). The assemblages found are all referable to the upper Stage 2 of the Permo-Carboniferous zonal scheme established by Evans (1969). The BMR Rason 2 assemblage is probably slightly younger than those from the other boreholes. The age of Stage 2 assemblages in terms of the standard Russian sequence is earliest Permian (Sakmarian). For further details, see Kemp (1976).

Environment of deposition

The Paterson Formation formed in depositional environments ranging from subglacial through ice-contact, glaciolacustrine to fluvioglacial (Fig. 42). Sections which display some of the facies associations shown in the model are included in Appendix 5.

Glacial deposits. The lack of sorting in the diamictite facies, with boulders up to several metres in diameter occurring in a clay-sand matrix, the presence of facetted and striated clasts, the mostly random fabric, the great variety of rock types present as clasts—some

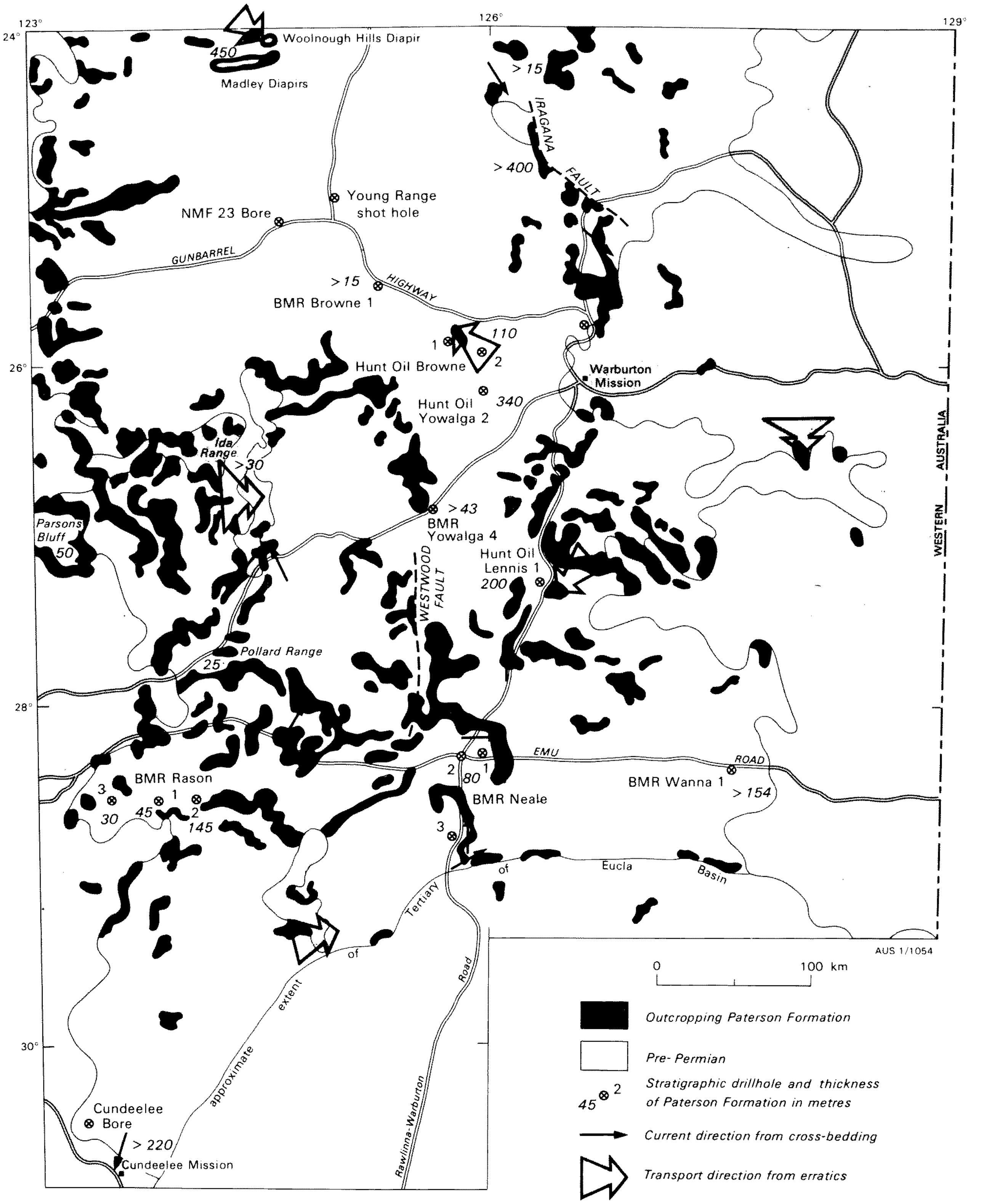


Fig. 41. Distribution of outcrops and thicknesses of Paterson Formation; palaeocurrent directions from cross-stratification and transport directions from erratics also shown.

of which have been transported for hundreds of kilometres, and the very wide distribution indicate that the diamictite is a tillite (cf. Flint, 1971, p. 182). That striated pavements have not been observed within the area is mainly due to the deep weathering of Paterson Formation and bedrock alike. However, Crowe & Chin (1979) describe a striated pavement overlain by tillite on RUNTON, just north of this area.

Though Flint (1971) suggests that tillite is unlikely to contain numerous rounded clasts, these are abundant in tillites of the Paterson Formation. Bergersen (1973), however, showed that in many Pleistocene tills over

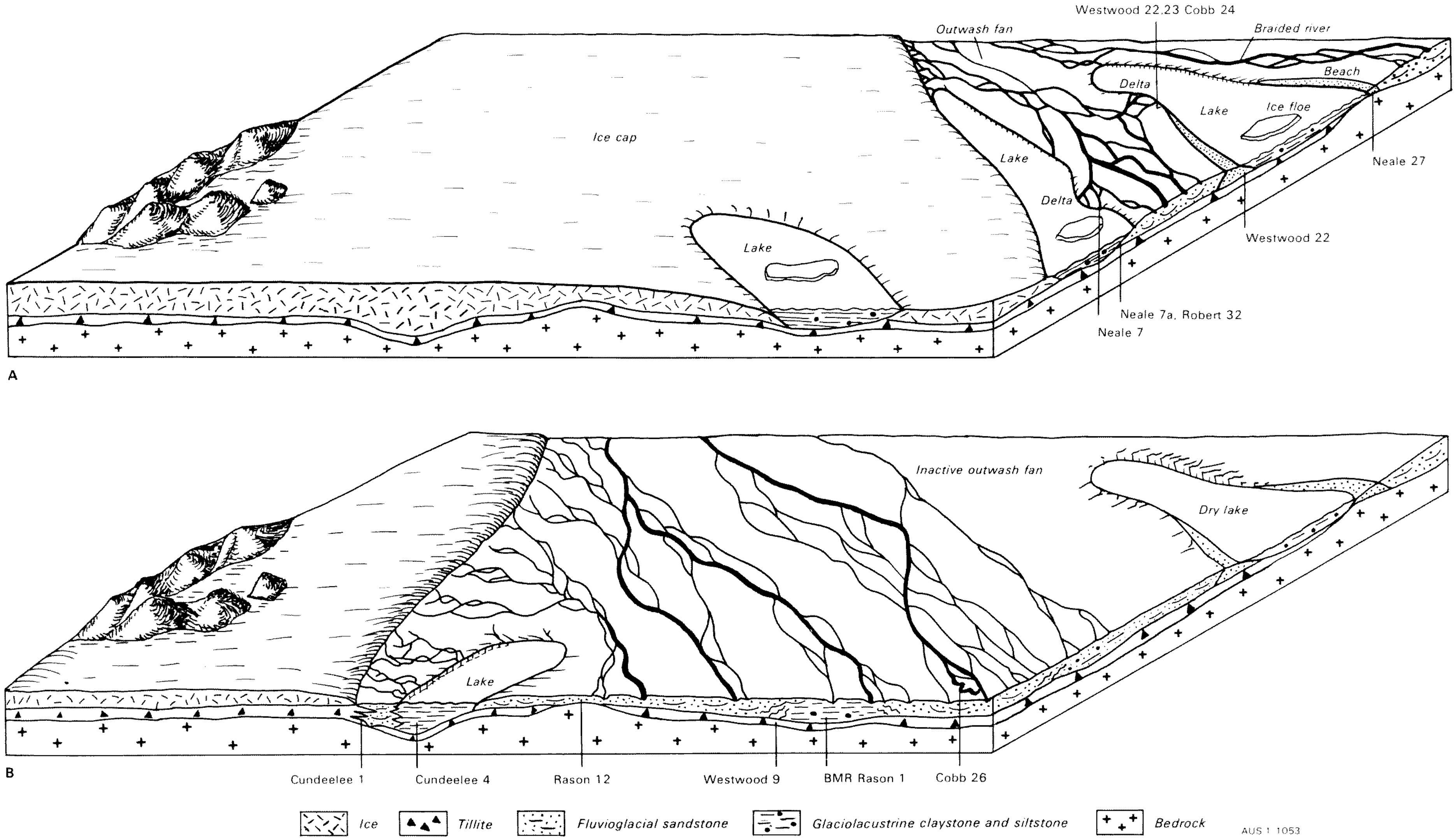


Fig. 42. Block diagrams illustrating the various depositional environments envisaged for the Paterson Formation.
No intended orientation; vertical scale 1:10 to 1:1000, horizontal scale 1:1000 to 1:1 000 000. Upper diagrams shows environments with a retreating ice cap: lakes have formed in front of and between tongues of the ice cap. Lower diagram shows situation where ice has retreated a long way: ice-supported sediments have collapsed and the area is covered by migrating outwash fans. The locations of measured sections reproduced in Appendix 5 illustrating the various facies/subenvinronments are shown.

Fig. 43. Graded and reverse graded sandstone beds in fluviolacustrine Paterson Formation at CUNDEELEE 1.

50 per cent of the erratics are rounded; this was attributed to transport in supraglacial, englacial or outwash rivers with subsequent re-incorporation in the ice and final deposition as tillite.

The sequence of interbedded tillite and graded sandstone beds at CUNDEELEE 1, which is partly deformed by minor slump folding and synsedimentary faulting, is interpreted as an ice-contact deposit. The graded sandstone beds (Fig. 43) are interpreted as turbidites which formed in a lake or quiet part of a stream, while the interbedded tillites were deposited from water-logged till. The interbedding of the two rock types is thought to be due to the repeated, but intermittent flow of water-logged till (mudflow) into an environment where the turbidite sands were being deposited.

Ice-contact deposits are also preserved at WESTWOOD 9 (Appendix 5) where intensely contorted, originally well-bedded strata occur. These contortions are due to the collapse of a sequence of well-bedded rocks that were deposited in an ice-dammed lake, when the ice forming the dam wall melted. The alternative interpretation of ice-pushing is considered improbable, as in that case tillite and fluvial glacial sediments could be expected to be equally involved. In addition clear evidence of overthrusting, as is common in ice-pushed deposits (e.g. Flint, 1971, p. 122), has not been seen in the intensely folded fine-grained deposits.

Involutions are present at RASON 12 (Fig. 36) and are believed to have formed by the differential freezing and thawing of the uppermost layer of sediment or soil overlying permafrost (Smith, 1949; Johnson, 1962). Though it is impossible to prove that the structures at RASON 12 cannot have formed as ordinary load casts, their presence strongly suggests periglacial conditions with permafrost.

Though the presence of a number of tillite layers does not necessarily indicate multiple glaciations, there is some evidence that several advances occurred. The presence in the Hunt Oil Lennis 1 area of two tillite horizons separated vertically by about 150 m of fluvioglacial and lacustrine sediments suggests that at least two separate advances took place. The presence of a thick tillitic sequence with interbedded, laterally continuous fluvioglacial or glaciolacustrine sediments at Woolnough Hills also suggests multiple glacial advances.

Fluviatile deposits. The coarse-grained to conglomeratic sandstone facies is interpreted as a fluviatile deposit on the basis of the moderate to poor sorting, moderate rounding, and types of cross-bedding. The lack of fining-upward sequences probably indicates that the streams depositing the sandstone had a low sinuosity (Allen, 1965) and were most likely of the braided type. Such braided rivers are typical of fluvioglacial outwash plains. The alternation of cross-bedded sandstone with evenly-laminated siltstone and fine-grained sandstone, which is quite common in the Paterson Formation, indicates important fluctuations in the strength of flow in these braided rivers (e.g. Church, 1972).

Except for some channel-type cross-bedding, such as exposed at NEALE 7 (Fig. 34), the cross-bedding present in this facies is considered to have formed by migrating mega-ripples. Mega-ripples such as those at CUNDEELEE 3 must have formed in large, powerful streams. The height of at least 1.8 m of the largest cross-set indicates a depth of flow of between 2.5 m and 10.0 m for the stream in which it formed (Allen, 1967).

Lacustrine deposits. The well-bedded claystone, siltstone, and fine-grained sandstone facies formed in a quiet aquatic environment. This is indicated by the fine grain sizes and by the small scale of the cross-stratification. The absence of marine fossils, the generally simple types of trace fossils, and the rareness in these deposits of palynomorphs suggestive of marine influence indicate a lacustrine rather than marine environment of depositon. Bioturbation on a limited scale is fairly common, but has occasionally been so intense that original structures are nearly obliterated.

The fine-grained, calcareous and carbonaceous sequence in BMR Wanna 1 is also interpreted as a lacustrine deposit, because of fine grain size and monotonous lithology.

The isolated large clasts, usually quartz and quartzite, which occur in these fine-grained lacustrine deposits are interpreted as dropstones from melting ice floes. If these had been transported by icebergs, it could be expected that they would be as variable compositionally as the erratics in tillite. The predominance of quartzite and quartz dropstones can only be explained if they were derived from the outwash fans where significant concentration of resistant material took place. The dropstones were therefore mainly transported by ice floes that formed as the river ice on the outwash fans broke up in spring and summer, as described by Van Straaten, (1946, p. 12) for the Pleistocene of the Netherlands. This interpretation implies that, where the glaciers were in contact with glacial lakes, these lakes were rarely deep enough to permit the glaciers to float, which is a necessary condition if significant calving is to occur (Flint, 1971, p. 49).

The evenly and continuously laminated, graded siltstone and claystone facies with scattered dropstones is interpreted as a varved lacustrine deposit. Other well-bedded siltstone and claystone sequences may also be varved, but absence of distinct grading prevents a definite interpretation. The presence of varves confirms a freshwater environment as the salts in sea water are believed to rapidly flocculate suspended clay particles thus preventing the development of clean grading.

Shoreline sub-facies of this lacustrine facies can also be recognised. Two types of coarsening-upward sequences, which form as a result of the prograding of a shore-line (Visher, 1965, Selley, 1970), have been recognised. One type, which consists of coarse-grained to pebbly sandstone in its upper part, is interpreted as a fluviatile deltaic deposit; the other, which consists in its middle and upper parts of well-sorted, well-bedded sandstone with low-angle cross-bedding and rare symmetrical ripples, is interpreted as a sandy littoral deposit. The sequence at COBB 24 (Appendix 5) contains both types. The presence of well-sorted sandy beach deposits indicates that the lakes within which they formed were at least several kilometres across. Only on sizeable lakes would the wind have sufficient fetch to generate waves strong enough to form well-sorted beach sands.

The minimum depth of the lakes can also be estimated from the thickness of the coarsening-upward sequence. If it is assumed that subsidence was negligible during the formation of a deltaic deposit, it is clear that the depth of water was at least the same as the preserved thickness of the deltaic sequence. For COBB 24 this would imply a minimum depth of water of 20 m to 25 m.

The borehole near CUNDEELEE 4 penetrated more than 220 m of lacustrine claystone of Permian age. The drillhole site is 325 ± 15 m above sea level, but approximately 11 km to the southwest, Archaean granite crops out at 380 ± 20 m. Depth to basement at the drill site is estimated on the basis of geophysical data to be about 600 m. As it seems most unlikely that differential subsidence or post-Permian movements of this magnitude could have occurred in this area of crystalline basement (van de Graaff & others, 1976), it suggests that an original depression at least 220 m deep was filled with lacustrine sediments and that the lake waters were at least that deep. It seems most likely that this deep water-filled depression was scoured out by glaciers. Flint (1971) presented figures of similar magnitude for differential glacial erosion on the North American shield during the Pleistocene.

This is the only reasonably well-established case in the study area where the glaciers are believed to have eroded a depression at least several hundred metres deep. Elsewhere, relatively little differential erosion appears to have occurred.

Synthesis. The widespread occurrence of tillites in the Officer Basin, the generally low relief of the pre-Paterson Formation unconformity, and the intimate association with extensive fluvioglacial outwash and glaciolacustrine deposits indicate that the Paterson Formation was deposited by, or under the influence of, a true continental ice cap (Fig. 42) rather than by coalesced piedmont glaciers. The rock types which occur as erratics indicate that the ice flowed from the present-day basement blocks towards the Officer Basin. Figure 41 shows the probable provenance directions of erratics collected at a few widely scattered localities, and some current directions as measured on cross-bedding.

The presence of rare acritarchs in parts of the formation (Kemp, 1976), and the trace fossil *Tasselia* in sediments tentatively mapped as Paterson Formation, indicates the possibilty of some marine influence. In the Canning Basin the partly equivalent Grant Group contains marine macrofaunas (Crowe & Towner, 1976), indicating open marine conditions to the north of the Officer Basin. A regional facies change from freshwater lacustrine in the south to open marine in the north is thus indicated. It is comparable to facies distributions in the Baltic Sea, which during the Pleistocene was alternatively a freshwater lake and a marine body of water (Flint, 1971).

Samuel Formation

The name Samuel Formation was proposed by Lowry & others (1972) to describe a unit of variegated, laminated to thin-bedded siltstone, sandstone, and claystone that crops out throughout the Gibson Desert. The Samuel Formation partly corresponds to the 'Undifferentiated Cretaceous' of Wells (1963), 'Cretaceous' of Leslie (1961), 'Undifferentiated Lower Cretaceous' of Jackson (1966a) and the 'Jurassic and Cretaceous' of Wilson (1964). The name is derived from Mt Samuel on the Gunbarrel Highway, where about 16 m is exposed. The sequence exposed at Mt Charles, 25 km east of Mt Samuel is designated the type section. The 79 m intersected in BMR Browne 1, approximately 70 km WNW of Mt Samuel, is here designated as a reference section.

Lithology

The Samuel Formation comprises mainly interbedded siltstone and claystone with fine to medium-grained sandstone. Below the weathered zone the primary colours are grey to dark grey and black, with minor green sandstone where glauconite is present. At the surface and within the weathered zone, the colours range from yellow and orange through red to dark brown. Although rare, coarse to very coarse-grained beds are present. The formation is notably finer grained than the Paterson Formation. Most of the sandstones are moderately to well sorted, and composed of mainly moderately to well-rounded grains. Poorly sorted sandstones containing angular grains are present, but they form only a small percentage of the total sequence. Quartzose, micaceous, feldspathic, carbonaceous, and glauconitic sandstone and siltstone are all present. The sandstones are mainly wackes (containing more than 20% matrix material), commonly grading through silty sandstones to sandy siltstones; few clean, mature arenites were seen. The lutites in the Samuel Forma-

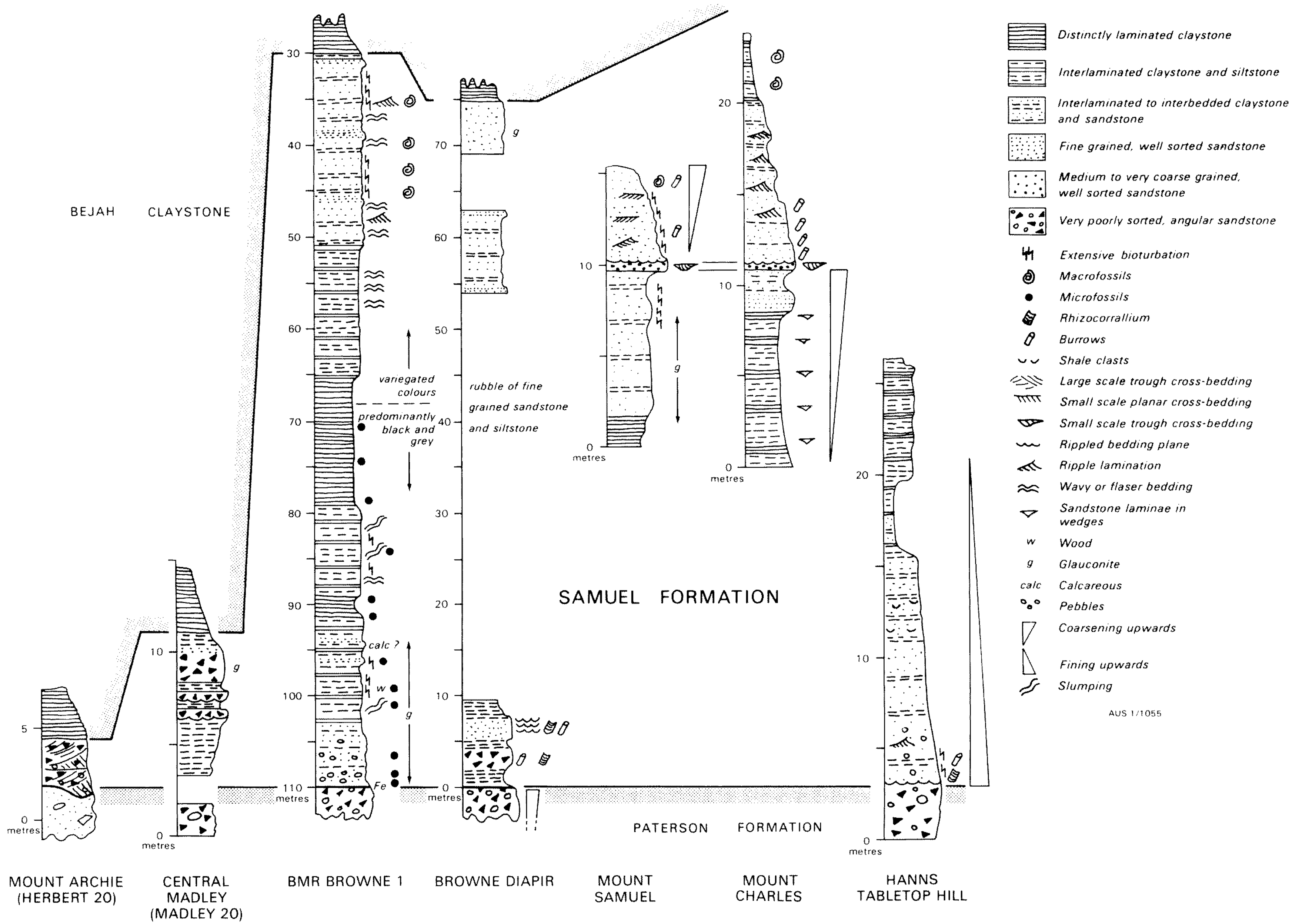


Fig. 44. Measured sections of Samuel Formation.
Sections run (left-right) NW to SE across the northern part of basin.

tion are usually well indurated, as they are very susceptible to silicification and ferruginisation.

The Samuel Formation contains a range of bedding types. Irregular, discontinuous to wavy bedding is very common in thinly interlaminated claystone and siltstone intervals. Thicker beds of claystone or siltstone containing very thin (usually few millimetres thick) laminae of sandy siltstone only a few centimetres in lateral extent are also a characteristic lithology. In some outcrops these sandy laminae form small ripples so that lenticular bedding is developed. Although the irregular, wavy bedding is more common (it probably forms about 80 percent of the formation in BMR Browne 1), distinctly parallel-laminated and thin-bedded lutites are preserved in some outcrops. Extensive bioturbation and burrowing have destroyed the original bedding in many outcrops and homogenised what were probably interbedded sands and silts. Cross-stratification is present, but is less common than in the Paterson Formation. It is of the low angle, small-scale type in medium to coarse sandstone beds or ripple lamination type in finer sandstones.

A distinct, transgressive fining-upwards sequence, consisting of a basal medium to coarse-grained pebbly sandstone grading upwards through interbedded fine-grained sandstone and siltstone to claystone, is present in the basal 20 m of the formation in BMR Browne 1 and at Hann's Tabletop Hill (Fig. 44). Rare coarsening-upward and fining-upward sequences, 3 to 10 m thick, are also present higher up in the formation (e.g. at Mount Samuel and Mount Charles).

Stratigraphic relations

The Samuel Formation disconformably overlies the Paterson Formation, commonly with a gradational contact, but with a sharp lithological break at a few localities such as Mount Archie and BMR Browne 1. At Browne diapir, Hann's Tabletop Hill, and Woolnough Hills, the contact between the Paterson Formation and the overlying Samuel Formation occurs in a predominantly fine-grained sequence. In such a sequence it is extremely difficult to define the boundary between the two units. In BMR Browne 1, which continuously cored through the Samuel Formation into the underlying Paterson Formation, the contact between the two formations is a sharp disconformity. A fining-upwards sequence of grey to black, micaceous, feldspathic, glauconitic, and carbonaceous bioturbated siltstone and fine-grained sandstone is underlain at 109 m by mottled, poorly sorted, coarse to very coarse-grained poorly indurated sandstone (Fig. 44). This marked change in lithology is well illustrated on all of the geophysical logs, (see Appendix 1). The contact is probably located in a weakly indurated interval of silty sand overlying a 4-m interval of no core recovery. Three reddish-brown to black, indurated, silicified and ferruginised beds, each about 3 cm thick, are considered to mark the top of the Paterson Formation. These hard bands consist of sub-angular to sub-rounded grains of quartz and feldspar set in a matrix of hematite and a manganese mineral.

In outcrop silicified and ferruginous beds are common at about the contact between the Samuel and Paterson Formations. In BMR Browne 1 the bands are located in the porous, poorly indurated, weathered top of the Paterson Formation. Although the possibility of Tertiary ferruginisation and silicification at a lithological contact within a sequence cannot be disregarded, an alternative interpretation is that these altered beds are a pre-Cretaceous weathering feature. However, in outcrop no distinct soil profile has been recognised at this contact, and if the ferruginisation and silicification are pre-Cretaceous phenomena, only the lower part of a weathering profile is preserved.

Recognition of the contact between the Paterson and overlying Samuel Formations relies on distinguishing features such as the presence of *Rhizocorallium* or transgressive sandy sequences lacking drop-stones. The information from BMR Browne 1 indicates that, in areas where both formations are composed of similar lithologies and where the outcrop is good, detailed examination of the sequence for evidence of pre-Cretaceous deep weathering with the formation of ferruginous beds may assist in recognising the actual contact.

The Samuel Formation is overlain with a conformable gradational contact by the Bejah Claystone. In BMR Browne 1, and in outcrops where the upper contact is exposed, the variegated interbedded sandstone, siltstone, and claystone of the Samuel Formation grade upwards, within about 20 cm, into white claystones, which at some localities are micaceous and silty.

Distribution and thickness

The Samuel Formation is widespread throughout the northern part of the area mapped; it is the unit on which the extensive undulating laterite plains synonomous with the Gibson Desert are developed. It has been mapped as far south as Westwood Bluff in the eastern part of WESTWOOD, so it underlies an area of about 80 000 sq. km.

In BMR Browne 1, where the upper and lower contacts are well defined, the Samuel Formation is 79 m thick. In Hunt Oil Browne 1 & 2 and Yowalga 1 & 2, drilled between 60 and 100 km southeast of BMR Browne 1, Jackson (1966a) showed the Samuel Formation as between 80 and 90 m thick, but the BMR drilling and mapping suggest these figures are probably over-estimates by about 20 m. Early Cretaceous spores were found in a core from a BMR seismic hole near the western end of the Young Range. The core was taken from 81.7 to 83.5 m and, as the hole was spudded near the top of the formation, a similar thickness is indicated in this area.

The only complete surface sequence is at the Browne diapir where a very poorly exposed 70-m thick sequence occurs (Fig. 44). At Woolnough Hills, in the far north of the area, the formation is at least 50 m thick, but the top is not exposed. Elsewhere, usually only 15 to 20 m of the unit is exposed. From the central part of the present outcrop area—vicinity of Mt Everard—which we interpret as the basin axis, the formation thins towards the west and east. At several localities on the western margin of the basin, the Samuel Formation is thinner and distinctly coarser grained. At one of the localities, Mt Archie, (central-western HERBERT) the formation is 2 m thick and consists of very coarse-grained pebbly sandstone. At MADLEY 20 the formation is about 10 m thick and also contains coarse-grained sandstones (Fig. 44).

Leslie (1961) recorded a maximum thickness of 76 m for a unit he called *Cretaceous*, which is equivalent to our Samuel Formation, but he also noted that throughout the greater part of the Gibson Desert the thickness remaining after erosion is generally less than 30 m.

The Samuel Formation extends north from the area mapped and crops out in MORRIS, RUNTON and RYAN (Towner & others, 1976). The lithologies are similar except further northward coarser-grained interbeds become more prominent and the formation grades laterally into the Anketell Sandstone.

Fossils and age

An Aptian (Early Cretaceous) age for the Samuel Formation and overlying Bejah Claystone is indicated by their molluscan fauna (Skwarko, 1967). There appears to be no significant difference in the age of these two formations as determined by the fossils, therefore, to avoid repetition, the details of the fossils in the two formations are described together below.

Skwarko identified twenty-eight different fossils, mostly bivalves, but including a gastropod and ammonite. Age-diagnostic fossils include *Maccoyella sp.* aff. *M. corbiensis* (Moore, 1870), *Maccoyella sp.* aff. *M. reflecta* (Moore, 1870), *'Pseudavicula anomala'* (Moore, 1870), *Eyrena sp.* cf. *E. linguloides* (Moore, 1870), *Fissilunula clarkei* (Moore, 1870), *Tancredia plana* (Moore, 1870). *?Aphrodina woodwardiana* (Hudleston, 1884), and *Sanmartinoceras?* sp. The fauna closely resembles the molluscan faunas obtained from Aptian marine deposits in the Eromanga Basin, and Skwarko suggests a direct marine and faunal connection between these two areas, either across the far north of Australia or via the Eucla Basin. The regional mapping, however, indicates that only one of the connections existed. The Aptian Cretaceous of central Western Australia changes from an open marine facies (Samuel Formation, Loogana Sandstone, Madura Formation) in the Eucla and Officer areas, through a marginal marine facies (Anketell Sandstone) to a fluviatile facies (Callawa Formation) in the southern Caning Basin, indicating a gradual northward shallowing sea with a shoreline somewhere in the vicinity of 22° South.

A diverse and well-preserved assemblage of spores, pollen and microplankton was recovered by Kemp (1976) from the Samuel Formation, especially from BMR Browne 1. Saccate pollen grains dominate and belong to the form species *Microcachryidites antarcticus* Cookson, *Podosporites microsaccatus* (Couper), and *Podocorpites ellipticus* Cookson. Fern spores are common and diverse with species of *Gleicheniidites* and *Cyathidites* most abundant. The most stratigraphically useful elements are among the rarer trilete spores, including *Foraminisporis dailyi* (Cookson & Dettmann), *F. wonthaggiensis* (Cookson & Dettmann), *Kuylisporites lunaris* Cookson & Dettmann, *Murospora florida* Balme, *Pilosisporites notensis* Cookson & Dettmann, *Trilobosporites purverulentus* (Verbitskaya), and *Cydosporites hughesi* Dettmann. The marine microplankton recovered included dinoflagellate cysts and acritarchs, all were generally well preserved but they were usually numerically subordinate to the spores and pollen. The species *Dingodinium cerviculum* Cookson & Eisenack and *Huderongia mcwhaei* Cookson & Eisenack were prominent in most specimens (Kemp, 1976 for detailed discussion).

The microflora confirmed the Aptian age indicated by the marine invertebrates; the spores and pollen add little to this age determination, but the microplankton suggests that the sequence may be of late Aptian age.

Recycled Permian palynomorphs were also found in samples from the Samuel Formation in BMR Browne 1. Species identified were *Didecitritetes ericianus* (Balme and Hennelly), *Dulhuntyispora inornata* Segroves, *Protohaploxypinus* sp., and *Parasaccites* sp. A late Permian (Stage 5) age is indicated by *D. ericianus* and *D. inornata* for the sediments which originally contained them.

The nearest known Late Permian rocks occur in the northeast part of the Canning Basin, approximately 700 km northeast of Browne 1. Three alternative interpretations to explain the presence of these reworked palynomorphs are possible: the reworked palynomorphs have been transported over long distances and come from Upper Permian sediments in the Canning Basin; there are unrecognised Upper Permian strata in the Officer Basin; an Upper Permian sequence was present in the area, but was eroded before the Early Cretaceous transgression finally covered the area. No meaningful choice between the alternatives can be made on the evidence available.

As noted in the section on lithology, the upper part of the Samuel Formation in Browne 1 is extensively weathered. This was confirmed by the microfossil studies as samples above 70 m are barren of palynomorphs; presumably these were destroyed by the leaching.

Environment of deposition

The macrofossils, microfossils, presence of glauconite, and sedimentary structures in the Samuel Formation attest to a mainly shallow marine environment of deposition.

The absence of large-scale cross-bedding and the general fine-grained character of the sediments indicate a low-energy environment. The high content of silty material, even in the sandstone, the common presence of carbonaceous material and angular flakes of mica suggest deposition without much reworking. Black pyritic clays in the lower part of BMR Browne 1 indicate reducing conditions within the sediments. The presence of wavy and flaser bedding and coarsening-upward sequences indicates shallow subtidal to possibly intertidal settings with local development of offshore sand banks. The rhizocorallid burrows in the basal Samuel Formation belong to Seilacher's (1967) *Cruziana* assemblage, and corroborate the interpretation of a shallow, low-energy environment.

The palynomorphs confirm the interpretations based on lithology and sedimentary structures. The marine microplankton are well preserved. However, they are generally numerically subordinate to the spores and pollen, indicating that deposition was at no time far from the Cretaceous shoreline nor from the parent vegetation which provided the source of the spores and pollen. Only two samples of the twelve taken from BMR Browne 1 contained more marine forms than terrestial.

One short interval of much higher-energy conditions is indicated by a thin sandstone bed exposed in the cliff faces at Mt Charles and Mt Samuel (Fig. 44). Although these localities are 27 km apart, the bed of sandstone is the same thickness and character at both outcrops. It is 30 cm thick and composed of coarse to very coarse-grained, rounded to very well-rounded, quartz wacke containing sparse shale clasts. It is festoon cross-bedded on a decimetre scale throughout, has a sharp base and a sharp rippled top. At both localities it forms a prominent marker-bed in a sequence composed predominantly of interbedded claystone, siltstone and minor fine-grained sandstone. As this bed is only 30 cm thick, but laterally extensive, and indicative of much higher energy conditions than the remainder of the sequence, it is interpreted as a storm deposit.

Bejah Claytone

The name 'Bejah Beds' was introduced by Veevers & Wells (1961) to describe a white siliceous claystone that crops out in the southern part of the Canning Basin. Wells (1963) recognised the unit throughout the Gibson Desert. Following regional mapping in the Officer Basin, Lowry & others (1972) modified the name to Bejah Claystone as the lithology, distribution, age, and stratigraphic relationships of the unit were then much better known. Although neither Veevers & Wells (1961) nor Wells (1963) nominated a type section, it is evident they considered Bejah Hill (in RUNTON) as the type section. In the Officer Basin area thicker exposures of Bejah Claystone have been found, and Lowry & others (1972) nominated an unnamed locality, BROWNE 24 (25°28′S, 125°06′E), as a reference section (Fig. 45).

Lithology

The Bejah Claystone consists predominantly of white claystone and siltstone with a few intercalations of very fine-grained sandstone (Fig. 46), is either soft, friable, and very light in weight (probably due to a large microporosity, owing to the radiolaria content), or hard with a conchoidal fracture where it is silicified. The silicification is part of the early Tertiary duricrust profile, and a typical outcrop comprises cliffs developed in the upper resistant silicified beds, overlying cavernous and decomposed soft claystone. The availability of large amounts of silica from the radiolarian tests may be the reason why the beds are commonly silicified. The white colour and the vertical cliff faces impart a distinctive airphoto-pattern, which is discussed in detail by Veevers & Wells (1961, p. 170). Although white is the most dominant colour, irregular streaks and mottles of pink, yellow, purple, and orange have been seen. The unit is indistinctly bedded, so it appears massive in outcrop. Close examination however, indicates that it has been extensively bioturbated and much of the original bedding has been destroyed. Veevers & Wells (1961) noted the presence of a medium-grained sandstone bed containing claystone fragments at several localities in the south of the Canning Basin. Although this was not recorded in the Officer Basin beds of siltstone grading to very fine-grained silty sandstone are present in the larger outcrops throughout the Officer Basin (Fig. 45). These beds range in thickness from 10 cm up to about 3 m and are always distinctly burrowed and bioturbated. Their bases are sharp and they have gradational tops; they represent short, rapid influxes of slightly coarser-grained material.

Stratigraphic relations

The Bejah Claystone conformably overlies the Samuel Formation except in the southern part of HERBERT and the northern part of ROBERT, where it rests disconformably on the Paterson Formation. In BMR Browne 1, at Mount Beadell, and at the Browne diapir, where the contact between the Samuel Formation and the Bejah Claystone is exposed, the variegated, interbedded siltstone, claystone, and sandstone of the Samuel Formation grades upwards into white, indistinctly bedded claystone or siltstone. At one locality in the southeast of MORRIS (23°55′40″S, 125°43′25″E) Towner & others (1976) recognised a porcellanised clay-pellet conglomerate at the base of the formation, but elsewhere they describe the base as gradational. In northern ROBERT, where the Bejah Claystone appears to overlie the Paterson Formation directly, the contact is not exposed.

The upper limit of the formation is almost always erosional. It is either unconformably overlain by the Lampe Beds or it is the present erosion surface. However, at WARRI 3 a well-sorted fine to medium-grained quartz arenite, which is distinctly burrowed and bioturbated, caps normal Bejah Claystone. This may be equivalent to the coarse-grained sandstone at the top of the formation at two localities in MORRIS mentioned by Veevers & Wells (1961, p. 166).

The Bejah Claystone correlates with the lithologically identical Windalia Radiolarite of the Carnarvon Basin.

Distribution and thickness

The Bejah Claystone is preserved mainly north of 26°S as horizontal cappings on the tops of many of the mesas in the Gibson Desert. The lower slopes of the mesas and the intervening plains, which are covered by unconsolidated Cainozoic sediments, consist largely of the underlying Samuel Formation. The approximate extent of continuously preserved Bejah Claystone is shown on the solid geology sketch accompanying the geological map (Plate 1), and as shown, it covers a total area of about 19 000 km^2.

The thickest sections of Bejah Claystone are located in the central and northern parts of BROWNE, where up to 30 m of the formation is preserved (Fig. 45). In BMR Browne 1 it is 27 m thick (Appendix 1). To the west in MADLEY and HERBERT the formation is usually less than 20 m thick, although in some of the higher mesas the base of the unit is not seen and the formation could be slightly thicker. According to Towner & others (1976), the Bejah Claystone in the south Canning Basin may be 10 m thick at Traeger Hills (MORRIS) but elsewhere it appears to be thinner. Veevers & Wells (1961) interpreted about 15 m of Bejah Claystone at Bejah Hill, but Towner & others (1976) regard most of this outcrop as Samuel Formation and recognise only the upper three to four metres as Bejah Claystone.

Fossils and age

The molluscan fauna indicates an Aptian (Early Cretaceous) age. Radiolaria have been identified in samples of the Bejah Claystone collected from RUNTON, MORRIS, HERBERT, and BROWNE. Crespin identified *Lithocyclia exilis* Hinde and *Cenosphaera* sp. in thin sections of the samples from the southern Canning Basin (*in* Veevers & Wells, 1961, p. 169). Lloyd (1963) identified radiolaria in thin sections of the Bejah Claystone from HERBERT and BROWNE, and remarked that they appeared similar to *Lithocyclia exilis* Hinde, 1893. However, in a discussion of the radiolaria, Lloyd remarks that they have not been studied in enough detail to be of use for correlation purposes, and are not even well enough preserved to be adequate for specific identification. Additional radiolaria have been found by us in thin sections of the Bejah Claystone from core matrial from BMR Browne 1 and surface samples from BROWNE.

Environment of deposition

The molluscan fauna and radiolaria indicate a marine environment. Fairly uniform and quiet conditions, mostly below wave base and with a slow sedimentation

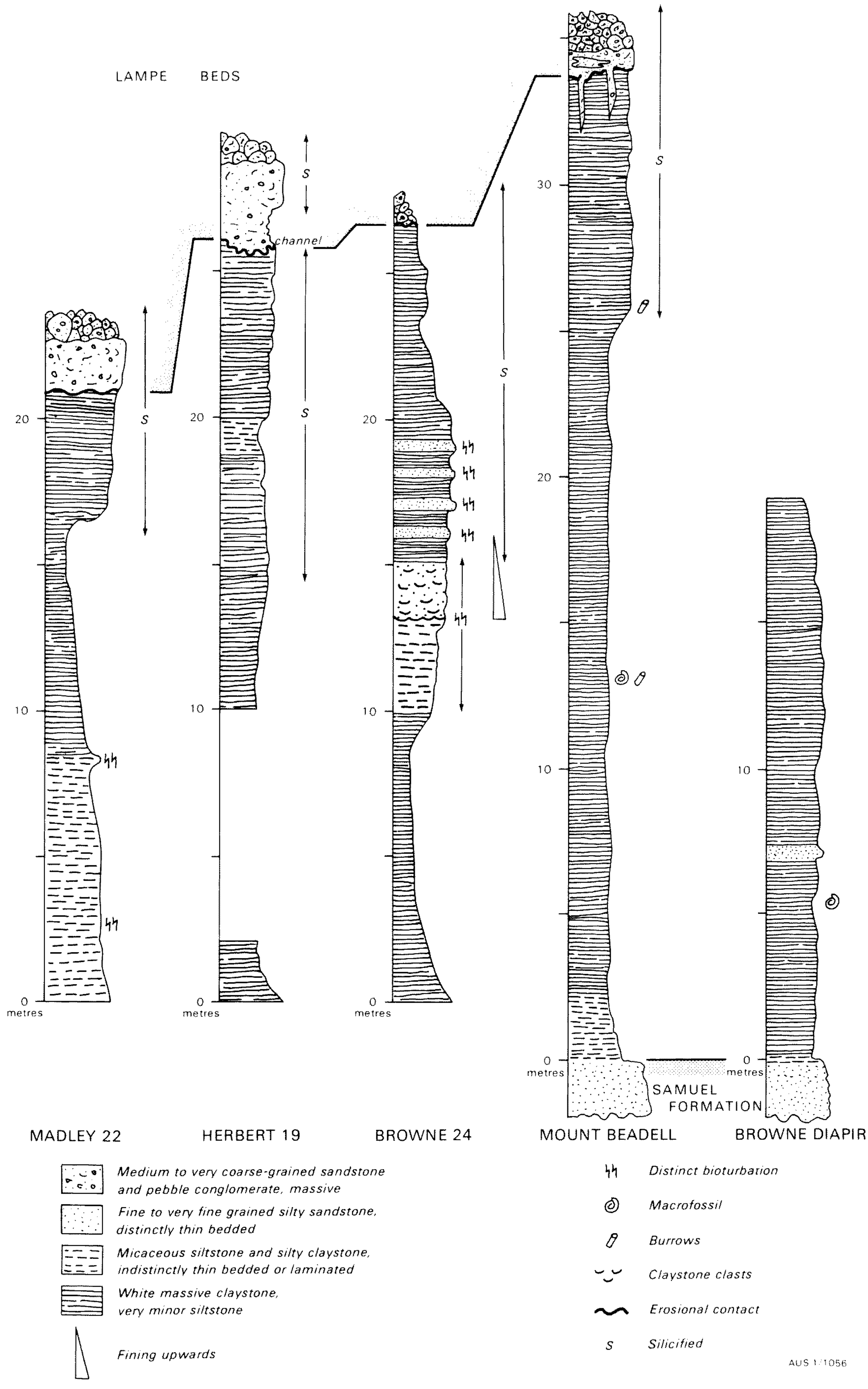


Fig. 45. Measured sections of Bejah Claystone.
Sections run (left-right) from NE to SW across the northern part of basin.

Fig. 46. Bejah Claystone at BROWNE 24 with resistant sandstone bed (near hammer) in cliff of 'massive' white porcellanised claystone (M1233).

rate, are inferred from the fine grain size, the presence of pelagic radiolaria, and the intense bioturbation. The thin beds of laterally extensive sandstone with sharp lower boundaries were probably formed during short-lived periods of slightly higher current activity and more rapid sedimentation, so that the burrowing organisms were unable to completely homogenise these beds into the uniform lithology characteristic of so much of the Bejah Claystone. The coarser-grained sandstone at the top of the formation probably represents a regressive coarser clastic event as the epicontinental seas retreated, indicating that the formation was probably not much thicker than about 30 m.

The stratigraphic setting of the Bejah Claystone indicates that it formed in a shallow epicontinental sea. The high content of radiolarians is unusual. Present day radiolarians are virtually restricted to deep-sea environments in which the pelagic rain of siliceous tests is not completely diluted by terrigenous debris or carbonates. In the case of the Bejah Claystone, however, the pelagic radiolarian-rich sediments accumulated and survived in an epicontinental sea, probably because most of the continent was submerged by the high Aptian sea level, leaving very little land to supply detritus. The absence of carbonates in such circumstances is, however, puzzling.

Loongana Sandstone

The Loongana Sandstone is a lenticular and discontinuous unit of sandstone and conglomerate, which overlies Precambrian basement and forms the basal part of the Eucla Basin sequence (Lowry, 1970). The type section is in Transcontinental Railway No. 2 Bore (also known as Loongana Bore), where it consists of fine to coarse-grained, soft sandstone with hard bands, and granite boulders.

In the Eucla Basin the Loongana Sandstone is only known in the subsurface, but outcrops of it were found during the Officer Basin mapping in the vicinity of Naries Point (28°52′S, 124°50′E) in NEALE, so a description is included here.

Lithology

In outcrop the Loongana Sandstone consists of moderately sorted, coarse-grained to conglomeratic sandstone. At one locality (NEALE 14) a basal conglomerate 0.5 m thick consists of subangular to rounded clasts of granite, quartz, and silicified oolite up to 0.45 m across. The sandstone is intensely weathered and partly silicified and/or ferruginised, but the original composition appears to have been quartz arenitic. The quartz grains range from angular to rounded, but some of the partly rounded grains which have ?resorption re-entrants may be of igneous origin and may have retained their original shapes rather than having been rounded by sedimentary processes.

The sandstone facies is commonly cross-bedded on a metre to tens-of-metres scale, and the shape of the cross-sets is partly controlled by the topography of the underlying basement. Abraded fragments of silicified sponges are present in the sandstone. The presence of the sponge fragments is the main characteristic which permits these sandstones to be separated from the Paterson Formation, which is lithologically similar.

Stratigraphic relations

In the Eucla Basin the Loongana Sandstone nonconformably overlies Precambrian basement and is apparently conformably overlain by the Madura Formation. Similarly, in the Naries Point area the formation nonconformably overlies basement. It also unconformably to disconformably overlies Paterson Formation, and is conformably overlain by the Madura Formation. The Aptian age inferred for the Loongana Sandstone in the central parts of the Eucla Basin suggests that the unit probably correlates with the Samuel Formation.

Distribution and thickness

Lowry (1970) concluded that the Loongana Sandstone in the Eucla Basin is a discontinuous unit with an irregular distribution in depressions of the basement surface. A similar interpretation is suggested for the Naries Point area, where erosion has removed large parts of the original sediment body.

Because of the irregular unconformity, thickness of the Loongana Sandstone is very variable, ranging from 2.5 m at NEALE 14 to a probable maximum of a few tens of metres.

Age

A poorly preserved palynomorph assemblage indicates a late Mesozoic age, but as the basal part of the overlying Madura Formation contains an Aptian palynomorph assemblage, this is probably also the age of of the Loongana Sandstone.

The siliceous sponges found in the Naries Point area are too poorly preserved to permit specific identification, and are, therefore, useless for dating.

Environment of deposition

From its lenticular and conglomeratic nature and the absence of microplankton, Lowry (1970) concluded that the Loongana Sandstone, in the central part of the Eucla Basin, is probably a fluviatile deposit. However, the Loongana Sandstone around Naries Point is more likely to be of marine origin, as it contains sponges identical to those in the overlying marine Madura Formation.

In the Naries Point area the unit probably formed during the initial stage of the Early Cretaceous transgression. The presence of quartz grains with preserved

?igneous textures indicates that the sandy material was little reworked before finally being deposited in depressions along the drowning coast.

Madura Formation

The Madura Formation consists of approximately equal amounts of glauconitic sandstone, carbonaceous sandstone, siltstone, claystone, and shale. The type section is in the Transcontinental Railway No. 1 Bore (also called Madura No. 1 Bore & Madura Bore), in the interval 283-640 m. It is described in some detail by Lowry (1970). Like the Loongana Formation, the Madura Formation is only known in the subsurface of the Eucla Basin, but was found during this mapping project in outcrops in the vicinity of Naries Point.

Lithology

The Madura Formation consists of poorly sorted, medium to coarse-grained quartzose sandstone, fine to medium-grained greensand, and indistinctly bedded claystone with scattered quartz grains. The green mineral is nontronite (an iron-rich montmorillonite), which is believed to be an alteration product of glauconite, as glauconite is common in fresh subsurface samples. The quartz grains are generally angular to sub-rounded and medium to coarse-grained. These rock types are similar to the ones present in the upper part of the type section as described by Lowry (1970).

Bedding in the greensand part of the sequence has been completely obliterated by intense bioturbation. The only recognisable trace fossil is spreitenbau of the *Teichichnus* type. In outcrops about 5 km to the south-southwest of Naries Point the contact with the underlying Paterson Formation is well exposed. At this locality borings filled with greensand penetrate 10 cm into the underlying white-weathering Paterson Formation. Small (diameter 8-10 mm) and large (25-50 mm across) burrows are present and form an irregular honeycomb pattern in plan. A few hundred metres laterally the same stratigraphic contact is undisturbed by burrowing; it is sharp and a thin basal sandstone grades upwards into greensand (Fig. 47).

Apart from the trace fossils, siliceous sponges and fragments of silicified wood with *Teredo*-type borings are common.

Stratigraphic relations

In the Eucla Basin the Madura Formation conformably overlies the Loongana Sandstone, but where that unit is absent, the formation directly overlies Precambrian crystalline basement. The Madura Formation is disconformably overlain by the Eocene Hampton Sandstone or, where that unit is absent, by the Eocene Wilson Bluff Limestone (Lowry, 1970).

In the Naries Point area the formation conformably overlies the Loongana Sandstone and, where this lenticular unit is absent, it disconformably to unconformably overlies the Paterson Formation. The Aptian-Albian age of the Madura Formation suggests a correlation with part or all of the Samuel Formation and the Bejah Claystone.

Distribution and thickness

The Madura Formation is present in the central Eucla Basin and has a maximum known thickness in the type section of 357 m, but offshore it may increase to over 600 m. Lowry (1970) assumed that the formation

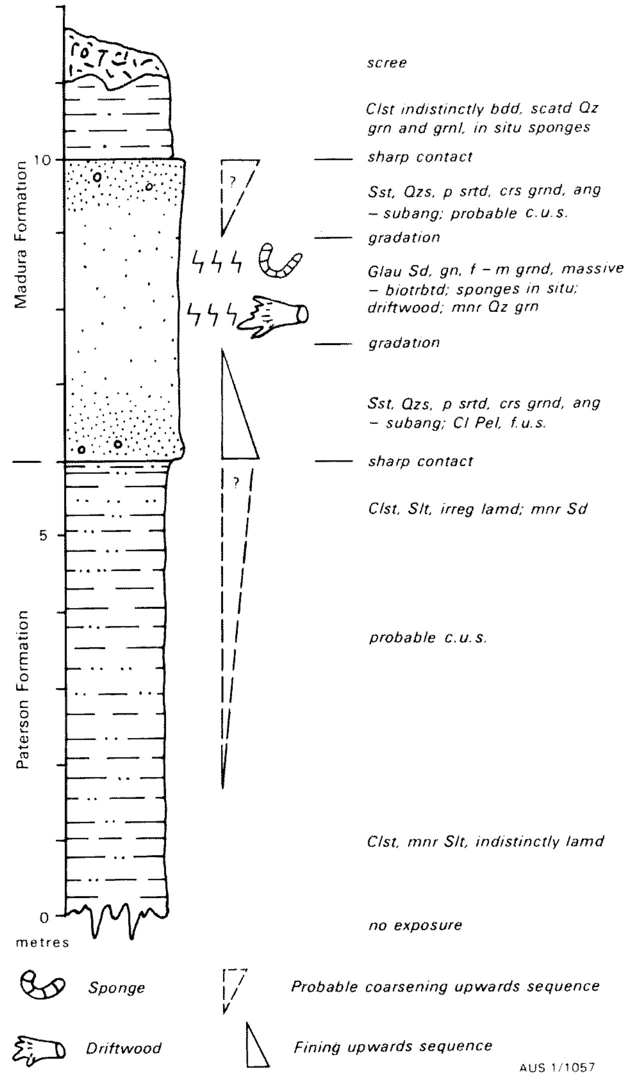


Fig. 47. Section through uppermost Paterson Formation and overlying Madura Formation at NEALE 31.

did not extend further north than about 20°30'S, but the outcrops near Naries Point prove that the unit has been much more extensive, and that its present distribution is determined largely by erosion.

Maximum measured thickness in outcrop is only 6 m, and it is unlikely that the preserved thickness in the Naries Point area greatly exceeds this figure.

Age

Ingram (1968) obtained three different palynomorph assemblages from the Madura Formation in the central part of the Eucla Basin. He regarded them as Neocomian-Aptian, Albian-Cenomanian, and Senonian. His findings largely confirmed the ages based on megafossils and foraminifers (Lowry, 1970 p. 55). The forms listed for the oldest assemblage do not contain any typically Neocomian forms (D.C. Lowry, pers. comm., 2.5.74) and this assemblage is here considered to be of Aptian age.

Geomorphological evidence also strongly suggests that these deposits are Cretaceous. Bunting & others (1974) and Van de Graaff & others (1977) showed that it is unlikely that the Eocene transgression ever reached further than the present 300-325 m contours on NEALE. The Naries Point locality is at an elevation of 360-375 m, and these sediments cannot, therefore, have been deposited in the Eocene sea. The possibility of a Senonian age for these sediments is rejected, as the Aptian-Albian transgression is the only Cretaceous transgression known to have affected the interior of Western Australia (Veevers, 1971). This strongly suggests that the deposits mapped as Loongana Sandstone and Madura Formation correlate with the Samuel Formation and Bejah Claystone, which are reliably dated as Aptian-Albian (Skwarko, 1967; Kemp, 1976).

Environment of deposition

Lowry (1970) concluded that most of the formation was deposited in a marine environment, with the exception of the older part of the sequence, which he suggested might be paralic. The Madura Formation at Naries Point is definitely a marine deposit, as indicated by the presence of sponges, *Teredo*-type borings in driftwood, and the occurrence of complicated burrows such as *Teichichnus*. The poor sorting of the sandy parts of the formation may in part be due to intense bioturbation, but the poor rounding of the coarse quartz grains suggests that wave and current action were of insufficient strength to produce well-sorted littoral sands. The abundance of altered glauconite points to a low sedimentation rate of siliciclastics and water temperatures not exceeding about 15°C (Porrenga, 1967). The presence of coarse quartz grains scattered in claystone (Fig. 47, 10-11 m) is probably due to bioturbation, as numerous burrows can be seen in thin section.

Lampe Beds

The name Lampe Beds was proposed by Lowry & others (1972) to describe remnants of a thin but widespread, ubiquitously conglomeratic unit. Previous works have referred to this unit as silcrete (Veevers & Wells, 1961), undifferentiated Tertiary (Jackson, 1966a) and and grey-billy (Leslie, 1961).

Where such silicified pebbly sandstone overlies fine-grained bedrock such as the Bejah Claystone, Samuel Formation, Wanna Beds, or some of the finer-grained Proterozoic formations, the coarse-grained clastic quartz must represent a separate depositional event with important mechanical transport. However, where it overlies the mostly coarse-grained Paterson Formation or quartz-rich basement rocks, the silicified material can also have formed as an in situ soil deposit without any significant mechanical transport of the constituent materials. In the latter case it is not possible without detailed study to ascertain whether the silicified material is an in situ weathering residue or the result of a new depositional event. Because of this uncertainty the name Lampe Beds is restricted to those areas of fine-grained bedrock where the silicified sandstone cannot have originated as in situ weathering products.

On aerial photographs the silicified Lampe Beds have a distinctive medium-grey mottled photo-pattern along the crests of the mesas in the Gibson Desert. Further south, undifferentiated silcrete has a similar photo-pattern, and also occurs as smooth rounded rises amongst the sandplain. The Lampe Beds are locally broken up to form indurated cobble to boulder rubble on top of the mesas (Fig. 48), but at most occurrences it does form continuous beds on older rocks.

Fig. 48. Boulders and cobbles of silicified Lampe Beds as clasts in silica-cemented lateritic gravel capping Mount Beadell (M/1233).

Lithology

The Lampe Beds consist of very poorly sorted, medium to very coarse-grained sandstone which grades into quartz pebble conglomerate and breccia. The formation has been everywhere deeply weathered and intensely silicified and original textures have been largely obliterated. The arenites and rudites are light-coloured with white, cream, grey, and pale brown hues being the most common. The sandstones are predominantly poorly sorted wackes. They consist of rounded to very angular grains of quartz set in a clay matrix. The matrix commonly forms about 5-10% of the rock, but in some localities it may form as much as 40%, so that there is little grain to grain contact. The high matrix content is due to soil-forming processes prior to complete silicification. The sandstones commonly contain rounded and fractured pebbles of quartz and lithic fragments, and grade through pebbly sandstones to quartz and lithic conglomerate and breccia. Bedding is usually indistinct and thick, but rare trough-shaped beds are present.

Stratigraphic relations, distribution, and thickness

The Lampe Beds have been mapped in areas of fine-grained Cretaceous bedrock, on Wanna Beds, and on some fine-grained Proterozoic formations.

The base of the formation is always sharp and commonly shows relief of a few metres. Channels up to 15 m across and a few metres deep are present at several localities. The top of the formation is always an erosion surface. Although they are laterally extensive in the Gibson Desert, the Lampe Beds are a very thin unit. Their maximum preserved thickness is just over 5 m (HERBERT 17), but in most outcrops they are usually only 2-3 m thick.

Age

The Lampe Beds are unfossiliferous and therefore cannot be directly dated. However, as they unconformably overlie the Aptian Bejah Claystone, their maximum age is Early Cretaceous. In many outcrops the silicified Lampe Beds are intensely ferruginised and are therefore distinctly older than the laterite which is pre-Miocene.

The fluviatile Lampe Beds, which are only preserved on the divides of the palaeodrainage system must have been deposited during an earlier fluvial episode. As the preserved palaeodrainage patterns in the Officer Basin area were established by the Late Eocene (Van de Graaff & others, 1977), the Lampe Beds must predate the Late Eocene, and a Late Cretaceous-Palaeocene age is favoured; Van de Graaff & others (1977, p. 393) suggested Eocene.

Environment of deposition

Although intense soil-forming processes have obscured much of the original texture and structure, the poor sorting of the quartz grains, the moderate rounding of many of the quartz pebbles, the indistinct thick-bedding and the channelled lower contact all suggest a fluviatile environment of deposition.

These fluviatile deposits were subsequently subjected to deep weathering, which caused the high matrix content. Lithologically similar, mixed fluviatile/colluvial and/or residual soil deposits, mostly mapped as silcrete, were simultaneously forming in areas of Paterson Formation or crystalline basement. Silicification produced a hard rock resistant to further denudation, hence the preservation of the Lampe Beds on the tops of mesas.

The Lampe Beds represent a widespread phase of post-Early Cretaceous alluviation.

CAINOZOIC

Introduction

Cainozoic sediments and soils cover most of the study area. The mapping was almost solely based on airphoto-interpretation, and most units are only distinguishable on subtle differences in morphology, vegetation cover, and photo-tone. The various mappable units commonly grade into each other.

As morphology plays an important role in the recognition of these superficial units, they are not purely lithostratigraphic or soil stratigraphic units, but mostly morphostratigraphic units in the sense of Frye & Willman (1962). With the exception of the marine deposits of the Eucla Basin, none of the Cainozoic map units have been formally named.

Mappability of superficial deposits

In such a large area the superficial units change imperceptibly from one region to another. This is due to changes in bedrock as well as subtle changes in climate, vegetation, and other geographic factors. Most of the superficial units shown on the 1:250 000 map series were defined in the northern part of the area, and some units are of doubtful validity in other parts. Especially in the southwestern part of the area mapped, it is a contentious matter whether some units can still be distinguished. A good example of this is the distinction of aeolian sand and duricrust. As described in more detail later in this bulletin, the laterite or silcrete duricrust is overlain in large parts of the area by a sandy horizon which forms the upper part of the lateritic soil profile and which is mapped as duricrust. It is mostly this sandy horizon which was reworked by wind to form aeolian deposits. Where dunes have formed the recognition of the aeolian nature of the deposit is easy, but where the sandy layer of the lateritic profile is thick and undisturbed, as is the case in parts of CUNDEELEE, its distinction from aeolian sheet sands becomes very difficult.

The above comments apply to most of the study area where continental conditions prevailed during the Cainozoic. The southern part of the area, however, was affected by Eocene and Miocene marine transgressions. In the Eucla Basin, formal stratigraphic nomenclature has long been used for the various formations recognised. Lowry (1970) gave a full description of the Eucla Basin sediments and the following descriptions summarise his work.

Tertiary sediments in the Eucla Basin consist of the Hampton Sandstone, Wilson Bluff Limestone, Toolinna Limestone, Abrakurrie Limestone, Nullarbor Limestone and Colville Sandstone, (Lowry, 1970). Lowry & others (1972) proposed the name Plumridge Beds for a poorly exposed siliciclastic unit, in the northwestern part of the Eucla Basin, which they considered to be the lateral equivalent of the Nullarbor Limestone and Colville Sandstone. The Princess Royal Spongolite is the only other formally named Cainozoic unit in the southern part of the area.

Though there is considerable overlap in the age between some of the superficial units in the desert areas and the formally named units in the south, the latter will for convenience be described first. For detailed information on these units (except Princess Royal Spongolite and Plumridge Beds) see Lowry (1970).

EOCENE

Hampton Sandstone

The Hampton Sandstone is a unit of medium to coarse-grained quartzose sandstone, which is locally calcareous and/or glauconitic. The formation does not crop out, but occurs in the subsurface in CUNDEELEE and SEEMORE. On Kanandah station (SEEMORE) it is up to 33 m thick. The Hampton Sandstone disconformably overlies the Cretaceous Madura Formation and is in turn conformably overlain by the Wilson Bluff Limestone. The formation is Middle Eocene in the south-central part of the Eucla Basin, but Lowry (1970) argued that it is diachronous, and likely to be Late Eocene in the Kanandah area. Nannofossil evidence in South Australia indicates a Middle Eocene age (S. Shafik, BMR, pers. comm). The occurrence of marine fossils and glauconite indicates a marine environment of deposition.

Wilson Bluff Limestone

The Wilson Bluff Limestone consists of bryozoan calcarenite with a lime-mud matrix. Clayey partings and chert nodules are common. The formation does not crop out in the area, but has been recognised in several bores on Kanandah station, where it also contains intercalations of claystone, siltstone, and fine-grained sandstone which may be related to its proximity to the edge of the basin. In the Kanadah area it is less than 30 m thick, and gradually thins towards the edge of the basin. The formation conformably overlies the Hampton Sandstone or, where that unit is absent, disconformably overlies the Madura Formation. To the southwest of the area the Wilson Bluff Limestone partly underlies and partly intertongues with the Toolinna Limestone. The formation is disconformably overlain by the Nullabor Limestone and/or the Colville Sandstone (cf. Lowry, 1970 figs. 19 & 32). In the south-central part of the Eucla Basin the formation ranges in age from Middle to Late Eocene, but Lowry (1970) considered it likely that near the basin margins only the Late Eocene part will be present. The Wilson Bluff Limestone was deposited in an open marine environment very similar to that prevailing in the present-day Great Australian Bight. The lateral equivalent of the Wilson Bluff Limestone, the Toolinna Limestone, formed on the inner part of the shelf in more agitated waters.

Princess Royal Spongolite

The Princess Royal Spongolite (Glauert, 1926; Clarke & others, 1948; Cockbain, 1968) consists of spongolite and claystone. The type locality is about 8 km north-northeast of Norseman, near Lake Cowan. The Princess Royal Spongolite forms part of the Late Eocene Eundynie Group (Cockbain, 1968).

About 2 km south of Cundeelee mission a small outcrop of spongolite is present, and a shallow drillhole near this penetrated carbonaceous sandstone, siltstone, and claystone overlying basement rocks. Another drillhole, 3.7 km northeast of the mission, penetrated similar sediments. A sludge sample, consisting of grey silty sand, siltstone, and dark-grey clay, contained the following early Tertiary palynomorphs: *Nothofagacidites* spp., *Proteacidites* spp., (inc. *P. pachypolus*), and *Microfoveolatosporites fromensis*. The rock types and early Tertiary age of these deposits indicate that they form part of the Princess Royal Spongolite.

The drillhole data indicate that the thickness of the formation probably does not exceed a few tens of metres. In the drillholes the unit nonconformably overlies basement rocks.

Cockbain (1968) considered the Eundynie Group to correlate with the Upper Eocene Plantagenet Group of the Albany-Esperance area, and with the Upper Eocene Toolinna and Wilson Bluff Limestone.

The spongolite formed in a marine environment, but the absence of microplankton in the palynomorph assemblage indicates that the Cundeelee deposits formed in a coastal setting with predominant terrigenous supply, near the limit of the Late Eocene transgression. That this is indeed the case is indicated by the elevation of the deposits, approximately 300 m above sea level. Bunting & others (1974) argued that it is unlikely that the Late Eocene transgression reached much further than the present-day 300-325 m contours in the Cundeelee area.

MIDDLE MIOCENE

Nullarbor Limestone

The Nullarbor Limestone consists of micritic, fine to medium-grained calcarenite, with grains composed largely of fragmented and entire foraminifers and calcareous algae. In the northern part of the Eucla Basin intraclasts are an important component. The Nullarbor Limestone is mostly obscured by soil in the Kanandah area, but drillhole data indicate that it does not exceed about 25 m, and that it thins towards the western edge of the basin. The formation disconformably overlies the Wilson Bluff Limestone, and around 30°40'S it grades laterally into the Colville Sandstone (Lowry, 1970, fig. 32). The Nullarbor Limestone is richly fossiliferous, and the association of the benthonic foraminifers *Marginopora vertebralis, Austrotrillina howchini* and *Flosculinella bontangensis* was considered to indicate an Early Miocene age (Lowry 1970, p. 99). However, following Clarke & Blow (1969) this assemblage is now regarded as indicative of the Middle Miocene. The faunas and rock types indicate that the Nullarbor Limestone was deposited in an open marine shelf environment where little or no terrigenous sediment was available.

Colville Sandstone

The Colville Sandstone consists of sandstone, claystone and minor calcarenite. The formation is widespread in the northern part of the Eucla Basin, but good exposures are rare. Where exposure is poor, a sandy soil with limestone slabs is considered to indicate the presence of Colville Sandstone, whereas clayey soil with limestone slabs is indicative of underlying Nullarbor Limestone. On the basis of surface sections on JUBILEE and from comparison with its lateral equivalent, the Nullarbor Limestone, the thickness of the Colville Sandstone is thought to be about 20-30 m. The base of the Colville Sandstone is nowhere exposed. Towards the centre of the Eucla Basin the Colville Sandstone grades laterally into the Nullarbor Limestone, whereas towards the basin margin it is believed to grade locally into the Plumridge Beds. The calcarenite contains the foraminifers *Marginopora vertebralis* and *Austrotrillina howchini*, indicating that the formation is the same age as the Nullarbor Limestone, i.e. Middle Miocene. The faunas present in the Colville Sandstone indicate deposition on a shallow open marine shelf. The larger amount of terrigenous material in this unit, as compared to the Nullarbor Limestone, is due to its being closer to the edge of the basin.

Plumridge Beds

The Plumridge Beds (Lowry & others, 1972) are poorly exposed, and consist of fine-grained sandstone, siltstone, and claystone with some intercalations of poorly sorted conglomeratic sandstone. At the type locality the conglomeratic sandstone is characterised by pebbles of laterite, ferruginised silcrete, and fragments of fresh feldspar. A short section at PLUMRIDGE 4 (29°43'S, 125°04'E) (Fig. 49) has been chosen as the type section, and the unit was named after the Plumridge Lakes, approximately 25 km northeast of the type section.

On morphological grounds, the Plumridge Beds, as mapped to the southwest of the Plumridge Lakes clearly form part of the Eucla Basin sequence.

Setting and correlations within Eucla Basin

The Plumridge Beds are here considered to be the lateral equivalent of the calcareous Colville Sandstone, as they consist in part of similar rock types and have a similar stratigraphic setting in the Eucla Basin. The inferred lateral sequence Plumridge Beds—Colville

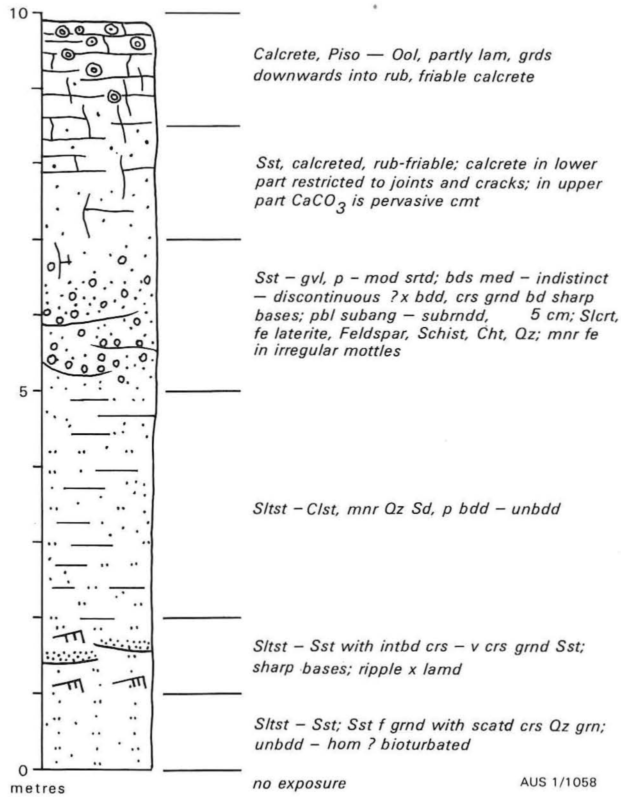


Fig. 49. Type section of the Plumridge Beds at PLUMRIDGE 4.

Sandstone—Nullarbor Limestone is interpreted as a transition from nearshore siliciclastics to open marine calciclastic sediments. The conglomeratic sandstone at the type section is interpreted as a fluviatile (?braided river) deposit, because of the moderate to poor sorting and rounding, and the irregular, discontinuous bedding. The finer-grained part of the sequence might be either marine or continental and the sequence as a whole probably formed in a coastal environment. The coarse-grained siliciclastics at the type locality were probably supplied by the river which once flowed from Lake Rason along the present day Salt Creek, and the presence of the Plumridge Beds along the northern margin of the Eucla Basin may be related to discharge points of rivers during the Miocene. It is considered likely that the Plumridge Beds are of similar thickness to the Colville Sandstone, i.e. a few ten of metres, and that they overlie older units disconformably to unconformably.

The presence of detrital laterite and silcrete in the Plumridge Beds, is highly significant if its correlation with the Colville Sandstone and Nullarbor Limestone is correct, as it indicates that laterisation in the areas to the north took place prior to the Middle Miocene.

Silcrete (part of Czd)

The term silcrete is used to describe intensely silicified rocks which commonly form a widespread crust on hills and rises. Silcrete occurs in a number of forms, ranging from thin, weakly indurated to massive erosion-resistant bands of highly silicified rock.

Lithology

The silcretes consist of intensely silicified conglomerate, sandstone, siltstone, or claystone, depending mainly upon the type of bedrock within or on which

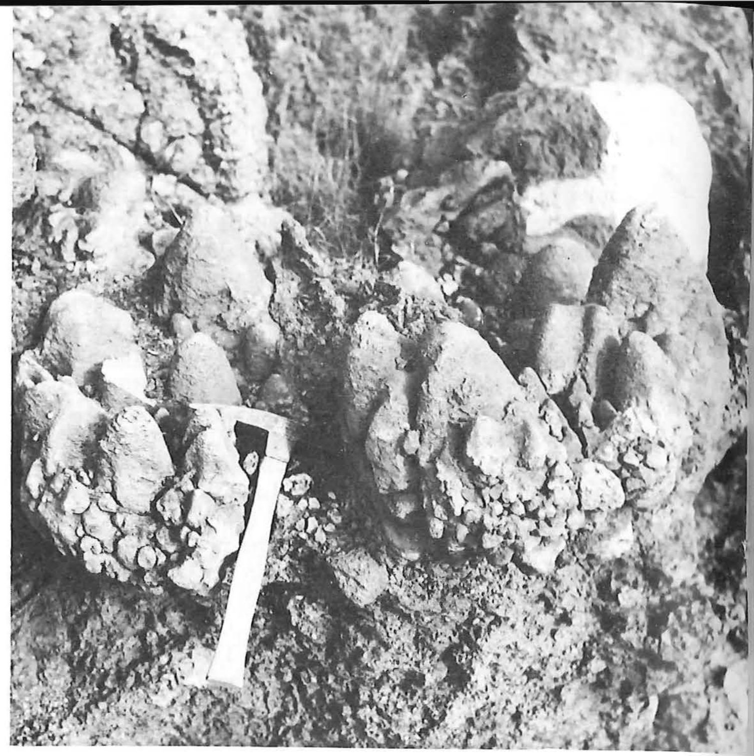


Fig. 50. Conical silicified soil at NEALE 8, indicative of upward movement of silca-carrying solutions in soil profile.

they are developed. The most common and widespread lithology, developed mainly on Paterson Formation and Lampe Beds, is a white to greyish-green, intensely silicified, coarse to conglomeratic sandstone. It consists of clastic particles (quartz and lithic fragments) in a matrix or cement of microcrystalline silica and minor chalcedony. Replacement of the constituent grains ranges from slight, where grains have slightly resorbed boundaries, to complete, where only ghost outlines of the original grains are preserved. This sandy silcrete tends to weather either spheroidally or in a conical fashion (Fig. 50). It usually forms hard protective cappings to mesas, and has a distinctive, mottled, light and dark grey pattern on aerial photographs (Fig. 9). On well-jointed Proterozoic bedrock the silicification has often penetrated deeper along the joints. During later erosion, the more resistant silicified joint zones tend to stand out as small rectilinear ridges of silcrete; such features are common on the Proterozoic rocks in ROBERT and THROSSELL.

Silcrete, like laterite, forms part of a deep weathering profile; in many cases the two are intimately related, with the silcrete commonly lower down in the weathering profile. In areas where silcrete is at or near the present erosion level it is usually overlain by a thin sandy soil and in turn overlies kaolinised bedrock. As discussed in the section on Physiography it is the breakdown of poorly silicified and/or partly lateritised silcrete that gives rise to sandy soils which are the source of much of the aeolian sand.

The Bejah Claystone, which consists of indistinctly bedded radiolarian claystone with minor fine-grained sandstone is commonly silicified to a porcelanite several metres thick. This porcelanite forms the lower part of the siliceous duricrust; the upper part of the duricrust is represented by the silicified Lampe Beds. Underneath the porcelainised interval is a thick mottled and decomposed profile of soft, low-density claystone. BMR Browne 1 which was spudded near the summit of Mount Beadell intersected 27 m of Bejah Claystone, consisting of about 13 m of porcelainised rocks, about

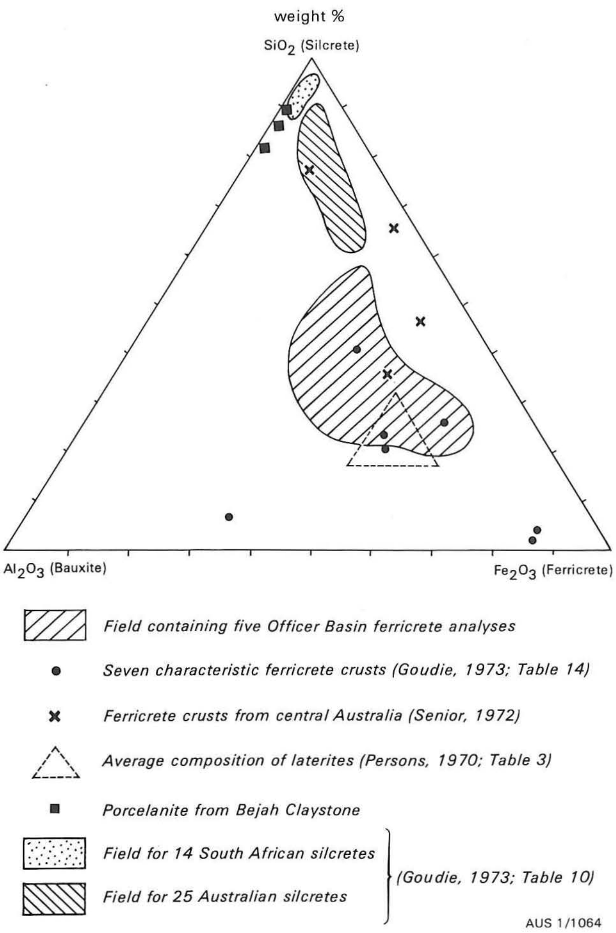


Fig. 51. Comparison of silcrete and ferricrete analyses from Officer Basin and elsewhere.

8 m of mottled claystone with vertical cracks, and 8 m of very low density, soft claystone (Appendix 1). Samples from the top, middle and bottom of the formation were analysed for SiO_2, Al_2O_3, Fe_2O_3 and alkalis. The results are listed in Table 4 and their composition is plotted on a ternary diagram and compared with other duricrust analyses. Three of the samples are highly siliceous and plot well into the silcrete field on Figure 51. X-ray diffraction analyses show that these samples (two from the silicified level and one from the mottled zone) are composed predominantly of quartz and kaolinite with proportions ranging from 2:1 to 7:1. The specimen from the pallid zone (4 m above the base of the formation) consists largely of alunite and Al_2O_3; it is not included in Figure 51.

Silcrete is also developed on igneous and metamorphic rocks in the southwest of the area. That developed on acidic rocks is similar in appearance to that on the Paterson Formation. Quartz veins have been traced from the underlying bedrock into the siliceous crust (Fig. 52), indicating that the silcrete was formed by in situ silicification of a little altered soil profile on the underlying crystalline rocks. Although such uneqivocal evidence is not present in the sedimentary rocks within the basin, the angularity and lack of sorting of much of the material indicates in situ silicification of soils or little altered bedrock.

Stratigraphic relations, distribution, and thickness

As silcrete is a product of silification of residual soils or pre-existing sediments, it can form on any stratigraphic units exposed at the time of silicification. The Cretaceous and Permian formations are the most commonly affected as they are the most widespread units in the area. However, the Lower Palaeozoic and

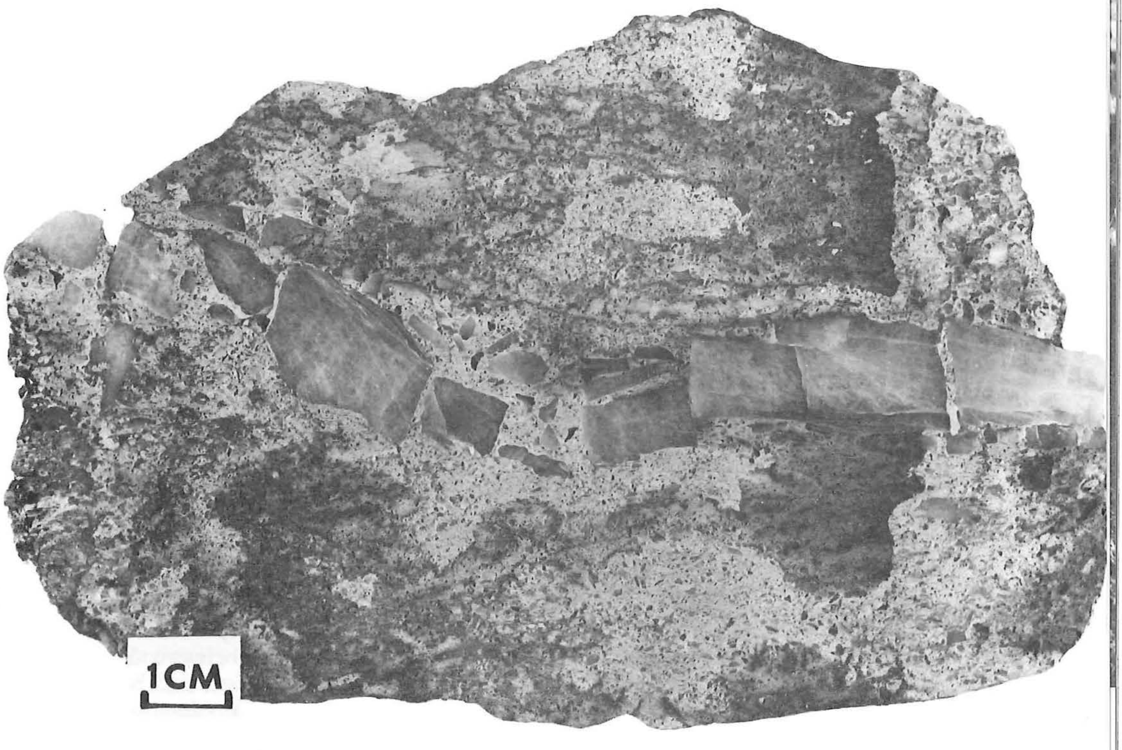


Fig. 52. Dislocated quartz vein in silcrete.
Silcrete formed in lower part of in situ soil profile on crystalline basement at NEALE 10 (GSWA sample 29150).

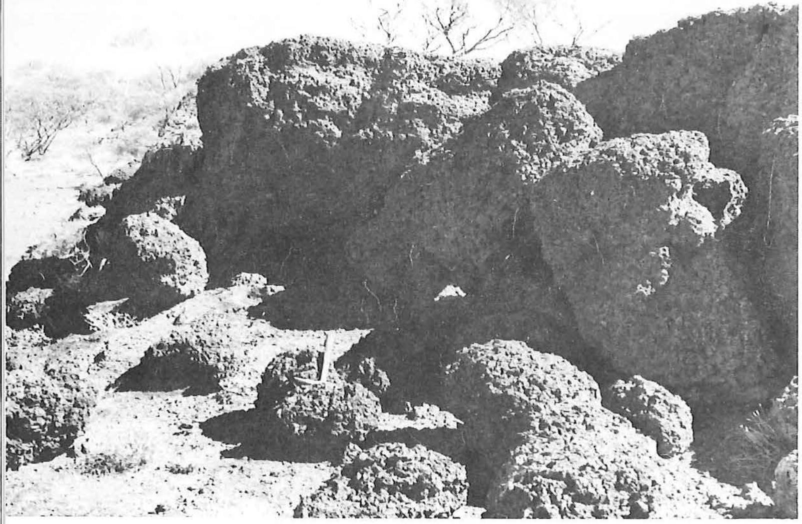


Fig. 53. Cavernous pisolitic laterite breakaway (YOWALGA) (M/1239).

Archaean rocks all have silcrete profiles developed on them.

There is little information on thickness of silcrete and its associated profiles. Most surface silcrete is less than about 3 m thick, but as it is always at the present erosion level, this represents only an average 'preserved' thickness. A silcrete 'bed' developed within fluvial sands of the Paterson Formation was intersected in BMR Neale 1 between 29 m and 30 m. The deeply weathered profiles underlying the silicified duricrusts within the basin are commonly tens of metres thick; fresh bedrock is not exposed even in the highest mesas (20 m high).

Age

The youngest rocks that have been silicified are the Cretaceous or Early Tertiary Lampe Beds. In some areas silcrete is intensely ferruginised in its upper part, suggesting that the formation of the silcrete pre-dated the formation of the laterite. The silcrete is therefore older than the laterite which is of pre-middle Miocene age.

Formation

Silcrete is produced by the cementation of residual soils or pre-existing rocks by silica. As it is often closely associated with laterite, a related genesis is indicated and this is discussed further in the section on laterite.

Somewhat different 'silcrete' beds were intersected in BMR Throssell 1 within a sequence of calcrete and lacustrine deposits. Intensely silicified carbonates and opaline rocks were intersected between 25-28 m and 58-60 m. As the calcrete and lacustrine deposits are probably Miocene or younger these types of silcretes are younger than the surface silcretes described above. They may have formed by the in situ silicification of material at depth or, alternatively, may indicate periods of stillstand and duricrusting during the filling of the major valleys of the palaeodrainage.

Laterite (part of Czd)

The term 'laterite' is here used to describe hard indurated ironstone crusts. It is synonomous with the commonly used term ferricrete (Gourdie, 1973), and forms part of a thick weathering profile.

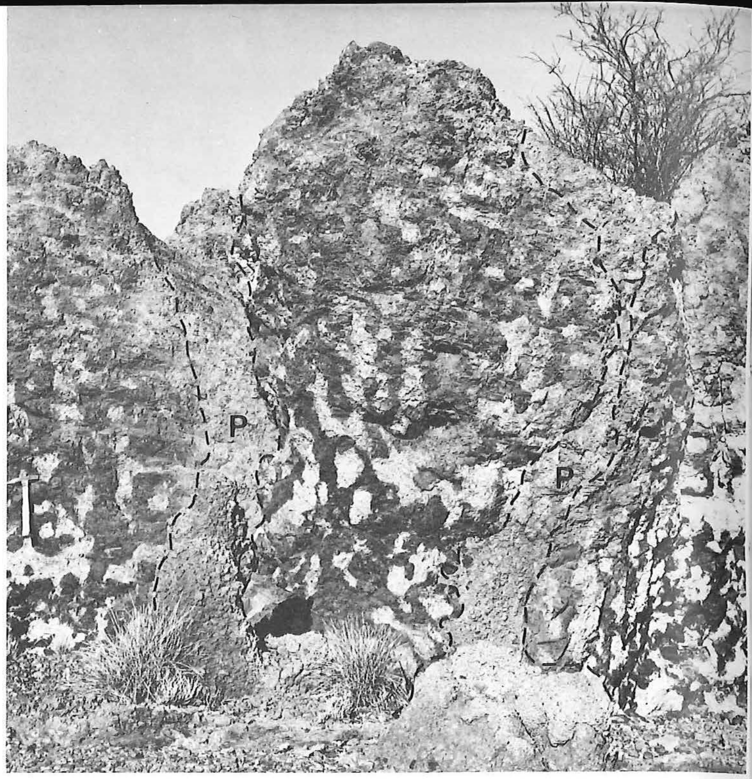


Fig. 54. Mottled zone of laterite profile with pipes (P) filled by pisolitic debris from overlying pisolitic zone.

Lithology

Laterite is well developed on the Samuel Formation in the northern part of the area. The upper part of the profile consists of a thin, loose to poorly consolidated sandy layer containing ironstone pisoliths. This is underlain by the laterite—a hard strongly cemented ironstone exhibiting a number of textures, of which pisolitic, nodular, cellular and vesicular are the most characteristic (Fig. 53).

Many of the breakaways in YOWALGA, where this ferricrete is well exposed, consist of a cliff-face of closely packed, round to irregularly-shaped pisoliths, which are welded together to form an extremely resistant layer up to about 3 m thick (Fig. 53). Below this hard layer is a soft, more easily eroded zone of kaolinised sediments with mottles and irregular patches of variegated iron oxides commonly several metres thick (Fig. 54). The amount of iron oxide decreases gradually downwards into the pallid zone, which consists of soft decomposed kaolinitic material. Because of the reconnaissance nature of the mapping, systematic sampling of the duricrust was not attempted, but drillhole samples from the laterite crust from BMR Rason 1, 2, 3, Wanna 1 and Westwood 2 were analysed for their major oxides (Table 4). The results have been included in Figure 51. Owing to the small number of samples, they cannot be considered to be representative of the Officer Basin area as a whole, but they show that these duricrusts are more heterogeneous than many others.

Distribution and thickness

Although best developed on the clayey Cretaceous Samuel Formation in the Gibson Desert, laterites are present throughout the area. The limited drilling results available show that the deep weathering profile is commonly thicker than 50 m, and that the ferricrete layers are between 2 m and 8 m thick (Appendix 1). The thickest weathered profile is in BMR Yowalga 3, where fresh Paterson Formation was intersected just below 100 m. The resistivity results along the AGC line in

TABLE 4. CHEMICAL ANALYSES OF BEJAH CLAYSTONE AND LATERITE CUTTINGS

	Bejah Claystone from Browne 1				*Laterite cuttings*				
Sample No.	73880* 246	* 231	* 235	* 242	+ 177	+ 178	+ 189	+ 210	+ 335
SiO_2	75.0	72.5	74.0	3.3	22.0	15.5	42.5	52.0	35.8
Al_2O_3	8.3	13.8	10.7	36.8	10.5	22.5	16.2	12.5	21.7
Fe_2O_3	1.1	1.3	1.5	0.5	58.0	41.5	31.0	27.0	30.0
CaO	0.1	0.1	0.1	0.1					
MgO	0.25	0.13	0.19	0.04					
Na_2O	0.12	0.08	0.11	0.30					
K_2O	0.3	0.35	0.3	10.0					
LOI					7.6	17.3	8.9	6.9	ND
Reactive silica (SiO_2)					14.2	8.7	21.0	20.8	ND
U(ppm) °					10	4	6	4	6
Th (ppm) °					105	46	55	55	70
	8.7 m	10.97 m	20.40 m	25.90 m	Rason 1	Rason 2	Rason 3	Wanna 1	Westwood 2

Specimens analysed at Australian Mineral Development Laboratories, Adelaide
* direct reading emission spectrography
+ computer-controlled emission spectrography
° X-ray fluorescence spectrometry

RASON and NEALE (Fig. 2), however, could indicate weathering down to about 250 m in acidic basement rocks (see Appendix 1). The thicknesses quoted above are very similar to those suggested by Goudie (1973, p. 32-37). However, commenting on Australian duricrusts (p. 16) he remarks that . . . 'the thickness of the combined ferricrete crust and pallid zone appears to depend on the permeability and porosity of the parent rock. It is greatest both on argillaceous rocks and on well-jointed types, and least on rocks like sparsely jointed massive igneous rocks'. This does not appear to be the case in the Great Victoria Desert. For although thick weathering profiles have developed on the porous Permian and argillaceous Cretaceous rocks, they are also well developed on massive, acid igneous basement rocks, indicating that original mineral composition rather than texture may be more significant in the development of deeply leached profiles.

Stratigraphic relations and age

Like silcrete, laterite is the product of alteration of residual soils or pre-existing rocks so it can develop on any stratigraphic unit of suitable lithology. The Lampe Beds of Late Cretaceous to Early Tertiary age are the youngest lateritised unit in the area. In the Eucla Basin the Plumridge Beds of probable Middle Miocene age contain detrital laterite, but are not themselves lateritised, indicating pre-Middle Miocene lateritisation. Van de Graaff & others (1977) argue that the laterite duricrust developed simultaneously with the palaeodrainage patterns, that is, during the Late Cretaceous to Early Tertiary. However, of greater interest is the period when lateritisation stopped. Considering the geomorphological and stratigraphic evidence, as well as Schmidt's & Embleton's (1976) results, a minimum age of Late Oligocene to Early Miocene is possible, and an Eocene to Early Oligocene age is probable.

Formation

An attempt was made to separate the siliceous from the ferruginous duricrusts during the regional mapping. In some areas, however they are closely related and have been grouped together in the unit called duricrust (Czd) on Plate 1. Where silcrete and laterite occur together in the same profile, the laterite invariably overlies the silcrete. This may indicate that the two types formed at specified horizons in the weathering profile or that the silcrete is older than the laterite. In other areas, silcrete and laterite appear to develop independently of each other. However, as both of them are associated with similar deep-weathering profiles, a similar mechanism of formation seems likely. Although numerous theories have been presented for the formation of laterites and silcretes (see review in Goudie, 1973), there is still argument as to whether they formed under wet tropical or wet temperate climates and whether the sesquioxides and silica have moved up, down, or sidewards, and under what controlling forces.

Woolnough (1918) suggested the laterites in Western Australia were formed largely by leaching of salts during seasons of heavy rainfall with upward movement and concentration of sesquioxides by capillary action during dry seasons. Most recent models have emphasised the influence of groundwater, and fluctuations in groundwater, especially for the formation of ferricretes. This appeals to us, as the duricrust accurately preserves the topography that was formed during the development of the dendritic Tertiary river systems. These must have been formed under a much more humid climate than the present with correspondingly much higher groundwater levels.

Calcrete (Czv & Czp)

Calcrete is here used to refer to authigenic carbonate accumulations in superficial deposits or near-surface bedrock, following Goudie's (1972) definition: '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'.

The carbonate deposits associated with valley-fills in the trunk valleys of the relict and active drainage systems of arid Western Australia, which have been called calcrete by, for instance Sofoulis (1963), and

Fig. 55. Calcrete (white areas) containing lumps of ferruginised, silicified Lampe Beds (dark grey clasts) at WANNA 3.

Sanders (1969, 1973, 1974), are here referred to as *valley calcrete (Czv)*. These contrast with thin laterally extensive sheets, such as on the Carlisle Plain, which are mapped as *plains calcrete (Czp)*.

Lithology

The calcrete consists of homogeneous and earthy, or rubbly, nodular, pisolithic and/or laminated, friable to highly indurated, mostly micritic, limestone with an admixture of fragments of underlying or enclosing superficial deposits and/or bedrock. At WANNA 3, for example, ferruginised lumps of the underlying silicified Lampe Beds are incorporated in the calcrete (Fig. 55). In valley calcrete such inclusions are not indicative of the bedrock, as they are derived from clastic valley-fill deposits.

Valley calcrete is locally dolomitic, and commonly contains concretions of laminar to structureless, white, opaline silica, which in part have a platy to sheet-like shape. Such silica concretions have not been observed in plains calcrete. In some places, however, (e.g. JUBILEE 1; part of BMR Throssell 1) the calcrete is completely altered to silcrete, with retention of original pisolitic structures.

The vertical profile of well-developed plains calcrete is normally clearly differentiated into three zones (e.g. MASON 7, PLUMRIDGE 4). In the lower zone the carbonate occurs as a friable, earthy material along narrow cracks. Upwards, the proportion of carbonate increases, and in the middle zone carbonate replaces most of the original bedrock fragments and becomes pervasive cement. The middle zone grades into the upper zone, which consists of nodules and pisoliths. The nodules and pisoliths, which are normally well indurated, may be discrete and uncemented or cemented into irregular lumps, which give the calcrete a rubbly appearance. The upper zone contains only minor terrigenous material and a few ghosts of bedrock fragments.

The complete profile is not present everywhere, and calcrete may be developed as discontinuous stringers in dune sand, centrimetre-thick laminar to rubbly limestone crusts on bedrock, or as a pisolitic layer in colluvial clay.

Valley calcrete is less well known, as the only sections are in boreholes. At the surface, valley calcrete is mostly laminated and/or nodular, but below ground level it is mostly structureless with minor nodules and is locally dolomitic. The nodules may be closely packed, or scattered in a homogeneous micritic matrix. Induration ranges from friable to highly lithified. Clastic material occurs both scattered and concentrated in beds and lenses. Cavities are common in the valley calcrete, the hummocky surface of which shows karst features such as sink holes and solution pipes.

Stratigraphic relations

Calcrete, being an authigenic deposit, does not only overlie pre-existing deposits, but can also partly or wholly replace them. Valley calcrete overlies and replaces, and is also locally overlain by valley-fill deposits such as alluvium, colluvium, aeolian sand, and fine-grained lacustrine deposits. The thinner, laterally extensive calcrete sheets, such as the plains calcrete on the Carlisle Plain, can overlie and partly replace bedrock, and replace other superficial deposits or grade into them laterally.

Lowry (1970) and Lowry & Jennings (1974) described various types of calcrete from the Eucla Basin. The plains calcrete described above corresponds to Lowry's 'kankar in residual sand and clay'. Details of the other types of calcrete in the Eucla Basin and their relationships are given in Lowry (1970).

Distribution and thickness

Extensive plains calcrete (Czp) is present in soils developed on the Eucla Basin sediments and in an irregular belt along the basin margin. In basement areas usually thin calcrete is commonly developed on ultramafic rocks.

Valley calcrete (Czv) is most common in those trunk valleys that, in part, drained Precambrian terrain, but it appears to be sparse in valleys south of 29°30'S (Fig. 56) (cf. Butt & others, 1977, p. 8).

Known thickness of plains calcrete with a well-differentiated profile is in the range of about 0.5 m to 4 m. Valley calcrete is much thicker, and may be up to 30 m thick (BMR Warri 3, Wells & Kennewell, 1974).

Age

The valley calcrete must be younger than the filling of the valleys and is therefore Miocene or younger; it probably continues to form at present. In South Australia, similar deposits, which contain gastropods and oogonia of *Characeae*, are considered to be Late Tertiary (Major, 1973d). The plains calcrete is also still forming, as evidenced by the calcification of dune sand and colluvium, and Lowry (1970, p. 116) argued that it probably started forming during the Pleistocene.

Conditions of formation

Calcrete can form under semi-arid to arid conditions and, according to Goudie (1973), the 500-mm isohyet is in many places the approximate boundary of modern calcrete formation. The presence of a well-developed vertical profile, the occurrence at or near the present surface, the blanketing of the topography, and the great lateral extent clearly indicate that plains calcrete is of pedogenic origin.

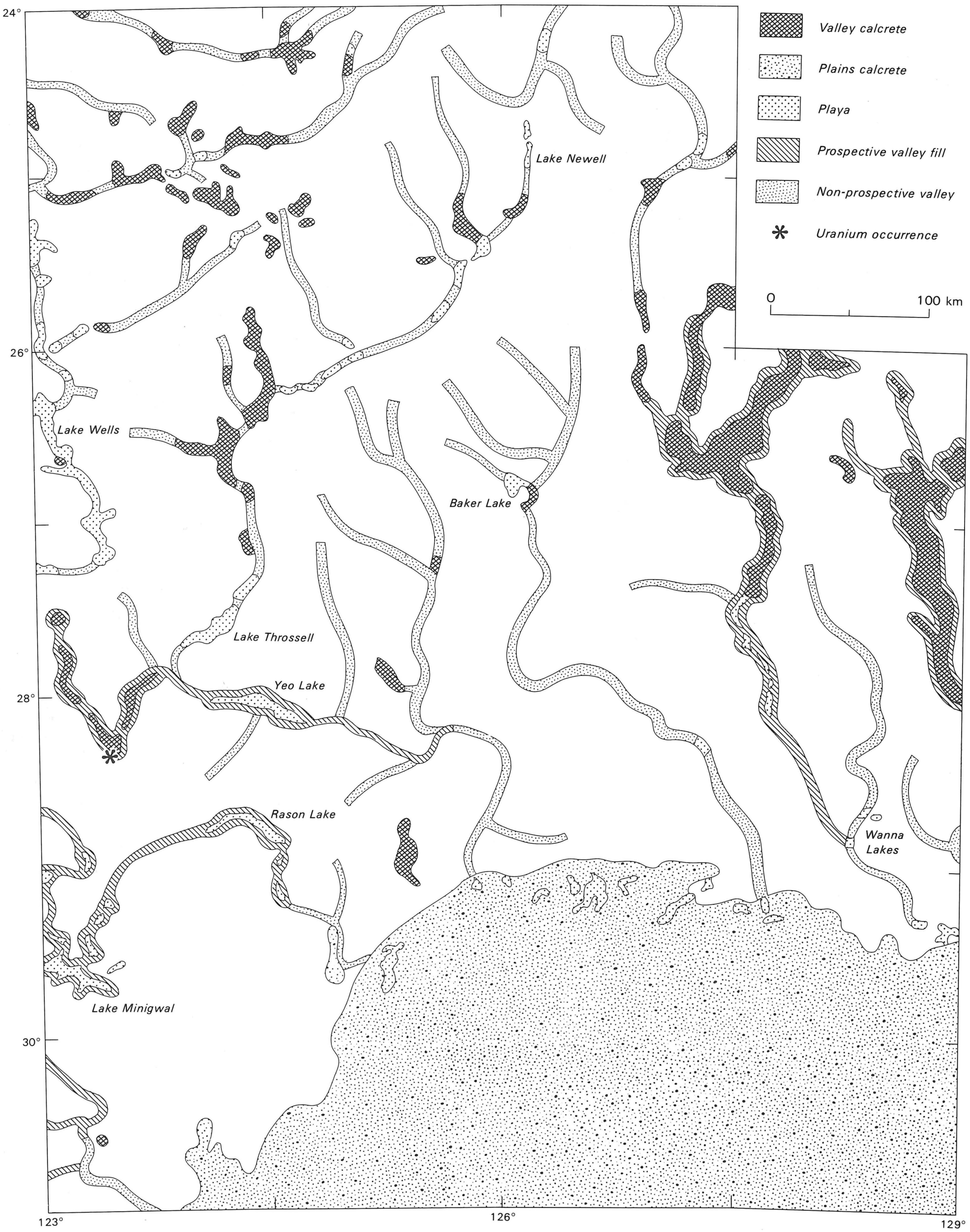


Fig. 56. Distribution of major valley-fill material and calcretes, showing areas considered prospective for uranium.

Where calcrete overlies calcium-rich bedrock, such as ultramafic intrusives or limestone-bearing Colville Sandstone, the carbonate contained in the calcrete may have been derived locally. In this case, the calcium carbonate is an alteration product of the bedrock itself, which is precipitated in a soil profile that is thus altered, by cementation and replacement, to calcrete.

Where plains calcrete overlies bedrock deeply leached during lateritic weathering, such as at WANNA 3 (Fig. 27), it seems unlikely that the calcium carbonate could have been derived locally. In this situation the carbonate must be derived from airborne dust or from precipitation. The occurrence of plains calcrete in an irregular belt along the margin of the

Eucla Basin indicates that the carbonate here may have been derived by deflation of the Bunda Plateau, as was suggested by Crocker (1946). This airborne carbonate dust may be redistributed and locally concentrated by sheet floods and streams.

The precipitation of limestone in pores and cracks can push the host rock apart in a manner analogous to frost wedging. As a result fragments of host rock may appear to float in the carbonate matrix, and upward displacement of bedrock fragments or the formation of teepee structures may result from these crystallisation pressures.

The restriction of valley calcrete to trunk valleys of the relict drainage systems indicates derivation of the carbonate from run-off water and groundwater, and ultimately from calcium-bearing bedrock and rainwater. Sofoulis (1963) suggested that valley calcretes may have formed as primary precipitates in ponded sections of the drainages, that is, as lacustrine carbonates. No lacustrine carbonates have been recognised in the area mapped. Sanders (1969, 1973, 1974), and Sanders & Harley (1971) argued, however, that most of the valley calcrete formed by precipitation of $CaCO_3$ from carbonate-saturated groundwater. The calcium carbonate cements, partly or wholly replaces, and also pushes apart the colluvial/alluvial sediments in which it is precipitated.

The replacement and/or pushing apart of the original sediment is evidenced by the locally patchy occurrence of the calcrete, the evidence of replacement of clastic grains as seen in thin section, and by the presence of some large 'floating' clastic grains in otherwise pure carbonate. Valley calcretes are thought to mostly form through precipitation of calcium carbonate from groundwater (Butt & others, 1977; Mann & Deutscher, 1978), which may result in the upward displacement of the overlying material. Such localised upward displacement would account for the irregular, hummocky surface of valley calcretes, although the possibility of these mounds being pseudo-anticlines caused by lateral compression, owing to crystallisation forces (Jennings & Sweeting, 1961), cannot be disregarded. As well as calcium carbonate precipitation from groundwater, pedogenic calcification of valley fill sediments, and also pedogenic alteration of 'groundwater' calcrete takes place. As these authigenic processes within clastic valley-fill sediments take place simultaneously with the slow aggradation of the valley floors, valley calcretes of substantial thickness have formed.

The 'cornstone' in the Devonian Old Red Sandstone of South Wales (Allen, 1960) is an ancient example of such thick calcrete bodies, which formed in areas where calcification and sedimentation were simultaneous.

In contrast, the plains calcrete forms in a soil on a stable surface where little or no sedimentation takes place, for example, on the Bunda Plateau, for which Lowry (1970) argues that residual soil formation and deflation have been the main geomorphic processes since the Miocene.

Mann (1976) noted that on the Yilgarn Block, 'calcrete occurs immediately on the upstream (less saline) side of salt lakes, or gypsum-halite deposits'. A similar setting, though lesss distinct, can be seen in the study area, for example at Lake Throssell. Mann concluded from this relationship that 'the precipitation sequence from an evaporating groundwater, namely calcium-magnesium carbonates (and celestite, strontium sulphate) calcium sulphate, sodium chloride (and numerous other salts of potassium, sodium, and magnesium), has at least some lateral manifestation in this arid/semi-arid region'.

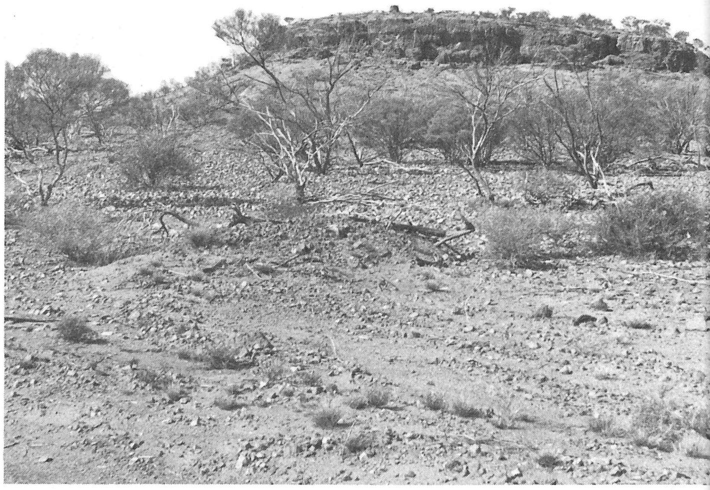


Fig. 57. Small butte near Mount Everard (BROWNE) of flat-lying Bejah Claystone surrounded by deflated scree slopes of colluvial silt, sand and gravel.

Colluvium and alluvium (Czc)

Colluvium and alluvium deposits have accumulated around ranges, at the foot of breakaways, on long gentle slopes and in major depressions. These deposits form a morphostratigraphic unit which is not characterised by a single rock type or a single distinctive photo pattern. It includes a wide range of largely unconsolidated material, ranging from cobble breccias flanking vertical cliff faces (Fig. 57) to stratified sand and silt in gently sloping outwash plains. Consequently, it includes a number of photo patterns, examples of which are shown in Figure 9. One of the most characteristic is that produced by the pale grey to white scree slopes of rubbly boulder-strewn ground cut by heavily vegetated ephemeral creeks which flank most of the ranges (X on Fig. 9). Further out from the ranges the relief flattens and gently sloping pediments, covered by sand and silt with rock fragments, with a ribbed or striped vegetation pattern (Y on Fig. 9) are common. At even lower elevations, where relief is negligible, the unit comprises silty and clayey flats with a deflated mantle of silcrete or laterite fragments (Fig. 58). Deposits formed by distinct channel-confined streams are present, but form only a minor proportion of the unit. Most of the alluvium is carried in, and deposited from, short-lived ephemeral creeks or flash floods, to form small outwash fans or clayey flats. However, a larger, possibly older, alluvial deposit at least 3 m thick is present north of the Clutterbuck Hills (locality shown on Fig. 10). Here, a sequence of consolidated, medium-bedded, poorly sorted, alluvial sandstone cut by small channels filled with conglomerates is being actively incised by the present creek flowing north from the Clutterbuck Hills (Fig. 59). The channel fill contains detrital ironstone, which suggests a post-laterite (i.e. post-Miocene) age, and Late Pleistocene is inferred.

Throughout most of the area the colluvium and alluvium are probably less than 5 m thick, but may approach 30 m in the major depressions where they grade laterally into fine-grained playa deposits (which are up to 100 m thick).

Fig. 58. Fragments of silicified Lampe Beds forming a desert pavement on deflated colluvium (WARRI 5).
Note open vegetation and flatness (M/1233).

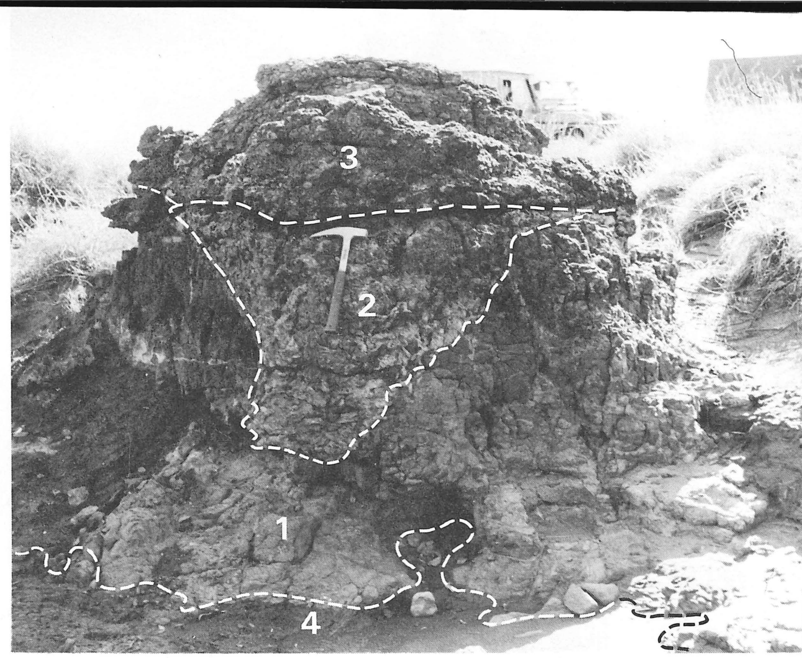


Fig. 59. Tertiary alluvium north of Clutterbuck Hills (see Fig. 10).
Photograph taken from centre of present creek, which runs from right to left. Creek has cut down through at least three consecutively older deposits: 1—oldest alluvium of soil—red-brown sandstone with rootlets, 2—channel of grey clayey sand with small pebbles, 3—unsorted gravel with laterite fragments and crude cross-bedding, 4—unconsolidated sand and silt of present creek.

Well-developed desert pavements have formed on many colluvium/alluvium deposits, especially where deflation is assisted by a lack of vegetation.

Colluvium and alluvium are still forming, but older deposits, for example, those near Clutterbuck Hills, which contain laterite pisoliths and calcareous nodules are possibly Pliocene or Pleistocene.

The colluvial/alluvial deposits grade laterally or interfinger with other Cainozoic morphostratigraphic units such as aeolian sand, reworked laterite soil, or playa deposits. Consequently, the boundaries between these units are often approximate.

Playa deposits (Czl)

Playa deposits are generally fine-grained sediments formed in freshwater claypans or salt lakes.

Lithology

In freshwater claypans the sediments consist of clay and silt with lesser amounts of sand and gravel. The gravel fraction is composed of laterite, silcrete, and bedrock fragments. Sorting is mostly very poor and the deposits are lithic wackes to mudstones. When dry, the surface of the playa deposits often exhibits desiccation cracks, and where coarse-grained material is abundant, a deflation pavement may be present. Freshwater claypans are a typical example of morphostratigraphic units mapped on photo-pattern, and distinction in the subsurface of their deposits from alluvium/colluvium is not possible.

Some older deposits of this type on WARRI (for example on the western side of Lake Cohen) are cemented and partly replaced by opaline silica.

Salt lake deposits consist predominantly of clay and silt with authigenic gypsum. Along the fringes of the salt lakes coarser-grained material may be present, but this is mostly restricted to discharge points of creeks. When dry, the surface of this type of playa is mostly covered with a thin salt crust. Near creek mouths, alternations of sand, silt, and clay produce distinct bedding. In the more clayey sediments, bedding is less distinct and is marked by grey to rusty brown colour-bands and concentrations of authigenic gypsum. In a number of shallow test pits in wet active salt lakes the gypsum was seen to occur in distinct layers, some of which are estimated to contain more than 75 percent gypsum. In some of these test pits the pH of the in situ sediment, as far as accessible (0.5 m at most), was in the range of 5.9 to 7.8 (average about 6.5; temperature 16°). These pH values suggest that at the time of measurement gypsum was not forming. No Eh readings were taken, but the predominance of reddish colours indicates that most of the sediment is in an oxidised state. Only minor black, fetid mottles were observed.

In a few of the pits, gypsum crystals in the uppermost layers are well sorted and have an average size of 1-2 mm, whereas downward, both average and maximum sizes increase. Maximum observed crystal size in active salt lakes is about 5 cm, but in dry inactive lakes crystals up to several tens of centimetres across have been observed. In an inactive salt lake at PLUMRIDGE 4, such large gypsum crystals are concentrated along the sides of an indistinct honeycomb pattern of shrinkage cracks with cells which are about 0.5 m-1 m across.

Stratigraphic relations

Playa deposits disconformably to unconformably overlie duricrust and bedrock. Where salt lakes have migrated laterally, the unconformable relationship with bedrock is mostly clearly visible, for example, at Lake Minigwal. The lateral migration of saline playas is due to the removal by wind of exsudation products on the upwind side of the playa (Jutson, 1934), in combination with the accumulation of gypsiferous lunette dunes on the down-wind side. Laterally, the playa deposits grade into colluvial/alluvial valley-fill sediments and lunette dune deposits that fringe the salt lakes.

Distribution and thickness

Playa deposits more than a few tens of metres across are restricted to the larger valleys of the relict drainage systems, except on the Bunda Plateau, where they occur along the northern edge of the Plateau.

Freshwater claypan deposits, several hundred metres across, occur in the north-central part of the area and on the Bunda Plateau. In the deserts, large claypan deposits are restricted to those valleys that drained areas with Cretaceous bedrock. Those valleys that drained areas with Permian and older bedrock contain saline playa deposits and only very minor claypan deposits.

Saline playas are mostly far larger than claypans. The largest freshwater claypan, Lake Gruszka, is only 6 km long, whereas the largest salt lake, Lake Wells, is about 80 km long.

Within the trunk valleys the distribution of the playa deposits appears to be random, but on the Bunda Plateau major salt lake deposits are mostly located near the discharge points of the relict drainages.

An average thickness of several tens of metres seems likely for the deposits that occur in the major trunk valleys. Maximum thickness may be over a hundred metres, as indicated by data from the Eastern Goldfields (e.g. Lake Cowan) and by BMR Throssell 1, which penetrated about 30 m of calcrete overlying 70 m of gypsiferous playa deposits.

Age

Playa deposits are forming at present, but though their maximum age is uncertain, it is obvious that they must be younger than the valleys in which they occur. As it is inferred that the filling of these valleys started during the Miocene and possibly as early as the Late Eocene, the maximum possible age of the playa deposits is in the same range. No palaeontological ages are available from playa deposits to support this interpretation.

Conditions of deposition

The predominantly fine-grained material which constitutes most of the playa deposits is washed into the lakes by short lived streams after heavy rains. Occasionally, the lake retains water long enough to permit some reworking of the sediment by waves, which produces moderately sorted sediments in miniature beach ridges, but this has only been observed in freshwater claypans (for example at WARRI 11). This probably reflects the greater viscosity of the brines in the salt lakes, which prevents the formation of waves.

After evaporation of the surface water in the salt lakes, a thin salt crust is precipitated on the surface, and authigenic gypsum forms from the hypersaline brines in the sediments. With continuous drying, the surficial sediment becomes susceptible to wind erosion and is swept away to form gypsiferous dune deposits.

The concentration of gypsum crystals in a honeycomb pattern at PLUMRIDGE 4 is interpreted as a gilgai structure, where alternate expansion and contraction of the clayey sediments have caused the concentration of the coarse crystals along shrinkage cracks.

Lunette dune and other playa-derived aeolian deposits (Czg)

Lunette dune deposits (Czg) are the gypsiferous sediments that constitute the lunette dunes on the lee-side of playas. Minor featureless gypsiferous deposits adjoining salt lakes are also included.

Lithology

Lunette dune deposits consist of fine to coarse-grained gypsum crystals with minor admixtures of siliciclastic material, which is mostly in the form of clayey pellets. No predominantly siliciclastic lunette dune deposits have been recognised.

Most of the visible outer part of the dunes has been cemented and recrystallized to a gypsum rock with only remnant clastic textures (Fig. 60). Parts of the dunes, however, are completely unconsolidated and consist of very fine powdery gypsum (kopi).

Stratigraphic relations

These gypsiferous deposits, like their playa source, are inferred to rest disconformably or unconformably on duricrust and bedrock. Laterally they interfinger with, and grade into, the salt lake deposits on the windward side, with longitudinal dune and sandplain deposits on the downwind side, and also with the colluvial/alluvial valley-fill deposits.

Distribution and thickness

As lunette dunes are derived from and closely associated with salt lakes, they have a similar distribution. The individual dune deposits are crescentic in plan or, where the salt lake has an irregular form, they follow closely the outline of the lake.

No accurate data on thickness are available, but in places these deposits are at least 5 m thick, the approximate height of the dunes.

Age

Gypsiferous lunette dune deposits are forming at present though apparently on a fairly minor scale. Several older generations of deposits can be recognised, but these are presently being eroded. In the more humid parts of southern Australia the latest generation of clayey lunette dunes has been dated at about 16 000 years B.P. (Bowler, 1973a, 1973b), and it is believed that the younger lunette dunes in the study area are at least partly of the same age. However, as lunette dune deposits are related to the formation of playas, which probably started to form in the Miocene, some buried lunette dune deposits may be as old as Miocene.

Conditions of deposition

The restriction of the gypsiferous aeolian deposits to the leeward margins of the playas, indicates short transport distances before deposition in lunettes. The same was noted for clay lunettes by Bowler (1973a), who concluded that reasonably exposed mudflats and strong, preferably unidirectional, winds coinciding with a hot dry season are required for their formation. The same is thought to apply to gypsiferous lunettes, and early cementation after initial deposition in a dune, prevents any further reworking. It is difficult to understand how the dust-sized kopi (cf. loess) could have been deposited in dunes rather than in sheet-like bodies. It is therefore suggested that this type of powdery gypsum forms through diagenetic alteration of originally coarser-grained, detrital gypsum.

Aeolian sand (Czs)

The aeolian sands comprise red-brown and minor yellow, dominantly fine to medium-grained, well-sorted quartz sand of aeolian origin that forms flat sheets or is more commonly heaped in dunes or sand ridges. Recognition of the unit on aerial photographs is largely on topographic form; naturally, the dune form with associated photo-pattern is distinctive and easy to disttinguish from other Cainozoic units, but flat areas of

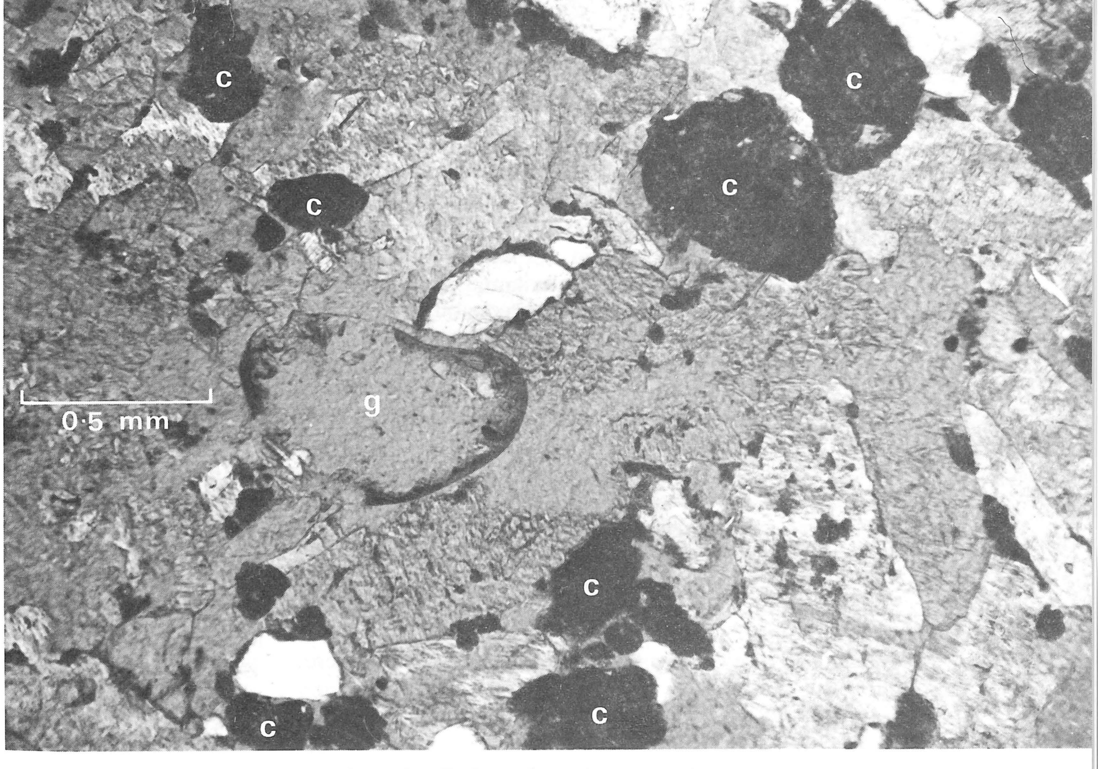


Fig. 60. Clay pellets (c) in tightly cemented/recrystallised, originally well-rounded gypsum sand (g).
Lunnette dune deposit at THROSSELL 29 (GSWA thin section 29143).

sand plain grade imperceptibly into coarser-grained lateritic soils (part of Czd) or finer-grained colluvial flats (part of Czc).

Systematic sand sampling and analyses have not been carried out, but, wherever examined, the unit consists of moderately rounded, very fine to medium-grained quartz sand, with each grain having a red coating. The red coating on quartz sand from the Simpson Desert is due to a hematitic red clay cutan around the quartz grains which is preserved by a thin silica coating (Folk, 1976); a similar surface texture is present in desert sand from the Officer Basin area. Coarser quartz sand is present, especially on the crests of dunes, and silt and clay form part of the lower flanks of some dunes (Fig. 61) and the interdunal flats. There have been no detailed studies on the dunes of this area, but some of the conclusions from Folk's work on the dunes of the Simpson Desert (Folk, 1971, 1976) are applicable to the Great Victoria Desert dunes. The crests of dunes are coarser and better sorted, and the flanks and interdune regs are progressively finer grained and not so well sorted. The fine sand size contains the reddest and darkest grains; coarser grains are commonly yellower. The interdune reg deposits contain more carbonaceous material and are usually darker.

Distribution and thickness

Aeolian sand occurs throughout the area; it is the most widespread of the surficial units. In the southern half of the area (south of 28°S) it dominates the scenery, but in the central part of the Gibson Desert, for example, on WARRI and BROWNE, it is subordinate to the lateritic duricrust. This difference probably reflects the difference in bedrock geology. The widespread dune fields in the south overlie quartz sandstone of Permian and Lower Palaeozoic age, whereas the Gibson Desert has a bedrock which is clay-rich.

In many of the interdunal corridors the underlying lateritic soil is often exposed, indicating that the sand thickness equals the dune height (and this ranges from 2 m up to about 30 m). Even in areas where sand sheets separate dunes, the sand does not appear to be more than a few metres thick. During the 1972 stratigraphic drilling program, nine of the holes were spudded into aeolian deposits: Rason 1 intersected about 4 m of sand, all the others intersected lateritised bedrock between 2 and 3 m (Appendix 1). This thin sand cover probably explains the poor development of draas in the Gibson and Great Victoria Deserts. Wilson (1972 p. 187) noted that draas are absent in all dune fields with a thin sand cover (less than about 2 m).

Age

There is no direct evidence for the age of development of the aeolian sand, except that it post-dates the formation of the duricrust (pre-middle Miocene). The

Fig. 61 Dessication cracks on flank of sand dune (COBB) indicating high clay content of some aeolian deposits.

formation of an extensive sand blanket by reworking of the exposed lateritised bedrock would have coincided with a change from the humid conditions prevailing during the formation of the relict drainage system and the duricrust to a more arid climate. Bowler (1976) recorded a number of well-documented periods characterised by marked reduction in precipitation, amongst which, events at 7-10 m.y., about 2.5 m.y., and about 17 000 years B.P. could all have initiated major phases of dune building.

Considering the youthful morphology of the dunes, and the total lack of clearly older aeolian sediments, the dune and sand plain deposits were probably completely reworked during the last arid glacial period, that is about 17 000 years B.P.

Origin

The numerous parallel longitudinal dunes were caused by unidirectional wind systems, which induce helicoidal flow at the ground surface and heap the dunes into elongated ridges (Bagnold, 1951; Wilson, 1973; Folk, 1971a, 1971b).

STRUCTURE

Origin and previous use of the term Officer Basin

The name Officer Basin was first published in a BMR report summarising oil-search activity in Australia to June 1959 (BMR, 1960, p. 39). There the term was introduced for a new basin that had been discovered in South Australia—

> 'A previously unknown basin containing more than 20 000 feet of Lower Palaeozoic (and Proterozoic) sediments (Glaessner & Parkin, 1958) has been indicated by aeromagnetic survey in the north-western part of the State, north of the Eucla Basin (Quilty & Goodeve, 1958). It appears to be confined at its eastern end but extends into Western Australia. Sturtian and Ordovician sediments crop out on the north-eastern margin. The name "Officer Basin", which was suggested for this basin by Mr R. C. Sprigg, has been accepted by the Geological Surveys of South Australia and Western Australia.'

In an unpublished BMR Record the basin was further defined and its margins delineated on a map (Reynolds, 1963). The northern margin was located where sediments unconformably overlie the metamorphics of the Musgrave Block; the western edge was drawn at the edge of the Archaean outcrops in Western Australia, and the northern edge of the Eucla Basin was taken as its southern margin. The northwestern and eastern limits were poorly defined, but they were tentatively related to geophysical anomalies. With minor modifications, these limits were then used to define the Officer Basin for the following 10 to 12 years. It was during this period that the term Officer Basin became virtually synonomous with the Gibson and Great Victoria Deserts.

Although the recent systematic mapping by BMR, the Geological Survey of Western Australia, and the Geological Survey of South Australia has shown that the tectonic and sedimentary history of this vast area is complex and that perhaps the use of Officer Basin for all the sedimentary sequences within such area is inappropriate (Krieg & others, 1976), there are still large gaps in our knowledge of the depositional and structural history of this region. Unfortunately, we are still not able to define adequately such features as depocentres, thickness variations, lateral stratigraphic changes, or significance of breaks with the accuracy that would enable a better definition and/or subdivision of the basin to be made.

South Australian use

In South Australia the Officer Basin has been described as containing Palaeozoic sediments both with and without the underlying Adelaidean rocks. Parkin (1969), Krieg (1972), and Krieg & others (1976) have described it in both these ways.

Western Australian use

In Western Australia Lowry & others (1972) proposed the following boundaries to the Officer Basin (W.A.):

- the Warri Gravity Ridge (now called Anketell-Regional Gravity Ridge, Fraser, 1976) in the north, separating the Officer from the Canning and Amadeus Basins (Fig. 62);
- the base of the Townsend Quartzite in the northeast;
- the northern limit of the Eucla Basin Tertiary deposits in the south;
- the limits of continuously-preserved Permian deposits in the west and southwest, separating the Officer from the Nabberu and Bangemall Basins and the Yilgarn Block;
- the State boundary at longitude 129°E in the east.

Most of these boundaries are merely convenient limits to a large area of thick sedimentary rocks, which can-

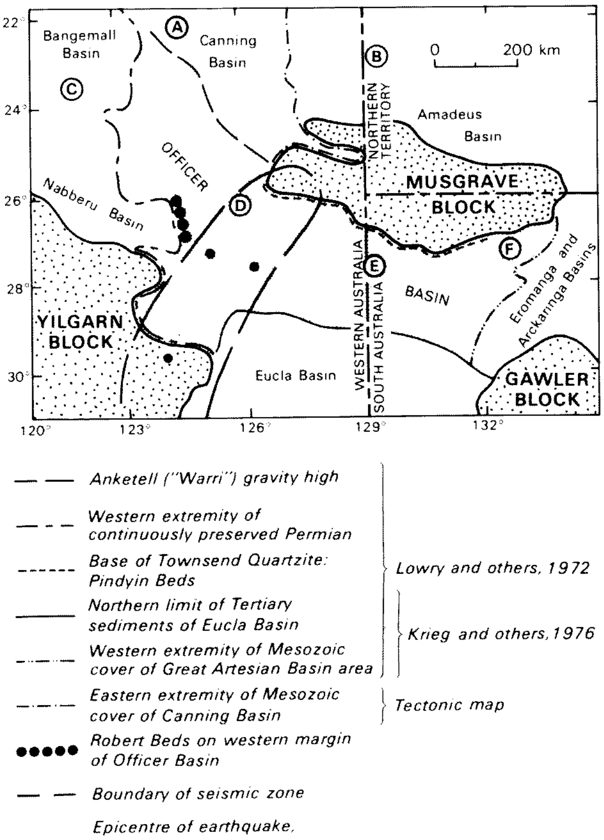


Fig. 62. Tectonic setting of the Officer Basin. Major seismic zone also shown. Circled letters refer to stratigraphic columns shown in Fig. 63.

not be defined on palaeogeographical or structural grounds. However, this definition was followed by Playford & others (GSWA, 1975), and has been used in this Bulletin.

REGIONAL SETTING

Figures 62 & 63 show generalised sedimentary sequences at six localities within the region, and the boundaries of the Officer Basin. As described in the section on stratigraphy, four broad groups of sedimentary sequences can be distinguished

- an older Proterozoic sequence
- a younger Proterozoic to earliest Cambrian sequence
- a thin, Early Palaeozoic sequence
- thin Permian and Mesozoic uints.

The older Proterozoic at locality C is part of the Nabberu Basin (Hall & Goode, 1975). To the north it is overlain by a younger Proterozoic sequence included in the Bangemall Basin (Williams & others, 1976, Brakel & Muhling, 1976). The layered sequences recognised on seismic surveys at depths below about 5000 m, in the vicinity of locality D, may be a lateral continuation of the Nabberu Basin. To the northwest of D, the deeper fill of the basin may, similarly, be a lateral equivalent of the Bangemall Basin.

The thin Permian and Cretaceous units between localities A and D and in the vicinity of locality F extend outside this region into other basins where they form parts of thicker more continuous sequences.

A comparison between the sequences at localities D and F indicates that in Western Australia the Officer Basin preserves a thick upper Proterozoic sequence capped by a thin Palaeozoic sequence; whereas in South Australia the thick upper Proterozoic sequence is overlain by a thick Palaeozoic sequence.

REGIONAL GEOPHYSICAL INFORMATION

Almost all the information on basin structures is based on the interpretation of geophysical surveys conducted in and around the area (Plate 3). The reconnaissance gravity survey of Western Australia provided information on large scale structures within this part of the continent; aeromagnetic surveys have been used to define basement blocks and infra-basin structural divisions; and seismic surveys combined with geological mapping have allowed more detailed interpretations of subsurface structures. As so much of the interpretation of structure is based on geophysics, the results of the more significant geophysical surveys are summarised here, and resulting geological interpretations are given in the succeeding section.

Gravity

Complete reconnaissance gravity coverage of the basin in Western Australia was obtained during three surveys: a reconnaissance BMR helicopter survey in the Gibson Desert in 1962 (Lonsdale & Flavelle, 1968); a semi-detailed ground survey by Hunt Oil between 1963 and 1965 in the central part of the Officer Basin, WA, (Jackson, 1966a); and a systematic helicopter survey throughout southern Western Australia by BMR in 1971-72 (Fraser, 1973a, 1973b). The results of these surveys have been summarised on the geological maps at 1:250 000 scale in the form of Bouguer anomalies at intervals of 50 $\mu m.s^{-2}$, using a uniform rock density of 2.2 $g.cm^{-3}$. These Bouguer anomalies are shown on Plate 3 at 1:1 million scale.

The Officer Basin is a region characterised by negative Bouguer anomalies. It is flanked to the north by a belt of positive anomaly (Musgrave Block), to the west and east by regions of complex patterns associated with shield areas (Yilgarn Block and Gawler Block, respectively), and to the south by a complex arc-shaped high-low anomaly pattern associated with basement underlying the Eucla Basin. Over most of the Officer Basin in Western Australia the Bouguer anomalies are generally broad and open. In discussion of the Bouguer anomaly patterns of Western Australia, Fraser (1973a, 1973b) divided the State into a number of gravity provinces. In a later paper, Fraser (1976) modified his terminology slightly and published a list of gravity provinces for the whole of Australia. The terminology used below and shown on Plate 3 follows his 1976 paper.

Yeo Regional Gravity Shelf

This province is characterised by flat gravity relief with Bouguer anomaly values generally ranging between −400 and −600 $\mu m.s^{-2}$. No consistent contour trends are obvious. The most noteworthy local gravity features are a northwesterly elongated high on RASON, and a broad east-trending high on THROSSELL, which swings round to a northerly direction in western WESTWOOD and BROWNE. The province extends across the western boundary of the Officer Basin, so it seems that the basin sediments and basement rocks are of similar density. The high on RASON is conformable with highs in the Archaean to the west, and it probably corresponds to a basic igneous body in the basement. The broad, east-trending high on THROSSELL is of unknown origin. It has a markedly different orientation from most gravity features associated with the Yilgarn Block and is therefore unlikely to be due to an intra-basement source. Fraser attributed the anomaly to either a basement rise or a dense intrusive body interbedded with or cutting across the sediments.

Rason Regional Gravity Low

This is an arcuate province stretching from SEEMORE, in the southweast of the region, towards the central part of the Officer Basin area and then swinging northwesterly towards MADLEY (Plate 3). It is a broad gravity trough with Bouguer anomaly values generally ranging between −600 and −800 $\mu m.s^{-2}$. Fraser suggested that the low Bouguer anomaly values reflect a mass deficient zone within the basement, rather than thick sediments.

Fraser Regional Gravity Ridge

The province is an elongate gravity ridge extending northeast from CUNDEELEE to the Musgrave Block on TALBOT. Bouguer anomaly values range from +250 to −500 $\mu m.s^{-2}$ with the contours commonly forming northeast-trending anomalies. Between northern PLUMRIDGE and TALBOT a reduction in intensity and Bouguer anomaly level has been attributed by Fraser (1973a) mainly to a general decrease in basement density, but with some attenuation by Officer Basin sediments. The province follows the buried southeastern margin of the Yilgarn Block, and Fraser considered it may correlate with a Proterozoic mobile zone containing dense metamorphic rocks (i.e. a continuation of the Albany-Fraser Province).

Officer and Wanna Regional Gravity Lows

These two provinces, located in the east of the area, have fairly uniform Bouguer anomaly levels between —500 and —1000 $\mu m.s^{-2}$. Gravity relief is broad and gentle, and Fraser related this mainly to low-density basement.

Anketell and Blackstone Regional Gravity Ridges

These provinces form a prominent zone of intense positive Bouguer anomalies in the northeast of the area. The Blackstone area especially is an intense, narrow, east-trending gravity high with several peaks exceeding +400 $\mu m.s^{-2}$, which can be attributed to the dense metamorphic rocks with basic intrusions that form the Musgrave Block. Fraser considered the Anketell Ridge probably represents the deeply-buried northeast margin of the Yilgarn Block. However, this gravity ridge roughly corresponds to a magnetic basement ridge (Goodeve, 1961), therefore it may also reflect shallower basement separating the Officer Basin from the Canning Basin. Seismic results at Contention Heights in the southern Canning Basin (Australian Aquitaine Petroleum, 1969) indicate shallowing of Canning Basin sequences against a buried ridge roughly coincident with this gravity province.

In summary, Fraser did not believe that the regional gravity provides much information on the character and structure of the sedimentary sequences in this area. He related most of the gravity anomaly patterns to variations in density of basement rocks, rather than to relief of the basement surface. However, in two areas at least, independent evidence shows that gravity highs and low are related to basement highs and lows.

Aeromagnetics

Four aeromagnetic surveys have been flown within the Officer Basin area. The contours from these and adjacent surveys are shown in Plate 3. The first, consisting of three lines, was flown by BMR in 1960, west of the Musgrave Block, and indicated the presence of a large area with low magnetic responses which was equated with a thick sedimentary sequence (Goodeve, 1961).

An aeromagnetic survey was flown over the Gibson Desert for Union Oil (Lynch, 1965): it covered the MADLEY, WARRI, COBB, and HERBERT areas. Three characteristic patterns were interpreted in magnetic intensity contours by Tucker (1974): (1) A belt of northwest-trending anomalies with amplitudes of about 1000 nT, attributed to magnetic basement at 'medium' depth. Some of the anomalies correspond in position with the Anketell Regional Gravity Ridge, and indicate a northwest extension of the Musgrave Block at relatively shallow depth (1000-3000 m). (2) Areas of broad anomalies of amplitude about 100 nT, attributed to magnetic basement at depths of 3000-5000 m or more. (3) An intense pattern of sharp anomalies with amplitudes of 50-500 nT in the southwest of HERBERT, which Lynch had attributed to volcanics at shallow depth (less than 1000 m).

A large-scale reconnaissance aeromagnetic survey was carried out in the Officer Basin area for Hunt Oil in 1961. Six northeast-trending lines spaced about 50 km apart were flown and the results used to contour depth to magnetic basement from BROWNE in the north to

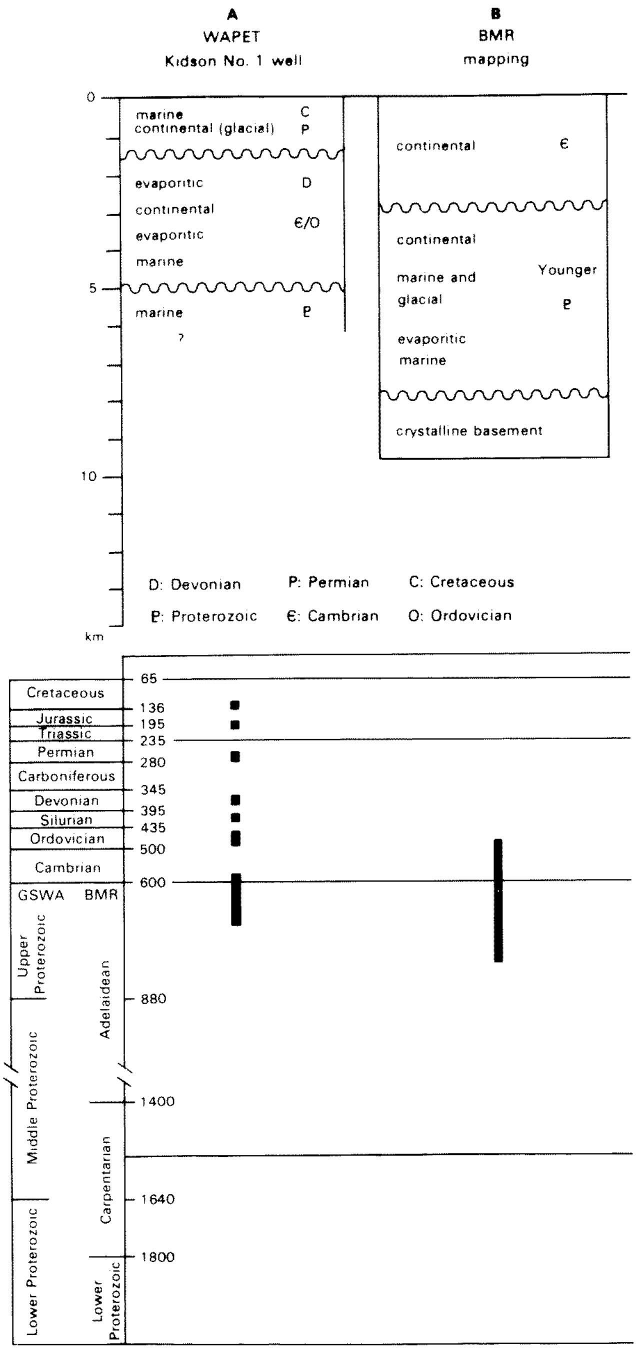
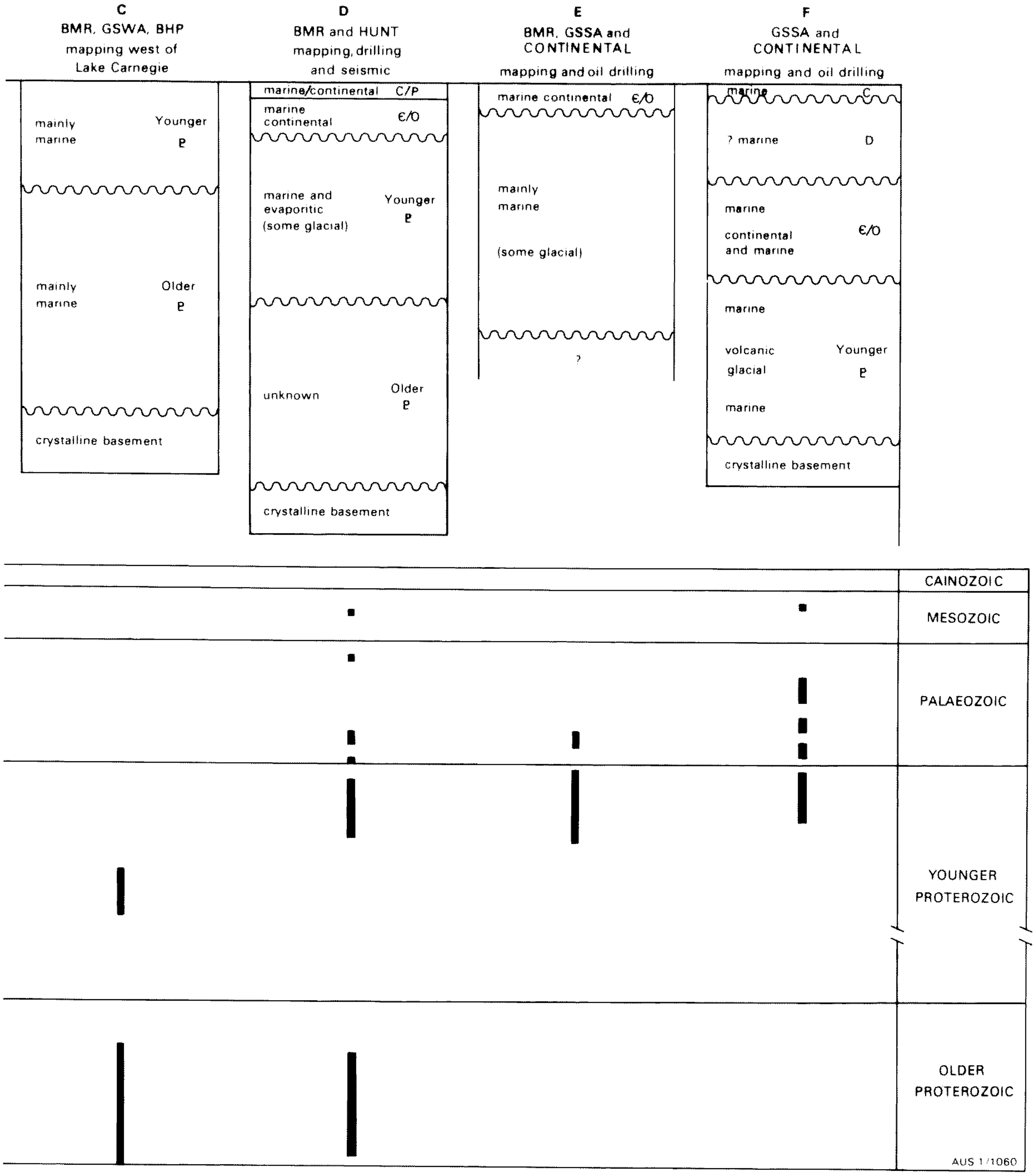


Fig. 63. Generalised sedimentary sequences in the Great Victoria Desert/Gibson Desert area, compared by thickness and general environment (upper diagram) and age (lower diagram).

30° south (Jackson, 1966a). The aeromagnetic contours defined an asymmetric basin with the deepest portion (5000 m) along the south flank of the Musgrave Block. Shallower sub-basinal areas were interpreted in southeast YOWALGA and southwest NEALE. These structural subdivisions were adopted on the Tectonic Map of Australia and New Guinea (GSA, 1971). Where they overlap, the Union Oil basement contours are generally 1500 m deeper than those compiled by Hunt Oil.

The results of the BMR 1976-1978 systematic aeromagnetic survey became available after the writing



of this Bulletin was finished. The aeromagnetic contours are reproduced at 1 000 000 scale on Plate 3.

Seismic

Seismic reflection and refraction surveys were made in the northern part of the Officer Basin by BMR in 1961-62 (Turpie, 1967) and in the central part by Hunt Oil between 1963 and 1965 (Campbell, 1964; Kendall & Hartley, 1964; Mickleberry, 1966a; Mickleberry, 1966b). A combined seismic, gravity, magnetic, and radiometric survey along the Warburton Road was made by BMR in 1972, to assist structural interpretation of the results of the reconnaissance mapping. The locations of the various traverses are shown in Figure 2. Harrison & Zadoroznyj (1978), Pinchin & Mathur (1972) and Jackson (1966a) gave detailed descriptions of these surveys and their results; only information pertinent to the structural synthesis of the area is summarised here.

The 1961-62 BMR surveys were recorded along the Gunbarrel Highway northwest of the Musgrave Block. The refraction results indicated sediments between 4400 and 5700 m thick over most of the traverse. However, fair quality reflections were obtained on the Lake Keene traverse (south MADLEY) which indicated a possible sedimentary thickness of about 12 km. Turpie identified three refractors, one with a velocity around 3200 $m.s^{-1}$, which was interpreted to be close to the base of the Permian; another with a velocity around 5000 $m.s^{-1}$, which was interpreted to be close to the base of the Phanerozoic sequence; and a deeper refractor, with a velocity of 6250 $m.s^{-1}$, which was thought to be from the top of igneous or metamorphic basement.

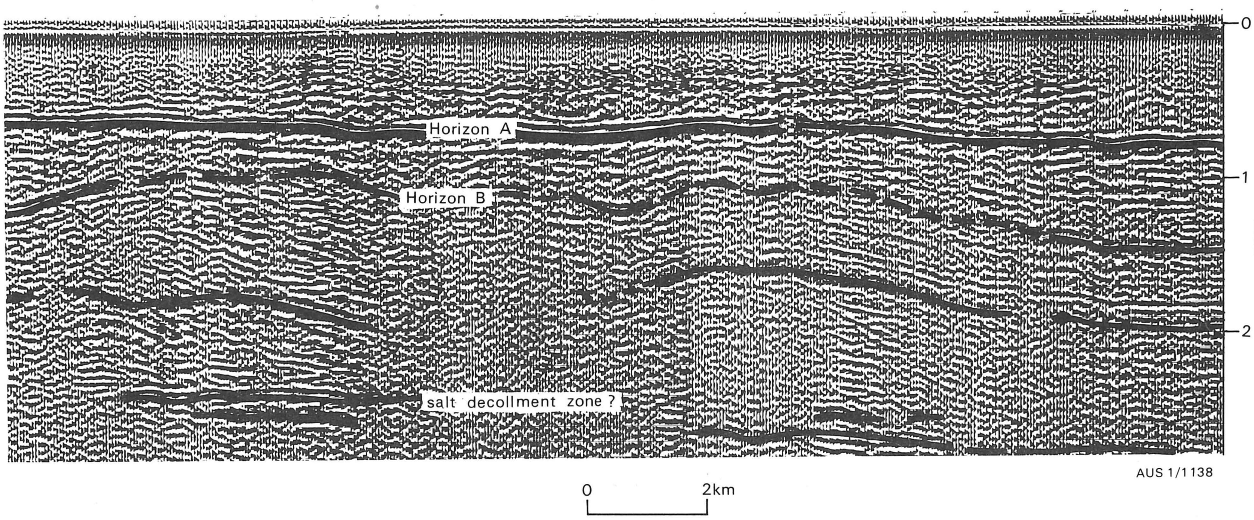


Fig. 64. Seismic section Hunt Oil 12-E.
Horizon A is the Table Hill Volcanics; Horizon B is a prominent reflector within the Younger Proterozoic to earliest Cambrian sequence.

Four seismic surveys were conducted by Hunt Oil. Most used the reflection method, but some refraction profiles were also run. A good reflector, called Horizon A, was mapped over most of the survey areas at depths down to about 1500 m. Numerous anticlines and synclines were mapped on this horizon (Table Hill Volcanics) in the area southwest of Warburton Mission. The axes of most folds are northwest, and dips along the flanks of most of the features are less than 5 degrees. In north LENNIS the structure of Horizon A is even gentler; it shallows to the northeast with a calculated regional dip of less than 10 minutes. A deeper reflector, 1000 to 3200 m deep, called Horizon B was also mapped in YOWALGA and north LENNIS. Reflector B was stronger in areas where A was weaker. Horizon B is located within a broad band of conformable reflectors, so it is unlikely that the same event has been recognised on every section. However, this sequence is more strongly folded than that containing Horizon A, and it is probable that some of the folding is caused by diapiric intrusion of evaporitic material originating from below the level of Horizon B. It is notable that on nearly all YOWALGA lines there are near-horizontal reflections below more strongly folded rocks, which suggests a salt décollement surface at depths between about 3000 and 6500 m. In north LENNIS Horizon B again shows gentler relief than in the Warburton area, but a faulted dome with dips up to 5° on its flanks is present in the northeast.

Minor faulting can be recognised on many of the seismic sections. It appears to be normal faulting, and usually occurs on the flanks of structures. A seismic section line, Hunt 12-E, showing most of these features is shown in Figure 64. Some weak discontinuous reflections indicating folding were also recognised below Horizon B down to about 7000 m.

The 1972 BMR survey consisted of a series of refraction and reflection probes along the Warburton Road from southwest YOWALGA to the Yilgarn Block on THROSSELL. Gravity, magnetic, and radiometric measurements were made at about 1-km intervals along the seismic traverse, on short cross-traverses, and also along the Emu Road from near Yamarna to Neale Junction.

The main result of the survey was the discovery of a sequence of layered rocks at least 10 000 m thick along most of the traverse, but up to a maximum of 12 500 m thick in the southwest. This thick layered sequence has been divided into three groups:

- An upper group of flat-lying sediments, thickest in the centre of the basin and thinning out gradually towards the margins, with a good reflector (Horizon A) at its base. This reflector has a refraction velocity of 5100-5430 $m.s^{-1}$.
- A middle group with interval velocities between 3300-5700 $m.s^{-1}$ which is estimated to be about 6000 m thick in the centre of the basin, but which thins out rapidly towards the southwest.
- A lower group with interval velocities between 6000-6500 $m.s^{-1}$ which is up to about 12 000 m thick in the southwest of the basin, but thinner in the northeast.

Folding and faulting of the sediments near the southwest margin of the basin is suggested from the seismic and gravity results.

Other geophysical surveys

A land magnetic survey by Hunt Oil near Neale Junction in 1965 located a sharp positive anomaly with an amplitude of 400 gammas, which was interpreted by Bazhaw & Jackson (1965a) to indicate basement between 2000 and 4000 m. The anomaly coincides with a pronounced gravity high, which is probably related to a northwards extension of the Fraser Range Province.

Aeromagnetic maps for RASON, PLUMRIDGE, MINIGWAL, and CUNDEELEE show a pattern of northeast and northwest-trending anomalies with amplitudes commonly in excess of 1000 gammas. Sharp, linear, easterly trending anomalies are also present in the west of this area. Tucker (1974) related the northeast-trending anomalies in the east of MINIGWAL and PLUMRIDGE to the intense Bouguer anomaly high in this area, which is caused by steeply dipping layered sources within the granulites of the Fraser Range Province.

A resistivity survey was made in 1971 across RASON for the Western Australian Public Works Department, by Australian Groundwater Consultants (AGC, 1971). They interpreted a number of depressions in the basement, but stratigraphic drilling by BMR in 1972 (Jackson & others, 1976) indicated basin sediments thickening gradually eastwards across the area.

REGIONAL STRUCTURAL SYNTHESIS

The subsurface structures in the northern, central, and southern parts of the Officer Basin, WA have been interpreted by combining the results of the geophysical surveys with those of mapping and drilling. These interpretations and the more important geophysical features, such as seismic reflecting horizons, are shown on the three cross-sections on Plate 1.

A more highly interpretive synthesis of the distribution, character, and relationships between the major structural elements is shown in the block diagram on Plate 1.

Basement

Exposed basement blocks include the igneous and metamorphic complexes of the Yilgarn Block in the west, which is contiguous with buried crystalline basement below the Eucla Basin in the south, and the exposed Musgrave Block and its buried northwestwards extension (coincident with the Anketell Regional Gravity Ridge), which form a northeastern margin to the sedimentary trough. Basement was intersected in BHP drillholes TD1 to TD4 in the centre of THROSSELL (BHP, 1978). These drillholes and the seismic results indicate the presence of a layered granite/gneiss basement geophysically distinct from the Yilgarn Block (which is non-layered on the BMR seismic records). The gravity and aeromagnetic contour patterns suggest this layered basement is close to the surface throughout most of Throssell; the seismic results to the northeast indicate that it underlies the Officer Basin sequence in WESTWOOD & YOWALGA.

Depth to, and nature of, crystalline basement in the north and southeast of the basin are largely unknown, although basement may be at about 12 000 m in southern MADLEY (Turpie, 1967). On the block diagram (Plate 1) the various crystalline complexes are shown to be continuous with each other in the subsurface, but their actual age and structural relationships are unknown.

Nabberu and Bangemall Basin sequences

These structural elements may form a wedge of sediments between the crystalline basement and the Officer Basin sequence in the north-western part of the trough. At the surface the sequences are characterised by gently-dipping to gently-folded, unmetamorphosed sedimentary rocks with minor basic intrusions; shallow-water sandstone, siltstone, carbonate, and iron formation are the major rock types. The nature of the subsurface transition from the Nabberu Basin sequence to the Musgrave Block across the northern part of the area, and the thickness and extent of the Bangemall Basin sequence and its relationship to the basement coincident with the Anketell Regional Gravity Ridge are unknown.

Proterozoic Officer Basin sequence

This structural element is only well exposed along the southern margin of the Musgrave Block, where it comprises a conformable sequence of sedimentary rocks up to about 6000 m thick (the sequence Townsend Quartzite up to and including the Wirrildar Beds), dipping steeply to gently south. However, small parts of it also crop out along the southern margin of the area (Ilma Beds, Neale Beds, Turkey Hill Beds), along the western margin (Robert Beds), and in the diapiric intrusions in the north (Woolnough and Madley Beds). In the block diagram (Plate 1) it is, therefore, shown as a fairly extensive element, stretching from the northernmost part of the trough southeast to the Western Australia/South Australia border, and on into South Australia. In the subsurface in the central part of the area (YOWALGA) it is up to about 6000 m thick, has interval velocities between 3300 and 5700 $m.s^{-1}$, and is usually gently folded. It forms an asymmetrical wedge with its deepest portion in the northeast. The northeast margin with the Musgrave Block is much steeper than the gradually shallowing southwestern margin. In places it is characterised by a décollement surface at depths of between 3000 and 6500 m, from which diapiric intrusions originate. Normal faults with small throws are present on the flanks of many of the anticlinal structures. The Hunt Oil magnetic basement profile (Plate 1, Section EF) corresponds approximately in shape to the base of this structural division, but it is about 1500 m shallower.

Lower Palaeozoic Officer Basin sequence

This structural subdivision comprises three flat-lying Lower Palaeozoic formations that unconformably overlie the Proterozoic sequence. They have a combined maximum thickness of about 650 m. All three formations extend eastwards into South Australia, but their distribution to the northwest of section line EF (Plate 1) is very poorly known. We have suggested a similar, but less extensive, distribution than that of the Proterozoic part of the Officer Basin sequence (block diagram on Plate 1), but as their presence north of Hunt Oil Yowalga 2 has not been confirmed, we have limited their northern extent to about 25°S. The Table Hill Volcanics, which form the base to this sequence, are a lithologically distinctive unit that is readily identifiable on seismic sections. Hence, using outcrop distribution and seismic interpretations, it is possible to produce an accurate structural configuration for the base of this sequence in the central part of the area (Fig. 23). The structure contours show that, in the area southwest and west of Warburton Mission, this subdivision is regionally folded into gentle northwest-elongated synclines and anticlines, and that elsewhere it is very gently dipping.

Upper Palaeozoic & Mesozoic sequence

A flat-lying veneer of Permian and Mesozoic rocks, up to 550 m thick covers virtually the whole area shown in the block diagram (Plate 1), but for the sake of clarity it is shown as a stipple overprint. This element is a southern extension of the sedimentary sequence that forms part of the Canning Basin.

Eucla Basin sequence

A thin sequence of rocks deposited in the Eucla Basin rests on top of older structural units forming part of the Officer Basin or its basement in the southern part of the area. Facies variations in the Eucla Basin indicate that the present distribution of most of the units closely relates to the original shape and extent of the sedimentary basin within which they were deposited.

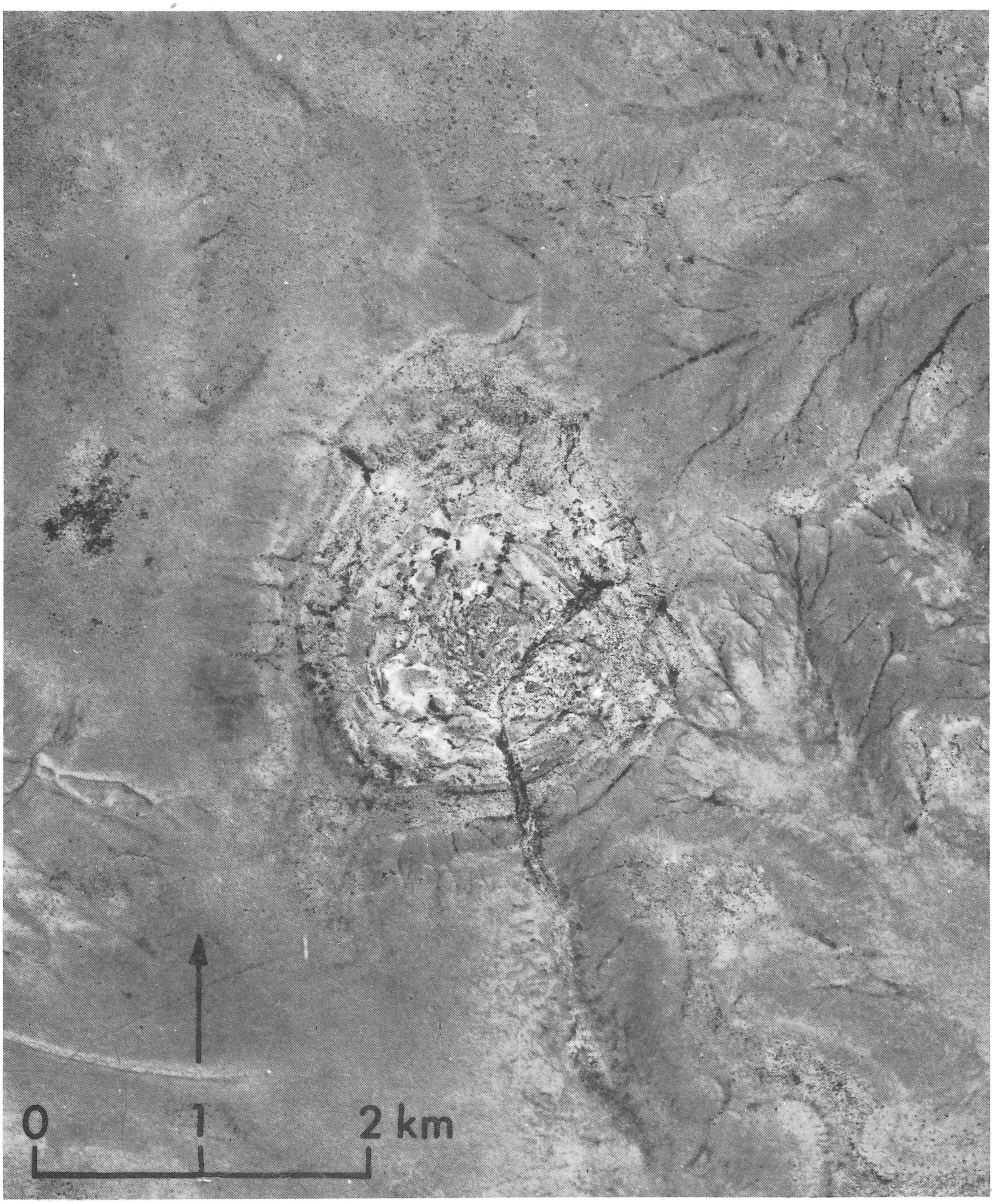


Fig. 65. Vertical aerial photograph of the Woolnough Hills diapir.

DIAPIRS

Diapiric structures occur at the surface in the north (Woolnough Hills and Madley diapirs) and in the central part of the basin, west of Warburton Mission (Browne diapir). Anticlines possibly related to diapiric intrusion also occur on several seismic records.

Woolnough Hills and Madley diapirs

The Woolnough Hills structure (Fig. 65) was first described as a salt dome by Veevers & Wells (1959a, 1959b). Leslie (1961) described the structure in more detail, confirmed that it must have formed by upward piercement of evaporites, and inferred an Upper Proterozoic or older age for the mother evaporite bed. Wells revisited the area in 1962, during the course of a reconnaissance helicopter gravity survey of the Gibson Desert area, and recognised a line of diapirs to the southwest of Woolnough Hills, which he called the Madley diapirs (Fig. 66). Wilson carried out detailed mapping and produced large-scale maps and descriptions of both the Woolnough Hills and Madley diapirs (Wilson, 1964, 1967). During the present investigation a detailed map of the Woolnough Hills structure was compiled (Fig. 19) and the Madley diapirs were revisited. Stratigraphic drilling was undertaken in 1972 to investigate the cores of these structures. Small amounts of halite were recovered from BMR Warri 20 (at Woolnough Hills) and BMR Madley 1 (Wells, 1980; Wells & Kennewell, 1974). As numerous published descriptions of these diapirs are readily available, only the details that relate to structure and update the published descriptions are summarised here.

The Woolnough Hills diapir is oval in plan and consists of a central core of intensely deformed gypsum surrounded by concentric bands of progressively less-deformed strata ranging from late Proterozoic to Cretaceous (Fig. 19). Radial and tangential faults were mapped mainly in the southern half of the dome, but an important concentric bedding-plane fault marks the contact between the Proterozoic sediments and the Paterson Formation (Van der Graaff, 1974b). Both Leslie (1961) and Wilson (1964, 1967) described the sequence at the diapir as consisting of Proterozoic, Permian, Jurassic and Cretaceous strata separated from one another by unconformities. However, except for the partly faulted unconformity separating the Proterozoic sediments from the Paterson Formation, none of these unconformities was recognised by us. As we found a tillite horizon in the 'Jurassic', we prefer to include this sequence within the Paterson Formation. Leslie (1961) & Wilson (1967) argued that the presence of several unconformities indicates a prolonged history of diapiric uplift at Woolnough Hills, but as a similar incomplete sequence is present in other parts of the basin where there are no diapirs, we do not accept their argument. Van de Graaff (1974b) considered that the diapirism probably occurred after deposition of the Lower Cretaceous sediments and before the formation of the ?Oligocene laterite, although he did not discount the possibility of earlier minor movements or slight post-laterisation intrusion. Wells & Kennewell (1974) suggested a salt dome 1000 m in diameter and 5000 m high (rock density of 2.1 $g.cm^{-3}$) intruding rocks of density 2.3 $g.cm^{-3}$ to explain the gravity values associated with the structure.

The Madley diapirs comprise twelve separate culminations along a west-southwest trend at least 20 km

Fig. 66. Airphoto mosaic of the Madley diapirs.

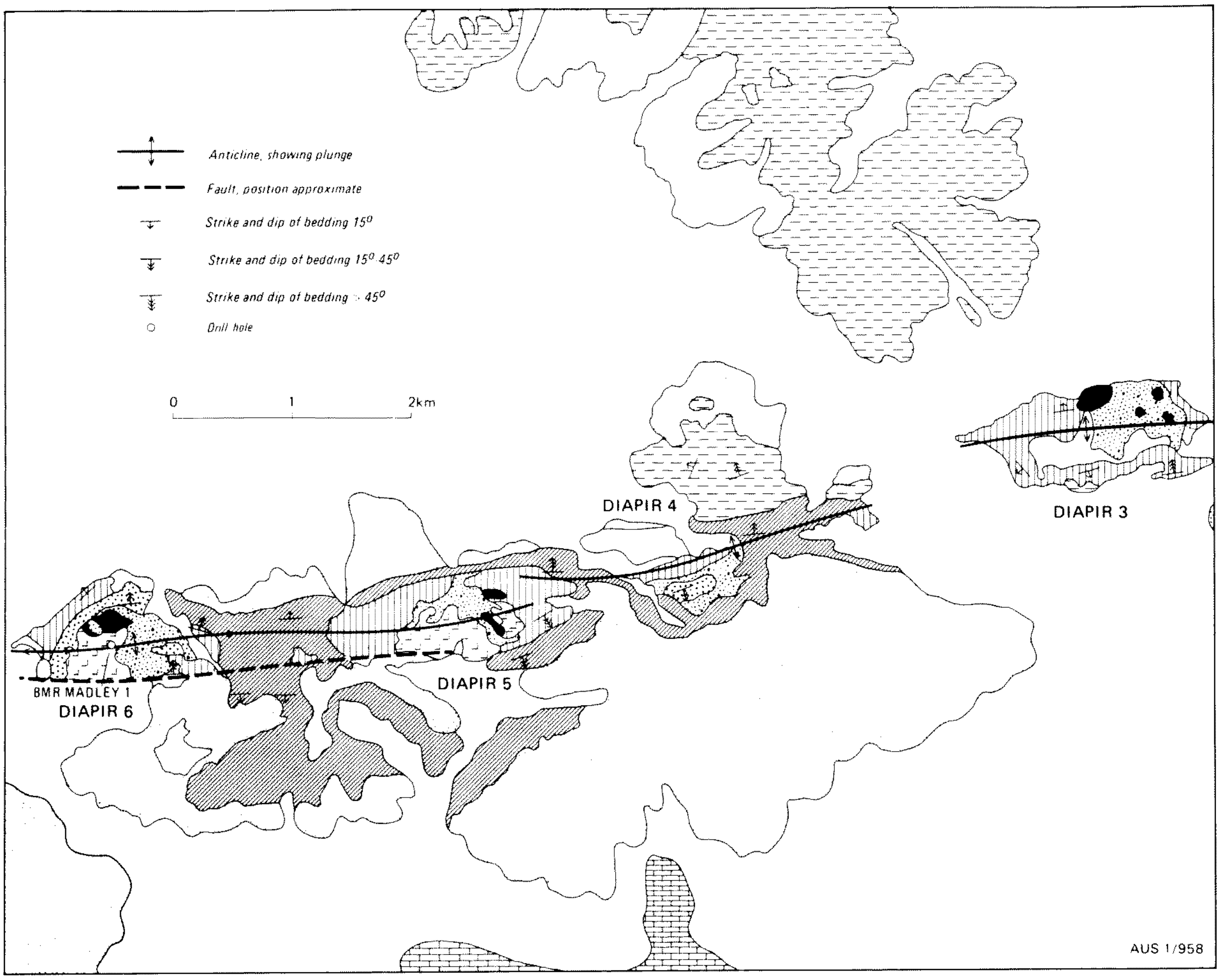


Fig. 67. Geological map, part of Madley diapirs.

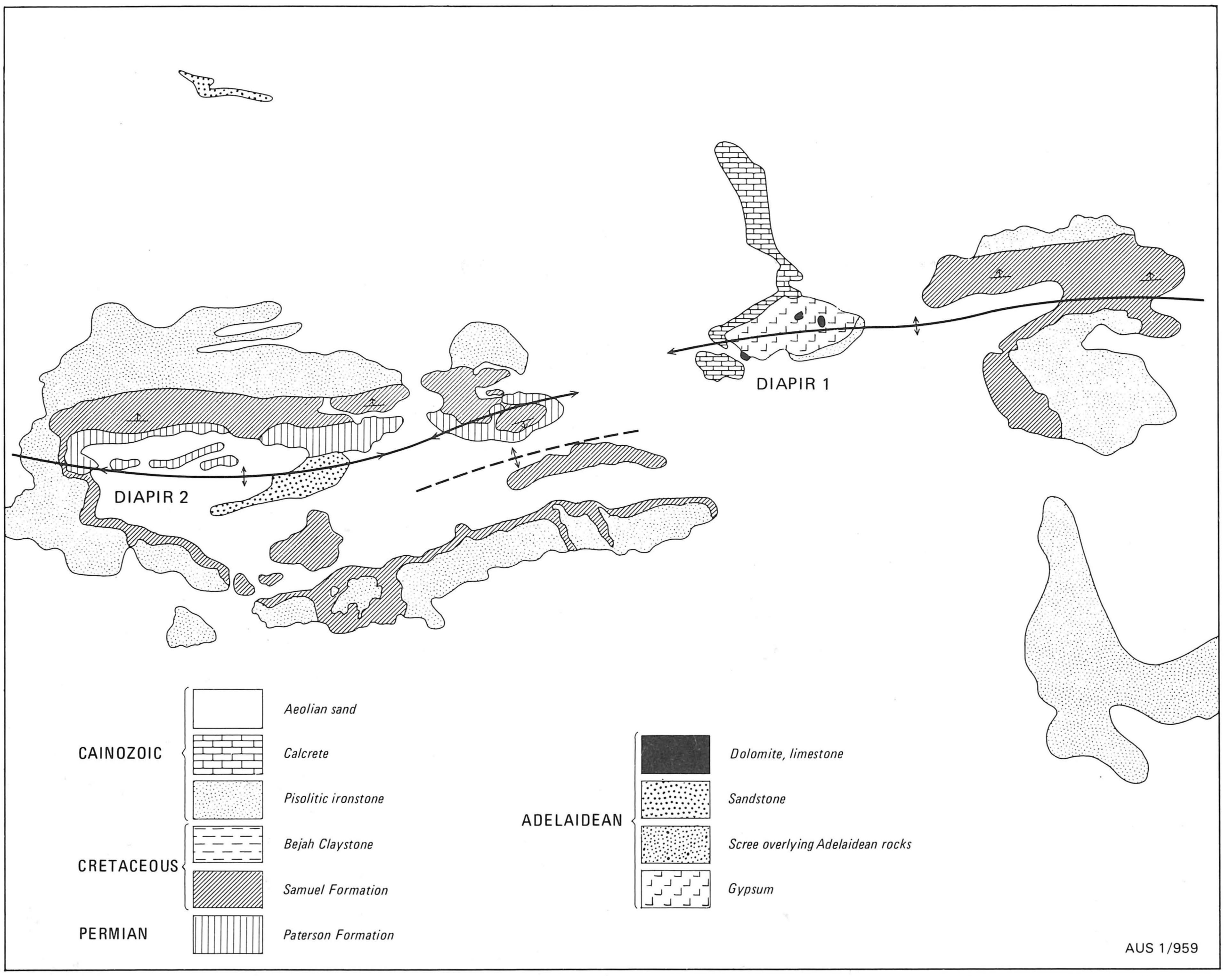
long. Wilson (1964, 1967) numbered the main culminations from east to west starting in the east at number 1, which is located 12 km south of Woolnough Hills. At three of the diapirs (Wilson's Nos. 1, 5, and 6) gypsum cores with blocks of sheared and brecciated dolomite are surrounded by steeply dipping sediments; at the others the cores consist of steeply dipping Proterozoic sandstone surrounded by steeply dipping Phanerozoic sediments (Fig. 67). As at Woolnough Hills, we do not separate out a 'Jurassic' unit as Leslie (1961) and Wilson (1967) did; the steeply dipping sediments surrounding the Proterozoic cores comprise the Permian Paterson Formation and the Cretaceous Samuel Formation and Bejah Claystone. Most of the diapirs are elongated east-west and some are offset in an en echelon pattern. Narrow saddles with plunge reversals separate the individual structures. Madley diapirs 5 and 6 are distinctly fault-controlled.

The linear pattern of the Madley line of diapirs suggests a regional structural control, such as large-scale faulting or folding. The easterly trend is parallel to major fold axes in the older, Bangemall Group and Yeneena Group rocks on the western margin of the Officer Basin (Williams & others, 1976).

Browne diapir

Wells (1963) noted folded Permian and Cretaceous strata in the southeast corner of BROWNE, but Jackson (1966b) was the first to relate these folds to diapiric intrusion. Hunt Oil recorded seismic lines 13C and 15G across folded strata in this area, and outlined a broad northwest-trending anticline with piercement type structures, which they called the Mount Samuel Anticline (Fig. 68). Stratigraphic wells Hunt Oil Browne 1 and 2 were drilled on the crest of this anticline and both intersected brecciated evaporites beneath the Permian Paterson Formation, thus confirming the diapiric origin of the structure. Detailed mapping of the area northwest of Hunt Oil Browne 1 was carried out in 1972, and Jackson (1976) proposed the name Browne diapir for the feature (Fig. 69). Folded and faulted Paterson Formation, Samuel Formation, and Bejah Claystone crop out in a northwest-trending belt approximately 8 km long by 2 km wide (Fig. 70). Several northwesterly elongated anticlines and synclines with limbs dipping between about 10° and 35° were defined in the southern part of the structure. The northern part consists of a circular basin with dips commonly between 20° and 40° and cut by radial faults with small throws. The evaporitic core of the diapir was not found at the surface, but intersected at 133 m in Hunt Oil Browne 1.

The similar folding of Paterson Formation, Samuel Formation, and Bejah Claystone indicates that important diapirism took place after the Early Cretaceous. Evidence for earlier movement is inconclusive. However, the fact that the Paterson Formation directly overlies the Proterozoic Browne Beds could indicate either



that the diapir had topographic expression during the Palaeozoic, so that the Table Hill Volcanics and overlying Palaeozoic sediments were not deposited on the feature, or that the Palaeozoic units were deposited across the area, but were subsequently removed when the area was uplifted before deposition of the Paterson Formation in the early Permian. The stratigraphic level of the mother salt bed is not known, but interpretation of seismic reflections on Hunt Oil lines 13C and 15G suggests an origin from the Younger Proterozoic, at least 4000 m below the surface (see cross-section ABCD on Plate 1). Regional correlation of the intrusive Browne Beds with the Lefroy Beds and Bitter Springs Formation (Amadeus Basin) would also imply an origin from the lower part of the Officer Basin sequence.

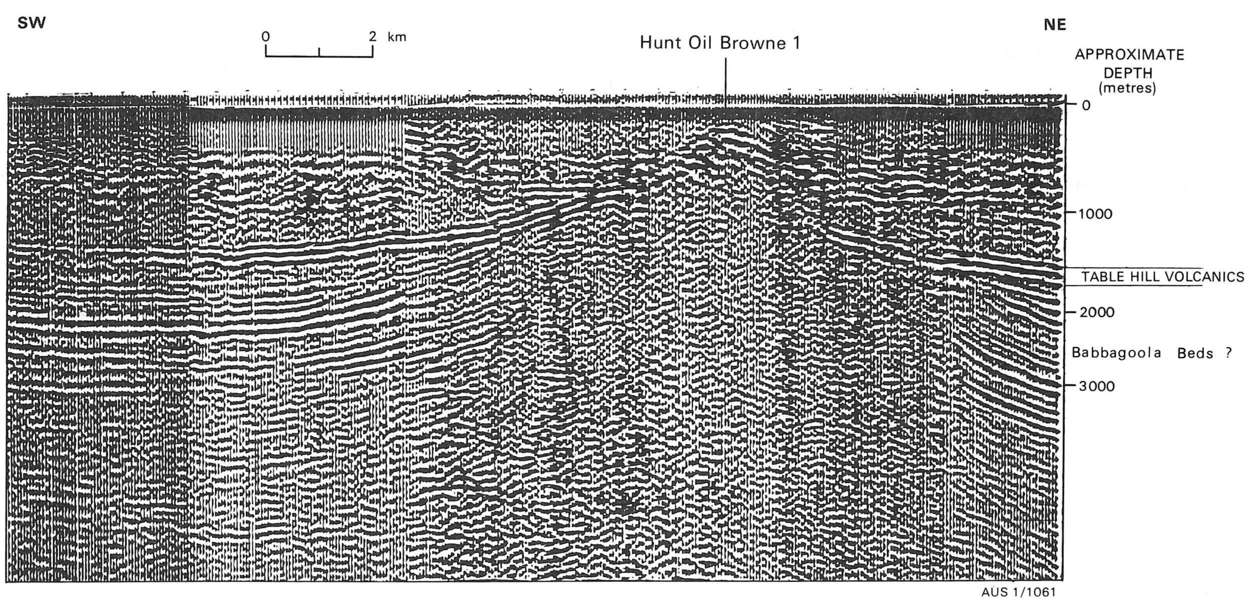


Fig. 68. Seismic line Hunt Oil 13-C, showing piercement of Table Hill Volcanics by Browne Beds.

Fig. 69. Vertical aerial photograph of the Browne diapir.

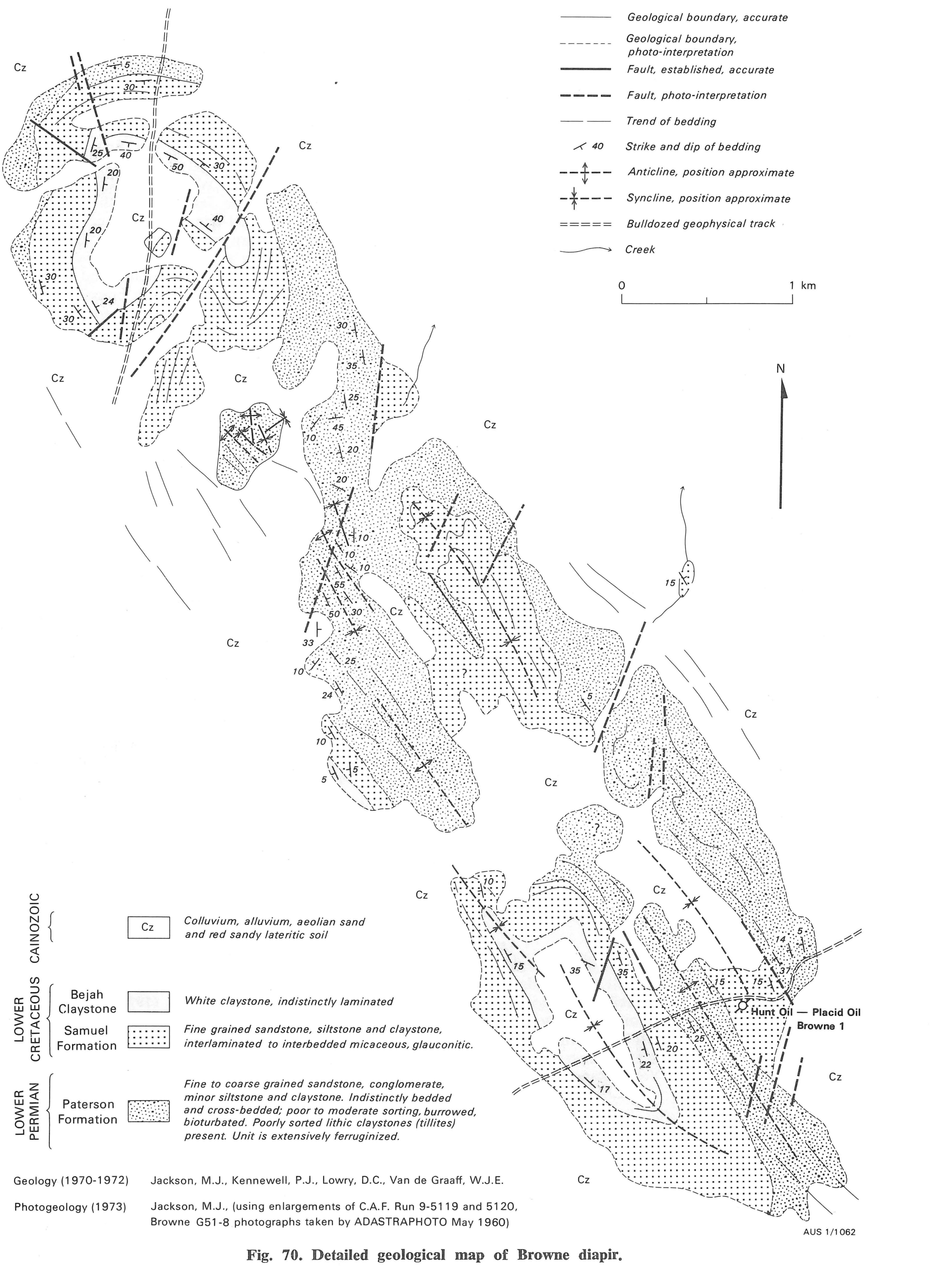


Fig. 70. Detailed geological map of Browne diapir.

Other diapirs

Reflections on seismic traverses, small areas of outcrop with steeply dipping beds, and circular air photolineaments have been used by various authors to suggest possible diapiric intrusions in various parts of the Officer Basin in Western Australia. Table 5 is a compilation of all known or suggested diapirs with an appraisal of the likelihood of the interpretation being correct.

FAULTS AND JOINTS

Few faults affecting the basin sequence have been mapped at the surface. This may in part be due to the reconnaissance nature of the mapping in this very poorly exposed area. The only two major faults mapped, the Iragana and Westwood Faults, are marked by pronounced lineaments which can easily be recognised on aerial photographs. Smaller linements with more subtle surface expression have also been observed in areas with flat-lying Lennis Sandstone or Wanna Beds and are interpreted as marking minor faults and/or joints. In the subsurface the presence of numerous faults has been deduced from geophysical data.

Iragana Fault

The Iragana Fault on COBB was first mapped by Leslie (1961) as an anticlinal structure. Wells (1963) recognised the fault, and Wilson (1964) mapped the area in some detail. The fault cuts both steeply dipping Proterozoic and flat-lying Phanerozoic strata, and forms the linear eastern boundary of the Clutterbuck Hills inlier. Its surface trace extends for over 80 km from the Clutterbuck Hills to the south and southeast. South of the Clutterbuck Hills a fault breccia is locally exposed in the steep eastern flank of a monocline. The presence of the Proterozoic Clutterbuck Beds to the

TABLE 5. DIAPIRS IN THE OFFICER BASIN
Key: D—Definite; L—Likely; U—Unlikely or doubtful

	Location	*Name*	*Description of feature or reason for suggestion of diapir*	*Reference*	*Assessment*
1.	NW WARRI	Woolnough Hills diapir	Well-exposed circular intrusion of brecciated halite & gypsum; folding of Proterozoic to Cretaceous sediments, dips up to 90°.	Veevers & Wells (1959)	D
2.	NW WARRI	—	Laterite domes trending north, 8 km north of (1) with dips up to 10°.	Wilson (1964)	L
3.	NE MADLEY	Madley diapirs	Well-exposed anticlinal domes with gypsum cores; Proterozoic dipping up to 90°.	Wilson (1964)	D
4.	NE MADLEY	—	Laterite domes with cores of Paterson Formation, dips up to 3°, trend parallel to (3).	Wilson (1964)	L
5.	N MADLEY	—	Arcuate photo-lineaments in sand plain on strike with Madley Diapirs.	Kennewell (1975)	L
6.	NE MADLEY	—	Lineaments in laterite rise 20 km SW of (3).	Kennewell (1975)	L
7.	W WARRI	—	Radial drainage pattern on Cretaceous rise.	Van de Graaff (1974b)	U
8.	Central WARRI	Lake Cohen	Dips of 20° in Samuel Formation at edge of clay pan.	Wells (1963)	L
9.	S MADLEY	Lake Keene	Dipping reflections on seismic records, regional doming of Permian rocks.	Turpie (1967)	L
10.	SE BROWNE	Browne diapir	Folded & faulted Permian and Cretaceous rocks. Brecciated evaporites in drillholes; piercement structure on seismic sections.	Jackson (1966a)	D
11.	S BROWNE	—	Seismic reflections—anticlinal features overlying horizontal beds.	Jackson (1966a)	L
12.	SE BROWNE	Notabilis Hill	Dipping reflections on seismic traverses.	Jackson (1976)	L
13.	SE BROWNE	Mt Charles	Dipping reflections on seismic traverses.	Turpie (1967)	L
14.	N BROWNE	Young Range	Photo-interpretation.	Wells (1963)	U
15.	Central TALBOT	—	Circular trends in Paterson Formation.	Daniels (1971b)	L
16.	Central COOPER	—	Circular bedding trends in Townsend Quartzite.	Daniels (1971a)	U
17.	W COOPER	Livesey Range	Anticline in Punkerri Beds.	Jackson (1966a)	U
18.	NE YOWALGA	—	Anticlines on several seismic records some showing breaching of overlying beds.	Jackson (1966a)	
19.	Central LENNIS	—	Circular and radial drainage pattern in laterite rise.	Jackson (1978)	U

west of the fault, the consistent easterly dips of the Paterson Formation in the monocline, and the presence of flat-lying Samuel Formation to the east of the fault indicate that it is a normal fault downthrown to the east. As the exposed part of the deformed zone is in places 0.5-1 km wide, the throw of the fault is at least of the same order of magnitude. The faulting recognised on seismic records at Contention Heights (200 km north) is similar in type, throw, and sense. Lynch (1965) considered the Iragana Fault to have affected magnetic basement, thus supporting the contention that the Iragana Fault is a major fault. It being parallel to major trends in the Musgrave Block also suggests it is a basement feature. The Iragana Fault, which occurs on the flank of a major gravity depression (Plate 3), affects Cretaceous strata, but is not known to cut across the laterite, which is probably no younger than Miocene. Fault movements are, therefore, Late Cretaceous to Early Tertiary. Van de Graaff & others (1977) argued, however, that distinct epirogenic uplift which disrupted relict drainage patterns has taken place in the Clutterbuck Hills-Iragana Fault area.

Westwood Fault

The Westwood Fault on NEALE and WESTWOOD is a north-trending feature that was first mapped by Jackson (1966a). Airphoto-lineaments suggest that it is a fault zone a few kilometres wide rather than a single fault. Seismic and gravity data combined with the occurrence of an inlier of Proterozoic sediments to the southwest of the exposed fault indicate that, although the fault has only a small throw in Permian and Cretaceous strata, it is a large fault with a throw of several hundred metres in the Proterozoic part of the basin sequence.

Outcrop evidence at WESTWOOD 4 indicates downthrow to the east of at least 18 m. An eastern downthrow is also implied by the Westwood Fault forming the eastern limit to the inlier of Proterozoic Neale Beds in central NEALE. Jackson (1966a) stated, however, that a seismic profile across the north end of the Westwood Fault shows it to be a horst block with the major downthrow to the west. The apparent conflict between these two interpretations is easily resolved, when it is realised that Hunt Oil seismic line 39-A, on which Jackson's statement was based, is approximately 65 km north of the northern-most surface expression of the Westwood Fault. In line 39-A there are two clearly defined faults that delimit a horst block. Instead of correlating the mapped Westwood Fault with the western fault as Jackson (1966a) inferred, we assume a correlation with the eastern fault of the horst block. This eastern fault can be seen on the seismic record section to have a throw of about 300 m, which is of the same order as the throw on the western fault. In line 39-A the faulting is restricted to the Proterozoic strata below the Table Hill Volcanics, and the Phanerozoic strata are not noticeably disturbed.

The Westwood Fault approximately coincides with the boundary between the Yeo Regional Gravity Shelf and the Rason Regional Gravity Low (Plate 3); and may therefore reflect a deep-seated basement feature. It is also interesting to note that, if the trace of the Westwood Fault is continued south into PLUMRIDGE, it lines up with, and has a similar orientation to, a major basement feature called the Fraser Fault. Unlike the Iragana Fault, the Westwood Fault cuts silicified Permian rocks and the siliceous duricrust has been displaced by several metres (downthrown 18 m at Middle Hill, WESTWOOD 4) indicating post-Miocene movement.

The presence of an east-trending branch of the Westwood Fault, as mentioned by Jackson (1966a), has not been confirmed during the present survey.

Other faults, and joints

Geophysical evidence suggests the presence of numerous other faults. These commonly displace beds in the Proterozoic part of the Officer Basin sequence, but do not appear to have affected the Phanerozoic sequence to any great extent. Examples of geophysically defined major fault-like features are the Fraser Fault, which probably extends to at least the northeastern corner of PLUMRIDGE, and the Madley diapirs lineament, that approximately coincides with an anticlinal feature mapped by Lynch (1965) on the basis of aeromagnetic data. Minor faulting has been observed in Phanerozoic strata, and has locally caused the affected strata to have multidirectional dips, for example, in the Lake Cohen area. Joints are ubiquitous, but are most common and clearly expressed in outcrops of silicified Bejah Claystone and in silcrete. Lineaments, which have mostly been mapped in areas with Lennis Sandstone or Wanna Beds bedrock, are probably ferruginised master joints or minor faults.

The presence of pronounced joint and/or fault systems is also indicated by palaeodrainage patterns. Van de Graaff & others (1977) interpret the large scale regular patterns formed by the tributaries of the Throssell and Baker palaeorivers (see inset on Plate 2) as reflecting joint and/or fault systems in gently tilted strata. A better example of structurally controlled patterns on a smaller scale is found in central LENNIS. Here the palaeodrainages very clearly have two preferred orientations (Fig. 71) forming a trellised pattern which has been modified to a radial pattern (perhaps by diapirism) in the central part of the area.

Seismicity

Known seismicity in the area is slight, and the maximum number of earthquakes of magnitude (M.L.) 3 or over recorded in a year is 5, in 1972. Epicentres of earthquakes with magnitude > 5.0 are shown on Figure 62. The epicentre on one of these was located in or near the Westwood Fault zone.

GEOLOGICAL HISTORY

Introduction

This description of the geological history is mainly concerned with the events that occurred during deposition of the Officer Basin sequence and overlying units. The histories of the underlying and adjacent basement areas are only touched upon (for details of these see Daniels, 1974; Bunting & others, 1976; Hall & Goode, 1975 and Williams & others, 1976).

Our fragmentary and incomplete knowledge of the geological history reflects the history itself, which is characterised by spasmodic episodes of deposition separated by long periods of non-depostion and/or erosion. Except for near diapiric intrusions, the whole sequence is remarkably undeformed; this due to its location on the edge of the stable West Australian shield.

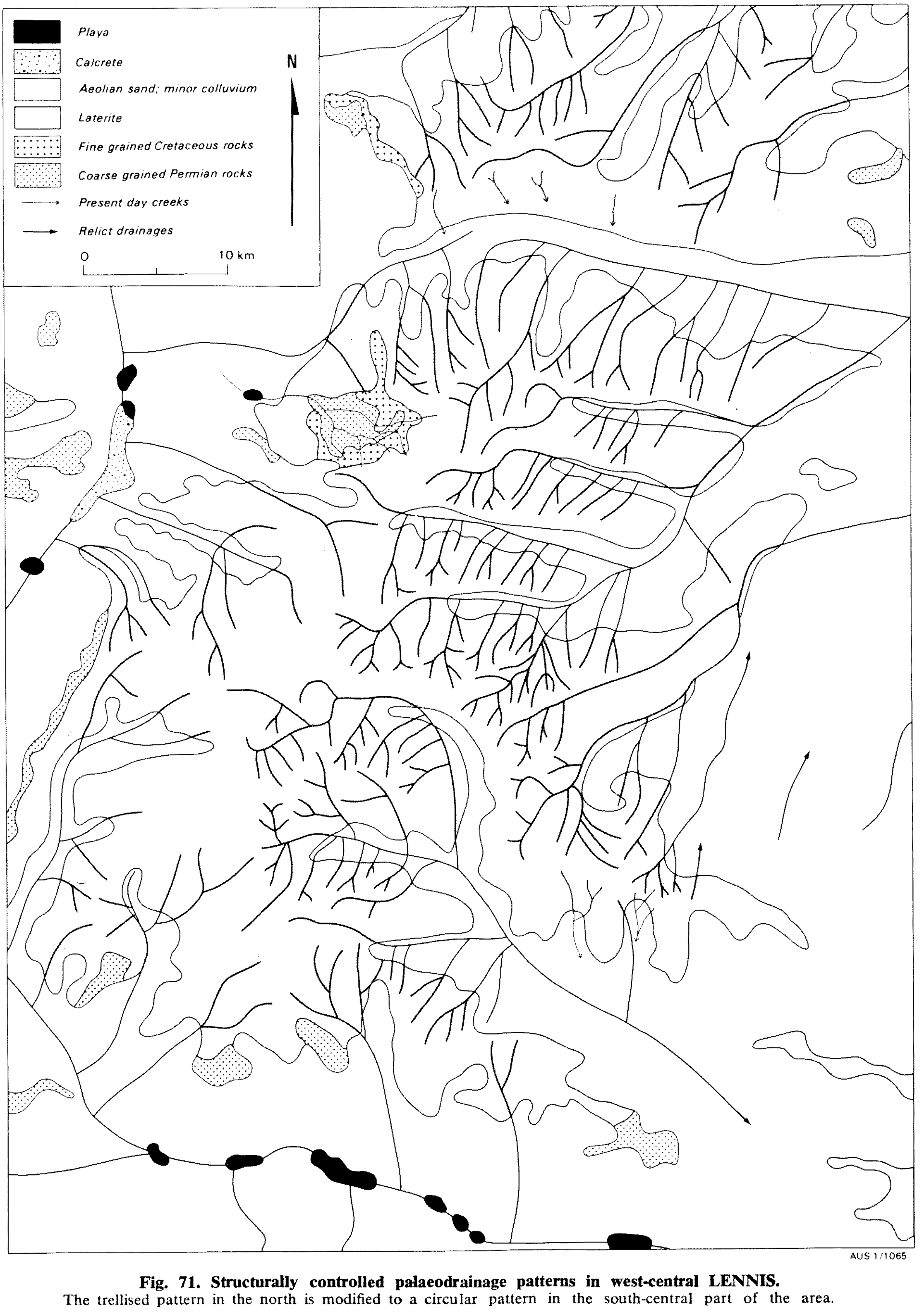


Fig. 71. Structurally controlled palaeodrainage patterns in west-central LENNIS.
The trellised pattern in the north is modified to a circular pattern in the south-central part of the area.

Basement

The earliest recorded events are the folding, metamorphism and granitisation in the Yilgarn Block which culminated towards the end of the Archaean (about 2.6 b.y. ago). During the Early and Middle Proterozoic thick sequences of mainly shallow marine rocks were laid down to the north and northeast of the Yilgarn Block, forming the Nabberu and Bangemall

Basin sequences. Several groups of sediments, separated by regional unconformities, can be recognised and episodes of folding and igneous intrusion, as well as periods of erosion and non-deposition, are present in the sequences forming these two basins. During the Middle Proterozoic, a few hundred kilometres to the east of here, near the present NT, SA, and WA borders, a complex sequence of events, including a granulite metamorphism, at least two phases of granite plutonism, the intrusion of layered ultrabasics, and the outpouring of thick acid and basic volcanics, took place and ultimately led to the formation of the Musgrave Block, as it is called today. A similar complex history of metamorphism and igneous intrusion also took place at about the same time along the southeastern edge of the Yilgarn Block, in the Albany-Fraser Province. Parts of these Lower to Middle Proterozoic blocks or basins form the basement on which the Officer Basin sequence was laid down.

OFFICER BASIN

Late Proterozoic

During the Late Proterozoic, a thick sequence of sedimentary rocks was deposited over a wide area of central Australia, initially in a stable epicontinental sea, but later in fault-bounded troughs; remnants of this sequence are preserved in the Officer, Amadeus, and Nglia Basins. Within the Officer Basin this sequence is only reasonably well exposed along the northeastern margin and most of the events described are based on information from that area. A basal quartz sand (Townsend Quartzite, Pindyin Beds, Robert Beds) deposited mainly within littoral or sub-littoral environments marked the start of sedimentation. This was succeeded by a varied sequence of mainly shallow marine deposits some of which were laid down in evaporitic environments. Oolitic and stromatolitic carbonates (Ilma, Neale, and Wright Hill Beds) attest to periods of very shallow, probably intertidal, deposition, while very thick and widespread sequences of evaporites (Browne Beds, part of Woolnough Beds) indicate extensive and long-continued evaporitic environments. However, some regions of deeper water sedimentation are indicated by sequences of well-bedded siltstones and shales (e.g. Lefroy Beds, part of Wright Hill Beds).

A subsequent period of mild tectonism is recorded in the area near Warburton, and the Townsend Quartzite as well as the volcanics of the Musgrave Block formed a source area for the tillites and fluvioglacial sediments of the Lupton Beds, which were then laid down. Although there are only two areas in which these upper Proterozoic tillites are preserved within the Officer Basin (i.e. near Warburton and in RASON), glacial rocks of this age are widespread throughout southern, central, and northwestern Australia.

The geological history from then on into the earliest Cambrian is very poorly known, but continued shallow water deposition is indicated by the Punkerri and Wirrildar Beds in the east, and the Babbagoola and Madley Beds in the northern part of the area. The seismic results indicate a conformable sequence some 4000-5000 m thick above the glacial rocks, and a return to conditions similar to those prevailing before the glaciation is indicated for parts of the sequence. The Punkerri Beds are a well-sorted marine sandstone containing trace fossils, which was probably deposited in a wide sub-littoral sea. The Wirrildar and Babbagoola Beds contain evidence of both sub-tidal or shallower deposition (oolites, stromatolites, evaporites) and deeper water deposition (thick shales). The Clutterbuck Beds and parts of the Wirrildar Beds contain immature arkosic sandstones, indicating periods of more rapid deposition. The Clutterbuck Beds, especially, were probably deposited in a steadily subsiding graben. The Babbagoola and Madley Beds also contain evaporites.

A mild tectonic event is indicated for most of the Officer Basin area in the earliest Cambrian as the thick late Proterozoic sequence was gently folded and faulted, and subsequently eroded, before the overlying volcanics were extruded (575 ± 40 m.y. ago). Although there is no conclusive evidence, it is possible that diapiric intrusion from near the base of the Proterozoic sequence could have commenced at about this time. This tectonic event was much more intense along the north-eastern margin of the basin and is probably comparable to the complex folding and thrusting of the Amadeus Basin sequence during the Petermann Ranges orogeny. The Townsend Quartzite is folded in TALBOT and COOPER, and further east (EVERARD, S.A.) the basin sequence has been overthrust by southwards-moving Musgrave Block.

Early Palaeozoic

The Early Phanerozoic was marked by the subaerial eruption of basic volcanics (Table Hill Volcanics). Two distinct flows, separated by thin beds of fluviatile sand, formed throughout a wide part of the basin. These volcanics are probably coeval with the Antrim Plateau Volcanics of northern Australia. Cross-stratified shallow marine sands with minor silt and clay were laid down on top of the volcanics throughout a similar area. The lower unit (Lennis Sandstone) contains minor evidence of subaerial exposure (mud cracks, rainpits), but the overlying Wanna Beds are of a slightly deeper water facies and were deposited mainly as mega-ripples in a sub-tidal marine environment.

Late Palaeozoic and Mesozoic

The next recorded event is the glaciation of the whole region during the Early Permian which was part of the glaciation of Gondwana. Several advances and retreats of the continental ice sheets from source areas on the surrounding basement ranges are recorded in the complex sequence of glacial, fluvioglacial and glaciolacustrine sediments that were deposited (Paterson Formation). A similar environment to that seen in parts of Arctic Canada today is envisaged with large glacier-lakes and extensive sandy-outwash fans fed by rapidly flowing melt-water rivers.

Following the final retreat of the glaciers the area underwent erosion, until it was inundated by the widespread Early Cretaceous marine transgression, which deposited a thin sequence of fossiliferous, marine clastics (Samuel Formation, Bejah Claystone, Loongana Sandstone and Madura Formation) over the area. Facies variations within the Lower Cretaceous rocks suggest a transgression from the south via the Eucla Basin. Following a regression of the sea, reflected in coarser sediments at the top of the Bejah Claystone, it seems likely that the area was never again inundated by the sea.

Late Cretaceous and Cainozoic

After emergence of the Lower Cretaceous rocks, faulting and diapiric movements occurred, simultaneously with the development of an integrated drainage system. The Lampe Beds were deposited during the early stage of drainage development, which took place under a relatively humid climate. Incision and development of the drainages removed most of the Lower Cretaceous rocks in the area, and transported the detritus towards either the Eucla Basin in the south, or the Indian Ocean to the northwest.

During the early Cainozoic, thick laterite and silcrete profiles developed, their distribution being controlled by the type of bedrock. A climatic change from humid to arid led to the induration of parts of these profiles to form laterite and silcrete duricrusts, which fossilised the Early Tertiary landscape. This climatic change may have been as early as the Late Eocene, but was certainly no later than the Middle Miocene (cf. Kemp, 1978).

During the Late Eocene the sea transgressed the southern part of the area and produced an erosional scarp and plateau and deposited clastic and carbonate sediments (Hampton Sandstone, Wilson Bluff Limestone & Princess Royal Spongolite). Following a regression, the sea again returned to this southern area in the Middle Miocene to deposit a predominantly carbonate sequence in the Eucla Basin (Nullarbor Limestone, Colville Sandstone, and Plumridge Beds).

From the Middle Miocene onwards the climate was semi-arid to arid, and the drainage valleys were gradually filled with debris. Playas formed through a combination of ponding in palaeodrainage valleys and subsequent deflation of the bare surfaces, and have since become the sites of gypsum precipitation. Slow aggradation of the valleys with detritus from the surrounding duricrusted terrain was accompanied by the local development of valley calcretes. Dunes were formed from surficial residual sands and alluvial/colluvial deposits during the latest glacial maximum, which was marked by great aridity on the Australian continent.

This climatic change during the Cainozoic from humid to arid has resulted in a combination of relict humid-climate landforms, and present-day arid-climate landforms.

ECONOMIC GEOLOGY

Introduction

On current knowledge, the sedimentary sequence in the Officer Basin has poor mineral potential, and because of its negligible economic interest the area has long remained unexplored.

The prospects for hydrocarbon accumulation are not good, as the sediments are mostly Proterozoic or early Phanerozoic in age, and the thin younger Phanerozoic sequence was probably never buried deep enough to generate significant quantities of hydrocarbons. Recent hydrocarbon discoveries in early Cambrian rocks in the South Australian part of the basin (Jackson, 1979b, McKirdy & Kantsler, 1980, Pitt & others, 1980) and the correlations suggested in this Bulletin now indicate that there could be potential source rocks in the WA part of the basin: good reservoir and trap situations have long been known. The large deposits of gypsum are remote from markets. Calcrete-uranium deposits occur on the margin of the Yilgarn Block and the possibility of economic deposits occurring in that area or to the south of the Musgrave Block cannot be excluded. Groundwater in the area will only be important if mining or additional pastoral development takes place.

Petroleum

Source rocks

Up until about 1978 the petroleum prospects of the Western Australian part of the basin were considered very poor because of an apparent lack of suitable hydrocarbon source rocks. Recent drilling and mapping in South Australia has indicated that carbonates within the Cambrian Observatory Hill Beds have excellent source rock potential.

Based on the lithological and microfossil comparisons the Babbagoola Beds in Western Australia are correlated with the Observatory Hill Beds of South Australia (Jackson & Muir, 1981). The carbonate section intersected in the WA drillholes is much thinner than that in South Australia, but only two drillholes have been drilled into the sequence containing the Babbagoola Beds and it probably underlies most of the basin. Hence, there now appears the potential for Cambrian source beds in the WA part of the basin.

Higher up in the sequence abundant well-preserved palynomorphs are present below the weathering profile in the Lower Cretaceous Samuel Formation in BMR Browne 1 (70 to 100 m); and in a slightly carbonaceous lacustrine facies of the Lower Permian Paterson Formation in BMR Wanna 1 (80 to 120 m).

Reservoir rocks

There appear to be ample reservoirs, much of the Phanerozoic and Upper Proterozoic sequence consisting of coarse-grained clastic rocks (e.g. Punkerri Beds, Lennis Sandstone, Wanna Beds) with high porosity and permeability. The Lennis Sandstone also contains thin, laterally persistent shale beds in parts of the basin. Core samples from the Lennis Sandstone and Wanna Beds from BMR Neale 1 showed porosities ranging from 23 to 31%, and permeabilities in the range 62 to 390 millidarcies. For comparison, oil and gas producing wells in the Pacoota Sandstone of the Amadeus Basin commonly have porosities in the range 5 to 12% and permeabilities between 1 and 300 millidarcies.

Traps

The broad anticlinal flexures mapped on the seismic sections in the younger Proterozoic sequence, and the diapiric structures penetrating through the basin sequence up to the surface represent classical examples of hydrocarbon traps. Apart from the doming of strata, the diapirs would probably offer numerous traps in the form of fault closures, pinch-outs, and truncation of reservoir beds.

Maturation history

There is conflicting opinion as to the amount of burial required to produce the right thermal conditions for the conversion of organic matter to petroleum. Petroleum is being generated by very shallow burial (60 m) of Holocene sediments in the Orinoco Delta (Kidwell & Hunt, 1958), but most large accumulations seem to require depths of burial in excess of about 1000 to 2000 m. This being the case, the sequence above the Table Hill Volcanics can probably be eliminated as a potential source sequence because it has probably never been buried deep enough. The sequence above the Table Hill Volcanics has a maximum thickness of about 1100 m, with the Mesozoic and Permian part of this occupying the upper 550 m. There is no evidence to suggest that the various formations within the Phanerozoic were more deeply buried. On the other hand, the Babbagoola Beds, which may contain source rocks, are part of the younger Proterozoic to earliest Cambrian sequence, generally found between about 1500 to 5000 m below the present surface.

Preservation potential

Studies of the surface textures of heavy minerals from the Paterson Formation by C. P. Gravenor (University of Adelaide, written communication 7.2.1978) suggest that the basin sediments have been affected by considerable flushing, which would have tended to destroy any petroleum accumulations.

Hydrocarbon shows

There are no proven oil or gas seeps known in the Western Australian part of the basin. Minor oil and gas shows were encountered during the drilling of Hunt Oil Browne 1 & 2. Gas cut mud, gas odours, and good fluorescent cuts were noted in well cuttings, between 134 m and 275 m in Browne 1. Subsequent core analysis showed traces of oil in core samples at 213 m, 214 m, 258 m and 259 m. Similar shows were encountered in Browne 2 between 259 m and 262 m and were similarly confirmed by core analysis. All of these shows were from the Proterozoic Browne Beds, which are probably equivalent to the Bitter Springs Formation in the Amadeus Basin.

Even though the recent drilling in South Australia has significantly upgraded that part of the basin the overall assessments for WA still remain pessimistic. However, at least one note of caution should be given. There are large tracts of country (tens of thousands of square kilometres) where the subsurface has not been explored by drilling or definitive geophysics. It is not inconceivable, that small sub-basins with better petroleum prospects could be present. The MADLEY, WARRI & BROWNE area in the north and the VERNON-WANNA area in the southeast are the two most obvious examples.

Water supplies

Surface water

There are no significant and reliable surface water supplies in the area. After heavy rain, water may be present for a few months in gnamma holes, rock-holes, in creekbeds, and playa lakes. Though these supplies sustained the nomadic Aboriginal population of the area and the European explorers, they are too unreliable and mostly of inadequate quality and quantity to permit domestic or pastoral use.

Talbot & Clarke (1917) and Forman (1933) listed waterholes between Laverton and the Warburton Ranges. The gnamma holes and rock-holes are purely surface catchments. Jackson (1966a) reports that a number of holes were pumped and that no recharge was noticeable after a three-week period. Hunt Oil also tested the quality of the water from the Kapi Kanpa, Kapi Papul and Kapi Narratha holes along the Warburton Road. Analysis showed that the water was unsuitable for human consumption.

The only known water holes which are probably permanent are karst pipes in valley calcrete (e.g. Empress Spring which was used and named by Carnegie in 1896), and the Wort native well near the northern end of Lake Throssell (Sofoulis, 1962b). These karst features reach down to the water table, and water drawn from them may equally well be considered groundwater.

The only other evidence of surface water was found at NEALE 7. Salt water seeps from a vertical cliff face of fluvioglacial sandstone and tillite of the Paterson Formation. Impermeable claystone beds of the underlying Wanna Beds form the base of the aquifer. The water is probably derived from a number of saline playa lakes located a few kilometres to the east on the plateau into which the cliff is cut. These springs mark the probable spot where the Eocene Throssell palaeoriver discharged into the sea, and in all likelihood are permanent, as they flowed in 1964, 1971, and 1972, when the locality was visited by geologists.

Some of the larger freshwater playa lakes (e.g. Lake Gruszka, Lake Cohen, Mungilli Claypan) retain fresh water after heavy rain.

Groundwater

Away from the mission and station settlements, which are situated on areas of Precambrian bedrock, very little information on groundwater resources is available. Table 6 lists most of the known bores and wells in the area. The yields stated are not considered reliable, as the supplies are partly determined by the pumping equipment used, and yields may reflect demand rather than potential.

In most of the area, water with sufficiently low salinities to permit domestic use can probably be expected locally, whereas supplies of stock-quality water should be present in most of the area. Generally accepted upper salinity limits are 1500 milligrams/litre total dissolved solids for potable water, 10 000 milligrams/litre for cattle, and 13 000 milligrams/litre for sheep. Apart from salinity there are of course other factors determining the suitability for domestic use. When this compilation was made, most of the bores at Warburton Mission were producing water with a nitrate content of over 50 milligrams/litre. A nitrate content in excess of 45 milligrams/litre is considered a likely cause of the disease methaemoglobinemia in infants less than one year old ('blue babies') (World Health Organisation, 1963).

Records are generally only available for those bores and wells that have been successful. Therefore, though Table 6 gives a fair indication of the water quality in some areas, it does not give an indication of the difficulty of actually finding water.

A drilling programme at Warburton Mission had a success rate of four out of a total of thirteen holes drilled. At Cundeelee Mission, no potable groundwater has been found, and the settlement relies on dams, stored rainwater, and water supplies trucked from the

TABLE 6. HYDROGEOLOGICAL INFORMATION FROM SELECTED BORES IN STUDY AREA

Name of bore	*Sheet area*	*Latitude Longitude*	*depth (m) Total*	*Salinity (milligrams/litre)*	*Nature of aquifer*	*Approximate yield (m^3/day)*	*Remarks*
BMR Warri No. 3	Warri	24°09′S 124°38′E	30	2700	Calcrete (28.6 m-30 m) ?Alluvial gravel (30 m-33 m)	43 65	Upper aquifer more saline than lower one.
Watertree bore	Herbert	25°41′S 123°07′E	57	9000	Precambrian sediments	90	
—	Browne	25°11′S 124°43′E	35	1000	Sandstone; Samuel Formation	25	Water level at 9 m
—	Browne	25°40′S 125°35′E	30	excellent quality	?Paterson Formation	8.6	Water level at 15 m
Beevers bore	Bentley	25°52′S 126°40′E	27	<1000	?Paterson Formation	38	?Basement area
Mulya Ngirie	Bentley	25°58′S 126°36′E	9	<1000	?	?	Basement area
Mulga bore	Robert	26°03′S 123°01′E	>30	7000	Alluvium	23	
Bullock bore	Robert	26°12′S 123°04′E	20	1500	Alluvium; ?Precambrian sediments below 12 m	108	
Packhorse	Robert	26°20′S 123°10′E	21	1000	Alluvium and calcrete	97	
Wharton bore	Robert	26°29′S 123°10′E	18	4500	Alluvium	54	
Midnight bore	Robert	26°35′S 123°01′S	27	2000	Alluvium	49	
Well Springs Well	Robert	26°30′S 123°01′E	1.5	5000	?Alluvium	52	
	Yowalga	26°40′S 125°55′E	40	low salinity	?Samuel Formation	?	dry after 3 months of use
No. 1 Yowalga	Yowalga	26°10′12″S 125°58′00″E	85	1228	Coarse-grained kaolinitic sand; ?Paterson Formation	86	Completed in interval 77.5 m-85 m; sand and silt prevent use of conventional pumping equipment T.D. 613 m.
Snake Well	Talbot	26°13′S 126°52′E	5.5	1000	Alluvium and calcrete	54	Basement area
Lilian Creek Well	Talbot	26°13′S 126°57′E	6	2570	Calcrete and volcanics	?	Basement area
Warburton Mission No. 1	Talbot	26°07′S 126°35′E	8.5	1250	Calcreted basic lava	65	67 ppm nitrate Basement area

TABLE 6. HYDROGEOLOGICAL INFORMATION FROM SELECTED BORES IN STUDY AREA

Name of bore	*Sheet area*	*Latitude Longitude*	*depth (m) Total*	*Salinity (milligrams/litre)*	*Nature of aquifer*	*Approximate yield (m^3/day)*	*Remarks*
Warburton Mission No. 2	Talbot	same area as No. 1	8	1000	Calcreted basic lava	65	106 ppm nitrate Basement area
Warburton Mission No. 4	Talbot	same area as No. 1	8	1550	Calcreted basic lava	43	87 ppm nitrate Basement area
Warburton Mission No. 5	Talbot	same area as No. 1	15	1700	Calcreted basic lava	92	73 ppm nitrate Basement area
Warburton Mission No. 6	Talbot	same area as No. 1	27	2250	Calcreted basic lava	65	308 ppm nitrate Basement area
Warburton Mission No. 8	Talbot	same area as No. 1	8	2000	Calcreted basic lava	?	51 ppm nitrate Basement area
Warburton Mission No. 9	Talbot	same area as No. 1	15	1450	Calcrete	65	Basement area
No. 7	Talbot	same area as No. 1	13	1660	?	22	Basement area
No. 12	Talbot	same area as No. 1	24	?	Calcreted alluvium	>22	Basement area
No. 13	Talbot	same area as No. 1	34	1810	Calcreted alluvium	53	Basement area
No. 4	Talbot	26°08′S 126°35′E	32	?	Precambrian sandstone	67	Basement area
Western Mining No. 1	Talbot	26°09′S 126°37′E	22	2000	Fractured volcanics	>65	Basement area
Western Mining No. 2	Talbot	same area as WM No. 1	28	?	Fractured volcanics	>65	Basement area
Simms Shaft	Talbot	26°10′S 126°37′E	27	2300	Fractured basic lava	>650	This is the shaft of a small copper mine; the mine had to be abandoned due to water problems. Hunt Oil used this as water source during the drilling of Yowalga No. 1. 5 ppm nitrate, 0.05 ppm copper. Basement area
	Talbot	26°13′S 126°22′E	33	Salty	?Paterson Formation	?	
Blackstone Camp	Cooper	26°01′S 126°22′E	30	500	Weathered basic volcanics	108	Basement area

TABLE 6. HYDROGEOLOGICAL INFORMATION FROM SELECTED BORES IN STUDY AREA

Name of bore	*Sheet area*	*Latitude Longitude*	*depth (m) Total*	*Salinity (milligrams/litre)*	*Nature of aquifer*	*Approximate yield (m^3/day)*	*Remarks*
Wingellina Camp	Cooper	26°04′S 128°57′E	24	910	Basic rocks	65	Basement area
D 66	Cooper	same area	38	970	Weathered gneiss	195	Basement area
CW 9	Cooper	same area	79	?	Weathered gabbro	22	Basement area
Limestone well	Throssell	27°55′S 123°10′E	?	630	?Calcrete	?	Basement area
BMR Throssell No. 1	Throssell	27°17′S 124°27′E		Salty	Calcrete (0 m-28 m)	?	water table at 10 m; T.D. 101.5 m
Lennis No. 1	Lennis	27°17′00″S 126°21′00″E	76	2943	Fine-grained sand; Paterson Formation	22	Water table at 50 m; completed from 61 m-76 m; T.D. 614.5 m
Outcamp	Rason	28°32′S 123°02′E	?	550	Alluvium and/or weathered granite	?	Basement area
Dwyer Well	Rason	28°32′S 123°06′E	?	2000	Alluvium and/or weathered granite	?	Basement area
Della Well	Rason	28°05′S 123°06′E	?	3600	Alluvium and/or weathered granite	?	Basement area
Condun Well	Rason	28°26′S 123°05′E	?	1510	?	?	Basement area
Salvation Well	Rason	28°10′S 123°40′E	?	825	?	?	Basement area
Homestead Well	Rason	same area	?	1550	?	?	Basement area
Yeo Homestead Well	Rason	28°05′S 124°20′E	6	slightly salty	Alluvium	<0.6	
Neale Junction Well	Vernon	28°18′20″S 126°02′15″E	43	slightly salty	Paterson Formation	?	Water at 21 m
Cundeelee Mission E	Cundeelee	30°40′S 123°25′E	48.5	8000	Alluvium	?	Basement area
Cundeelee Mission D	Cundeelee	30°42′S 123°25′E	36.5	salty	Alluvium and/or Paterson Formation	good supply	Basement area
Kanandah No. 95	Cundeelee	30°52′S 124°25′E	153	>12 000	Loongana Sandstone	?	Aquifer interval 123.5 m-126.5 m Eucla Basin
Scrubby Tank	Seemore	30°43′S 124°47′E	172	25 000 18 000	Madura Formation Weathered Schist	?	145 m-157 m 167 m-172 m Eucla Basin
Pink Eye Corner	Seemore	30°53′S 124°42′E	147	18 000	?Madura Formation or Loongana Sandstone	22	Eucla Basin

Rawlinna siding on the Trans-Australian Railway. On Kanandah Station (SEEMORE), results were equally disappointing, as the bores mainly proved groundwater too saline for stock (Lowry, 1970).

Large quantities of water were needed for the Mount Windarra nickel project (approx. 20 km northwest of Laverton), and the Officer Basin area seemed a possible source. A resistivity survey along an east-west line extending for about 250 km east of Squeakers Hill suggested considerable thicknesses (130-240 m) of partly water-saturated sediments and several test drill sites were proposed (AGC, 1972). BMR Rason 1, 2, and 3 were drilled at three of these sites, but all penetrated granitic basement at shallow depths (Jackson & others, 1976), and, except for BMR Rason 3, failed to find water. This hole produced a few litres of water (salinity 1600 milligrams/litre) from a weathered shear zone in the basement rocks.

In an attempt to run electrical logs in BMR Rason 1, approximately 4 cubic metres of water was poured into the hole in less than 10 minutes. The total volume of the hole would not have exceeded about 1½ cubic metres. The water disappeared as fast as it could be poured in and the water level never came within sight. This demonstrated the very high permeability of the sequence penetrated. If it had been water saturated reasonable production rates could have been expected.

Hunt Oil drilled nine test holes to at least 60 m to find water supplies for their operations. Of the three successful wells, only one, the 27th Parallel Well (WESTWOOD), remained a suitable and dependable water supply. In addition, Hunt Oil completed two stratigraphic holes as water wells, but in these the aquifers occurred below 60 m.

The groundwater potential of the area can best be discussed further according to the different types of aquifer.

Alluvial-colluvial valley fills and valley calcrete aquifers

Alluvial/colluvial valley fills and valley calcretes are easy to locate both on the ground and on aerial photographs, as they occur along both present-day and relict drainages. The thickness of these deposits rarely exceeds a few tens of metres, and they are, in general, not very indurated. The water table is normally quite shallow in these deposits (<15 m) and has low hydraulic gradients. Consequently, testing these deposits can be done with simple and cheap drilling methods. Because of generally high porosity and permeability, calcrete bodies are the more attractive targets.

Large valley calcretes occur mostly in the northwestern part of the area, i.e. THROSSELL, ROBERT, HERBERT, MADLEY and WARRI. Important valley calcretes also occur in the Musgrave Block area.

Valley calcretes in the East Murchison Goldfields are known to have produced large quantities of good-quality water. For instance, at Wiluna $4.5 \times 10^3 m^3$/day has been produced from 34 shallow wells in valley calcrete (Sanders & Harley, 1971). Potential supplies from the various calcrete and alluvial/colluvial aquifers can be calculated if the potential recharge for these aquifer systems is known. Sanders & Harley (1971) estimated that for HERBERT and ROBERT the recharge coefficient for valley calcrete is about 3 per cent of mean annual rainfall. Rainfall in the area averages about 20 cm a year. This gives an estimated potential recharge of $6 \times 10^3 m^3$/year per square kilometre of calcrete. For the large valley calcretes and adjoining alluvial/colluvial valley fills on the eastern part of ROBERT and HERBERT (e.g. Herbert Wash), this gives a potential recharge and safe yield of approximately $3.2 \times 10^6 m^3$/year. The quality of the water in that area is unknown, but Carnegie considered the water in Empress Spring to be drinkable when he visited it in 1896. It is likely that other valley calcretes in the area have similar characteristics.

Fractured and weathered Precambrian rock aquifers

A number of bores draw water from fractured and/or weathered crystalline or sedimentary Precambrian rocks. At the Warburton Mission most of the supplies are obtained from fractured and calcreted lavas. Some of these rocks are very good aquifers, e.g. Simms Shaft which yields more than 650 m^3/day. In the Warburton area most bores, which draw water from fractured bedrock, are located near creek courses where recharge can be expected following flow of water in the creeks, which occurs only intermittently.

Though fracture-sytem aquifers are probably more attractive targets, water may also be present in weathered and partly decomposed coarsely crystalline rocks or in sediments. These types of aquifers are less easy to find than those in valley fills, because there are few surface indications of their presence. Finding and proving this type of supply is expected to be more expensive, as the water may occur at greater depth than is the case in alluvial deposits.

Basin sediments

Attempts by BMR and Hunt Oil, during exploration or reconnaissance programs, to obtain small water supplies from the basin sediments met with moderate success. One bore produced from the Cretaceous Samuel Formation; the seven other bores that produced some water were all in the Paterson Formation. This is at least partly due to the fact that no other bores for water were drilled in the area with Cretaceous bedrock. The presence or absence of aquifers in either the Cretaceous or the Permian sequence at any one locality cannot be predicted.

The groundwater potential of the Wanna Beds and the Lennis Sandstone in the South Australian part of the basin appears to be considerable. At BIRKSGATE 1 two water-supply wells were drilled, which produced from the Wanna Beds and the Lennis Sandstone. Their yields were 250 m^3/day and 640m^3/day respectively (Zakis, 1966; Henderson & Tauer, 1967). It seems likely these formations could also be important aquifers in Western Australia.

The results of exploration so far indicate the cost of finding water in the basin sediments will be high, as relatively deep holes are required. Because of their depth and the general presence of relatively impermeable fine-grained intercalations in the sequence, recharge of aquifers is expected to be low. The basin sediments may nevertheless at some stage become attractive for groundwater exploration, as they will contain the only really extensive aquifer systems.

Uranium

Since the discovery of carnotite in valley calcrete south of Mount Venn (RASON) and the subsequent announcement by Western Mining Corporation of an economic carnotite deposit in calcrete at Yeelirrie, the valley fills of the ancient darainage systems described earlier must be considered to have potential uranium.

In the known occurrence, the uranium does not appear to have travelled far from the granitic source rocks, and it has been deposited either in calcrete or in saline playa deposits (Butt & others, 1977). Known carnotite-bearing valley calcretes are restricted to the Yilgarn Block. Extensive and thick valley calcretes do not seem to be present south of 28°30′S, with the possible exception of a 20 m thick calcrete at CUNDEELEE 4.

Reducing condtions associated with the presence of carbonaceous material are in general conducive to the formation of Colorado Plateau-type uranium deposits. Unfortunately, available borehole data show that little or no carbonaceous material is present in the valley-fill deposits.

Although at present, only the Yilgarn Block is known to have acted as a source for these uranium deposits, it would be unwise to disregard the other crystalline basement areas as potential sources, and Figure 56 shows those valley-fill deposits in the study area that may merit investigation.

Gypsum

Gypsum is present in large quantities in the numerous salt lakes and associated lunette dunes, and in the cores of the Woolnough Hills and Madley diapirs. For instance, in the Lake Throssell area alone, at least 18 x 10^7 tonnes of gypsum may be present (based on the assumption that about a quarter or 80 km^2 of the total area of salt lake and gypsiferous dunes is underlain by 1 m of gypsum). Elsewhere in Western Australia, gypsum from salt lakes is exploited commercially (de la Hunty & Low, 1958), but the remoteness of the desert deposits makes them uneconomic at present.

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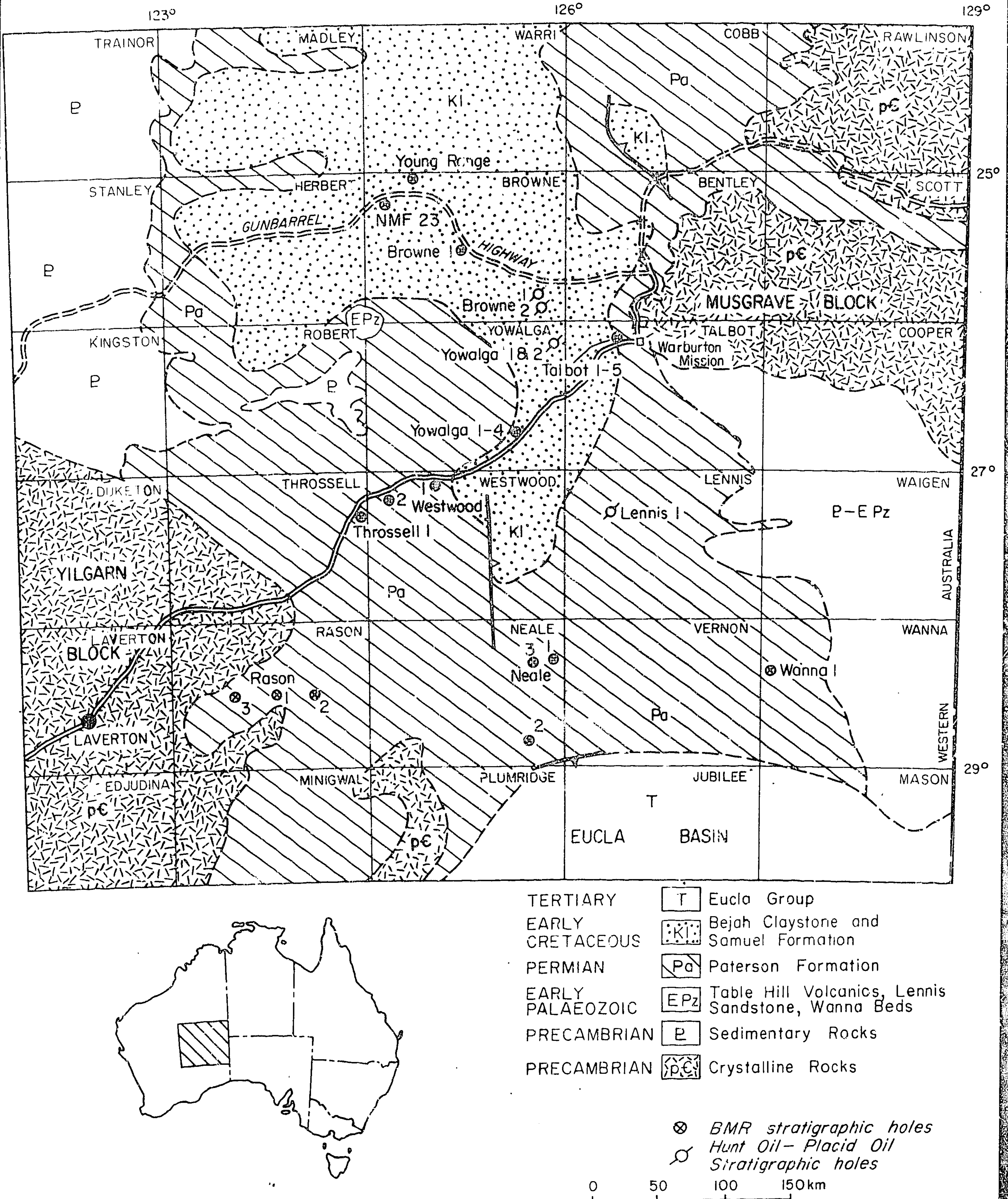


Drillhole locations and generalised geology

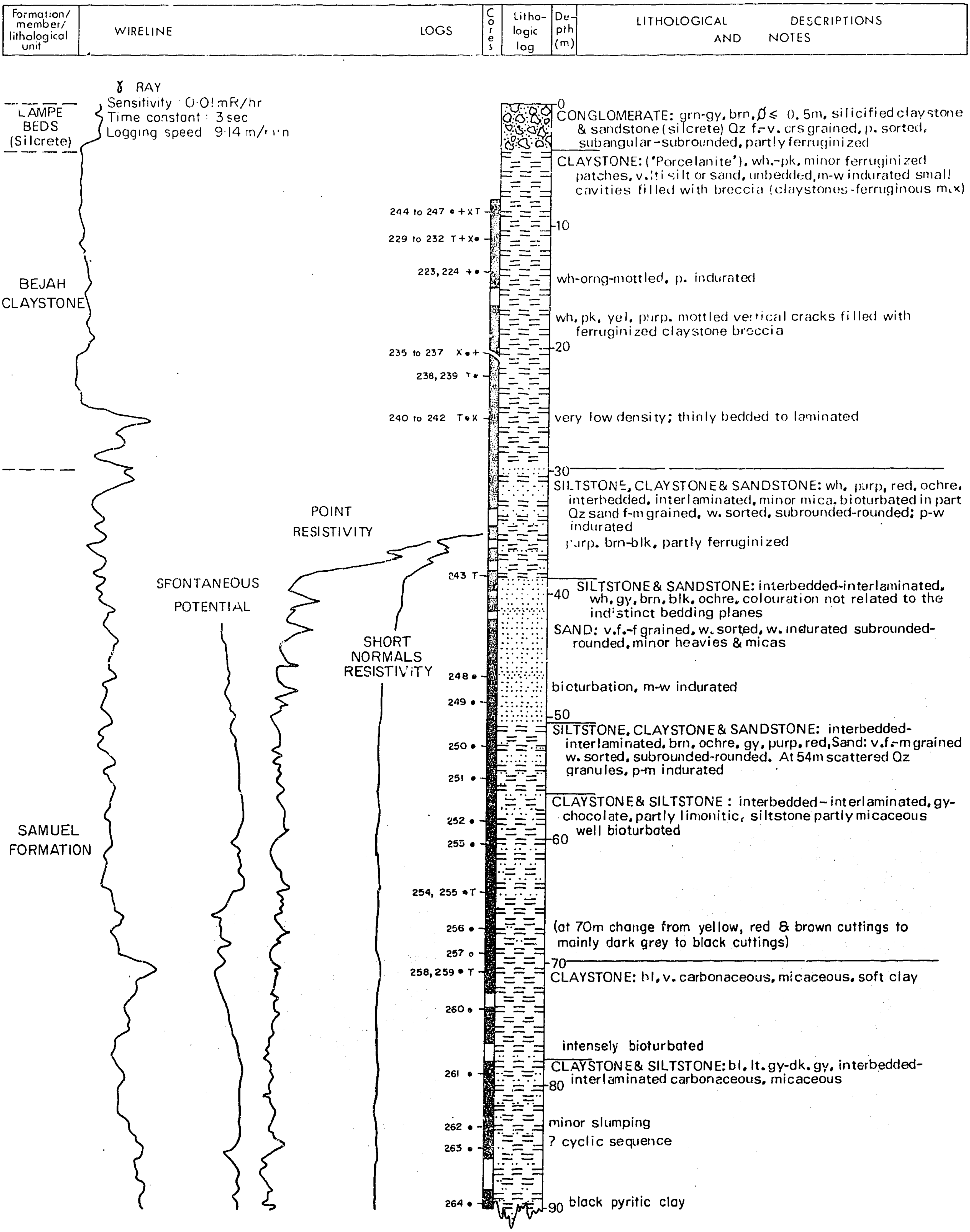
W/A/275-1

REFERENCE FOR WORK DONE ON BMR DRILLHOLE SAMPLES

x	Chemical analysis
+	X-ray diffraction analysis
T	Thin section
•	Palynology
S	Slabbing
P	Permeability & Porosity
♁	Detail petrology
◘	Examined for conodonts
∘	Sample taken, not submitted

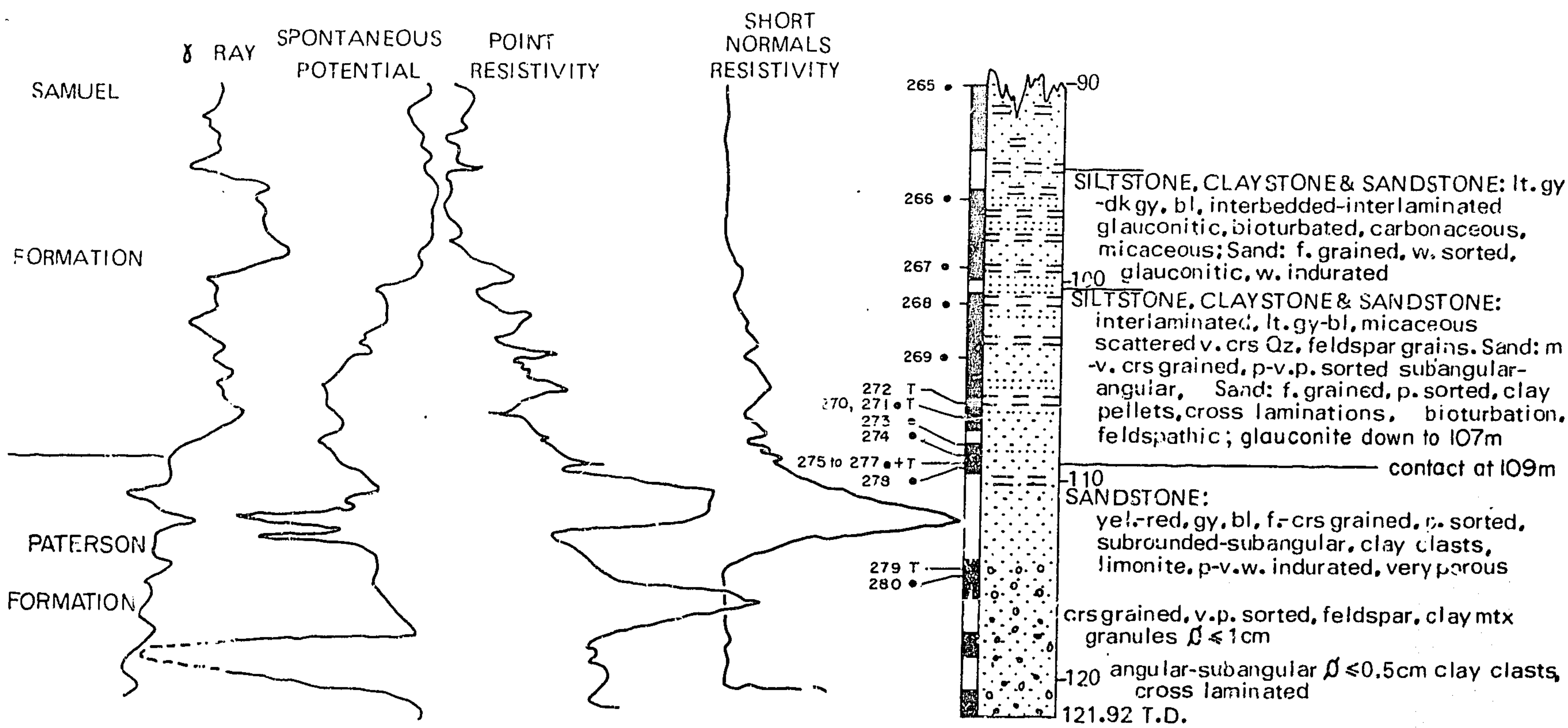
Note: 1. Number to left of symbol refers to BMR submission catalogue.

2. BMR Yowalga 1, 2, & 3 were holes drilled for deep seismic shots (TD = 90 m, 30 m, & 100 m respectively), and were not cored or logged.


Formation/ member/ lithological unit
WIRELINE LOGS
Cores
Lithologic log
Depth (m)
LITHOLOGICAL DESCRIPTIONS AND NOTES
γ RAY
Sensitivity 0·01mR/hr
Time constant : 3 sec
Logging speed 9·14 m/min
LAMPE BEDS (Silcrete)
BEJAH CLAYSTONE
SAMUEL FORMATION
POINT RESISTIVITY
SPONTANEOUS POTENTIAL
SHORT NORMALS RESISTIVITY
244 to 247 • + X T
229 to 232 T + X •
223, 224 + •
235 to 237 X • +
238, 239 T •
240 to 242 T • X
243 T
248 •
249 •
250 •
251 •
252 •
253 •
254, 255 • T
256 •
257 o
258, 259 • T
260 •
261 •
262 •
263 •
264 •
0
10
20
30
40
50
60
70
80
90
CONGLOMERATE: grn-gy, brn, Ø ≤ 0.5m, silicified claystone & sandstone (silcrete) Qz f-v. crs grained, p. sorted, subangular-subrounded, partly ferruginized
CLAYSTONE: ('Porcelanite'), wh.-pk, minor ferruginized patches, v. lit silt or sand, unbedded, m-w indurated small cavities filled with breccia (claystones-ferruginous mix)
wh-orng-mottled, p. indurated
wh, pk, yel, purp. mottled vertical cracks filled with ferruginized claystone breccia
very low density; thinly bedded to laminated
SILTSTONE, CLAYSTONE & SANDSTONE: wh, purp, red, ochre, interbedded, interlaminated, minor mica, bioturbated in part Qz sand f-m grained, w. sorted, subrounded-rounded; p-w indurated
purp. brn-blk, partly ferruginized
SILTSTONE & SANDSTONE: interbedded-interlaminated, wh, gy, brn, blk, ochre, colouration not related to the indistinct bedding planes
SAND: v.f.-f grained, w. sorted, w. indurated subrounded-rounded, minor heavies & micas
bioturbation, m-w indurated
SILTSTONE, CLAYSTONE & SANDSTONE: interbedded-interlaminated, brn, ochre, gy, purp, red, Sand: v.f.-m grained w. sorted, subrounded-rounded. At 54m scattered Qz granules, p-m indurated
CLAYSTONE & SILTSTONE : interbedded-interlaminated, gy-chocolate, partly limonitic, siltstone partly micaceous well bioturbated
(at 70m change from yellow, red & brown cuttings to mainly dark grey to black cuttings)
CLAYSTONE: bl, v. carbonaceous, micaceous, soft clay
intensely bioturbated
CLAYSTONE & SILTSTONE: bl, lt. gy-dk. gy, interbedded-interlaminated carbonaceous, micaceous
minor slumping
? cyclic sequence
black pyritic clay

BMR BROWNE 1

Formation/ member/ lithological unit	WIRELINE LOGS	C. i. e. ?	Litho-logic log	De-pth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

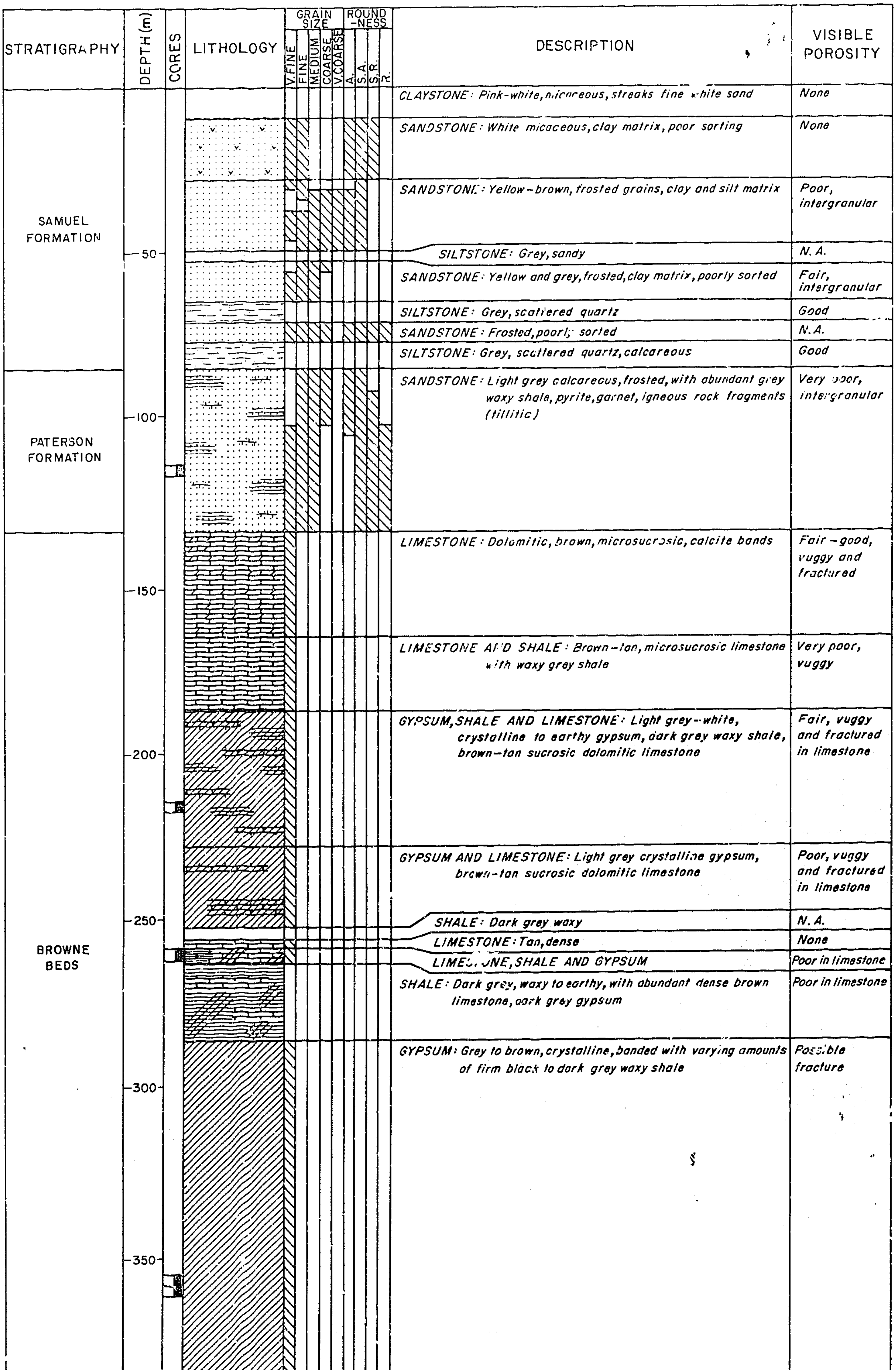


N.B. Very short intervals of lost core are not indicated

BMR BROWNE 1

M(S)347

LOCATION: LAT. 25°51'15" LONG. 12?°48'58" Seismic Line 13-C S.P. 65
ELEVATION: G.L. 454·1m
TOTAL DEPTH: 386·8m



HUNT OIL BROWNE I
(modified, after Jackson 1966a)

LOCATION: LAT. 25°56'00" LONG. 125°57'45" Seismic Line 15-G S.P. 105
ELEVATION: G.L. 483·1 m
TOTAL DEPTH: 292·6 m

STRATIGRAPHY	DESCRIPTION	VISIBLE POROSITY
SAMUEL FORMATION	*LATERITE: Ferruginous, brick-red, slightly magnetic, with wind blown sand*	*N. A.*
SAMUEL FORMATION	*CLAYSTONE: White-yellow-mauve, sub-conchoidal, fractured, micaceous, with streaks of medium-coarse angular-rounded clear quartz grains*	*None*
SAMUEL FORMATION	*SANDSTONE: White-yellow, micaceous white clay matrix, well sorted scattered heavy minerals*	*Good, intergranular*
SAMUEL FORMATION	*SANDSTONE: Conglomeratic, coated to clear quartz grains, white kaolin matrix poorly sorted*	*Fair, intergranular*
SAMUEL FORMATION	*SILTSTONE: Sandy, yellow-grey*	*None*
SAMUEL FORMATION	*SANDSTONE: Yellow-buff, fair sorting*	*Good, intergranular*
PATERSON FORMATION	*SANDSTONE: Feldspathic, buff-white, clear-frosted, white-flesh coloured feldspar, scattered igneous rock fragments, fair sorting*	*Good, intergranular*
PATERSON FORMATION	*SANDSTONE: Light grey, slightly calcareous, clear-frosted grains, scattered pink garnet, pyrite and igneous rock fragments, fair sorting*	*Good, intergranular*
PATERSON FORMATION	*SANDSTONE: Lithic, light grey, clear-frosted grains, abundant igneous and metamorphic rocks, pyrite and garnet, poor sorting, tillitic*	*Fair, intergranular*
PATERSON FORMATION	*SANDSTONE: Light grey, frosted-clear, well sorted*	*Good, intergranular*
PATERSON FORMATION	*SANDSTONE: Lithic, light grey, clear-frosted grains, abundant rock fragments, pyrite and garnet*	*Fair, intergranular*
BROWNE BEDS	*LIMESTONE: Dolomitic, dark brown, microsucrosic, pyrite, white and pink calcite, dark grey earthy shale*	*None*
BROWNE BEDS	*LIMESTONE: Red-brown-blue-grey with chocolate shale*	*None*
BROWNE BEDS	*GYPSUM: White, lathe-like crystals, dark shale partings*	*None*

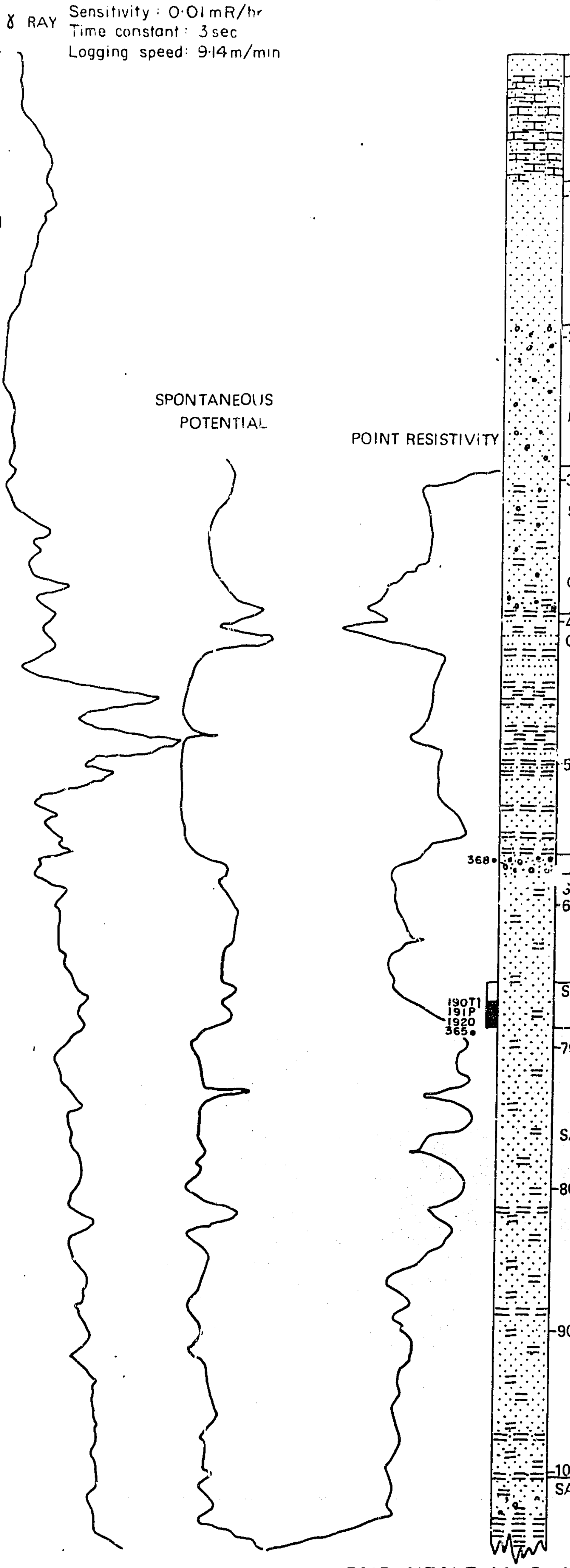
Depth (m): 50, 100, 150, 200, 250

Column headings: STRATIGRAPHY, DEPTH (m), CORES, LITHOLOGY, GRAIN SIZE (V.FINE, FINE, MEDIUM, COARSE, V.COARSE), ROUNDNESS (A., S.A., S.R., R.), DESCRIPTION, VISIBLE POROSITY

AUS 1/1067

HUNT OIL BROWNE 2
(modified, after Jackson 1966a)

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho- logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES



Formation/member/lithological unit:

- Aeolian sand
- Calcrete
- ?Aeolian sand
- PATERSON FORMATION (Fluvial)
- Silcrete
- PATERSON FORMATION (Lacustrine)
- (glacial) ? Sandy tillite
- WANNA BEDS

Lithological descriptions and notes:

0 SAND: red-brn, v.f- v.crs grained, subrounded to rounded, m. sorted, not indurated

LIMESTONE & SAND: wh.-pk, red-brn, v.f.-v. crs grained Qz sand, subangular-subrounded irregularly cemented by $CaCO_3$ m.-w. indurated gradational upper & lower boundaries

10 SAND to SANDSTONE: red-brn, v.f.-v. crs grained subrounded-rounded; m. sorted, v.p. indurated cuttings consist of loose grains

yellow rusty-a few rock cuttings: sandstone, bimodal sorting f.- v. crs grained

20 SANDSTONE: lt. gy-wh, f. grained-granular subrounded-w. rounded, bimodal sorting, p. indurated

Ø Qz ≤ 0.5cm
Qz partly milky blue
Ø Qz, oolitic chert, Qzt ≤1.2 cm

SANDSTONE: lt. gy-yel., f.-m. grained, Qz w. sorted rounded v.w. indurated, silcrete. Silicification on upper side probably along 'pipes' and cracks

30 gradational lower contact

SANDSTONE: lt. gy m. grained-granule sized, Qz ≤ 0.5cm subangular to rounded (different provenance?) clay mtx

Qz, chert subangular-subrounded Ø ≤ 1.2 cm Qtz rounded

40 CLAYSTONE, SILTSTONE & SANDSTONE: wh.-lt gy, probably interbedded, Clay with 'floating' Qz grains Ø 88μ-1000μ to w. sorted f. grained Qz sand with clay mtx

50

SANDSTONE — CONGLOMERATIC: lt gy, m. sorted, subangular-rounded, Qz & chert Ø < 2.5 cm, p. indurated

SANDSTONE: m. gy, f-m grained, subrounded to rounded

60 bimodal sorting-Qz w. sorted-v.w. sorted clay mtx, Qz wacke, p.-m. indurated, cuttings mostly loose grains, becomes slurry when washed

Core 1 cored 65.53-68.58 recovered 66.83-68.58

SANDSTONE: lt-m. gy, interlaminated f-m. grained (Ø 125-177μ 250-350μ), laminated 0.1-2 cm; grains along. 0.65-sph 0.85; subangular-rounded; grains 75-80% Qz, 15-25% chert, Qzt clay mtx; vague

70 cross lamination, minor muscovite & heavies, ? feldspar bimodally sorted, Qz wacke

SANDSTONE: as above; minor clay streaks Sph 0.75, heavies, pyrite

80

90

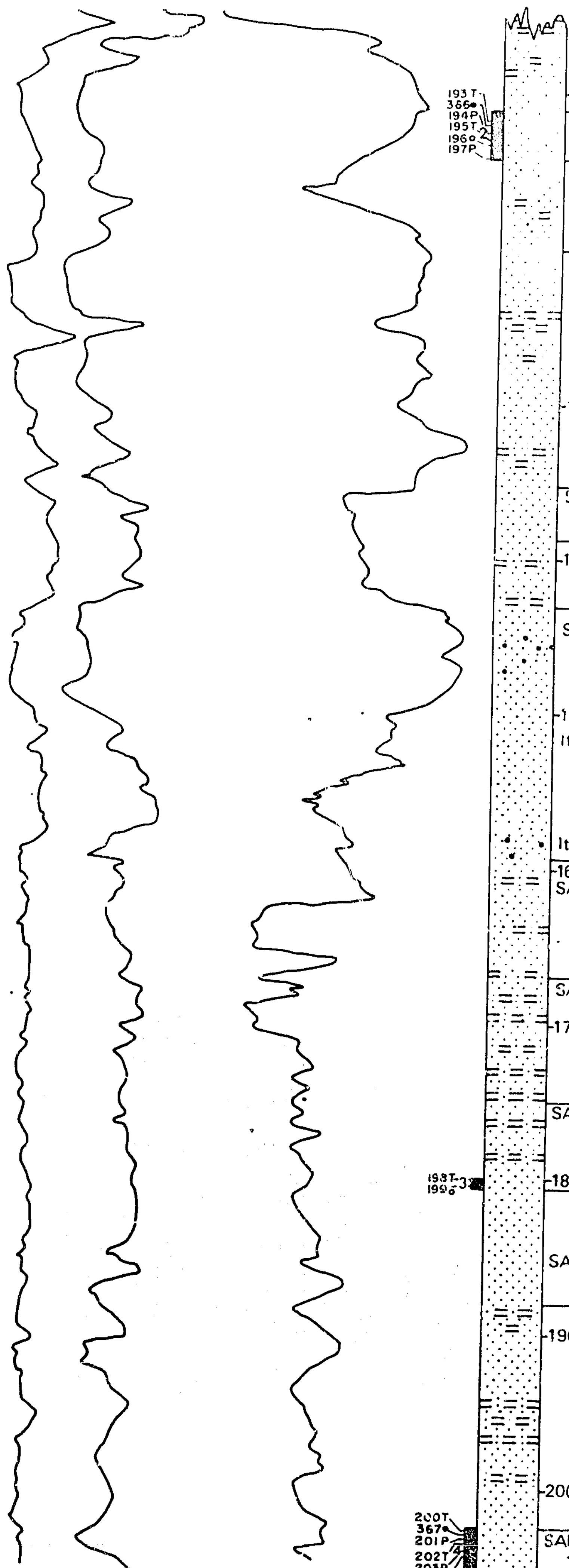
100 SANDSTONE, CLAYSTONE & SILTSTONE: m. gy-brn, interbedded, sand v.f.-f. grained, scarce crs-v. crs grained Qz & chert Ø ≤ 0.4cm m-p sorted, Sph 0.75 Qz; subangular-rounded

BMR NEALE 1A & 1B

M(S)334

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

γ RAY SPONTANEOUS POTENTIAL POINT RESISTIVITY



WANNA BEDS

LENNIS SANDSTONE

-110 Core 2 cored 111.25-114.30 100% recovery

SANDSTONE: m. gy. f.-m. grained, w. sorted,, subrounded -rounded, heavies, Sph0.75; laminated & crossbedded; angle of dip 30°-40°, m. indurated

SANDSTONE & minor CLAYSTONE: m. gy, f-m. grained, subrounded heavies, rare ?glauconite, feldspar, micas Sph 0.75, m. indurated

-120

-130

SANDSTONE: m. gy-lt. pk, f-m. grained, subangular-subrounded, bimodal sorted, Sph 0.55, heavies,

-140 SANDSTONE & minor CLAYSTONE: lt. gy-lt. red-alternating gy & red. Gy sandstone as above, red sandstone f. grained, subrounded Sph 0.75, heavies, ? glauconite, minor m-crs grained Qz, minor clay interbeds

SANDSTONE: as above, gradual decrease in number of gy sandstone cuttings, scattered granules of Qz, chert m-w indurated

-150

lt. red, f. grained, subangular-subrounded, m. sorted heavies,

lt. red-minor lt. gy, scattered Qz granules Ø≤3mm

-160

SANDSTONE & CLAYSTONE: sandstone as above, interbeds of clay

SANDSTONE & CLAYSTONE: sandstone as above, clay lt. gy, v.p. indurated, plastic; up to 50% clay

-170

SANDSTONE & CLAYSTONE: as above decrease in amount of clay

Core 3 cored 179.83-180.44m 100% recovery

-180 SANDSTONE: red, v.f., f-m grained, subangular-subrounded, Sph 0.65-0.75, laminated 1-5 mm, v.f. & f. sand laminations, m-w sorted. m. grained sand bimodal sorted, heavies.

SANDSTONE: red, v.f.-m. grained, subangular-subrounded, m-w sorted

SANDSTONE & CLAYSTONE: sand red, as above,

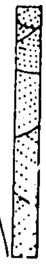
-190 scattered crs grains Qz, subangular-subrounded; clay interbeds

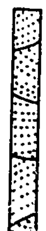
-200

Core 4 cored 202.69-205.74 100% recovery

SANDSTONE: lt. red, f-m grained, angular-rounded, Sph 0.65 -0.75, bimodal sorted, m.-w. indurated, heavies laminated & crossbedded

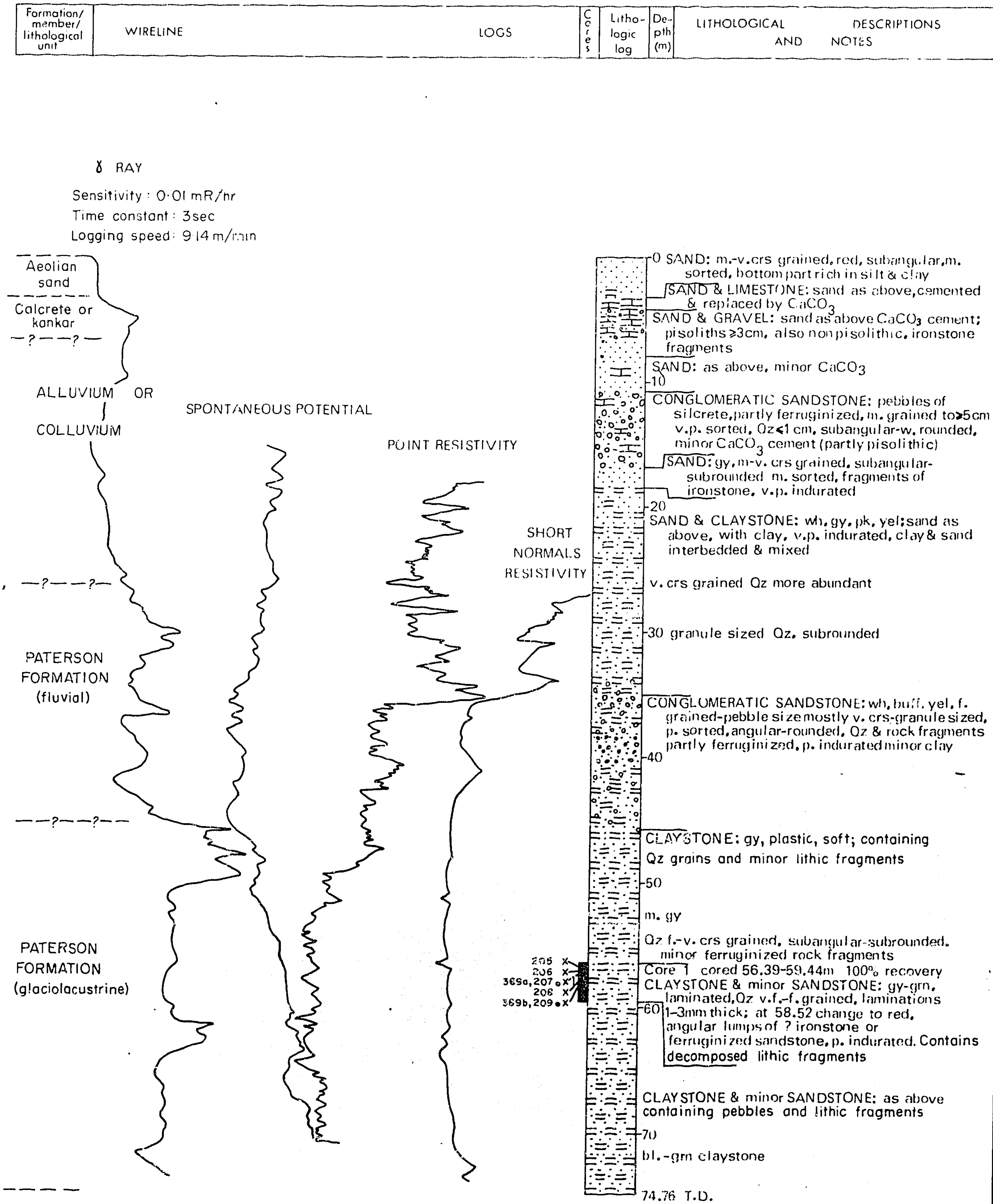
205.74 T.D.





BMR NEALE 1A & 1B

M(S)335-1


Formation/ member/ lithological unit
WIRELINE
LOGS
Cores
Litho-logic log
Depth (m)
LITHOLOGICAL DESCRIPTIONS AND NOTES
ɣ RAY
Sensitivity : 0·01 mR/hr
Time constant : 3sec
Logging speed : 9·14 m/min
Aeolian sand
Calcrete or kankar
ALLUVIUM OR COLLUVIUM
SPONTANEOUS POTENTIAL
POINT RESISTIVITY
SHORT NORMALS RESISTIVITY
PATERSON FORMATION (fluvial)
PATERSON FORMATION (glaciolacustrine)
0 SAND: m.-v.crs grained, red, subangular, m. sorted, bottom part rich in silt & clay
SAND & LIMESTONE: sand as above, cemented & replaced by $CaCO_3$
SAND & GRAVEL: sand as above $CaCO_3$ cement; pisoliths ≥3cm, also nonpisolithic, ironstone fragments
SAND: as above, minor $CaCO_3$
10
CONGLOMERATIC SANDSTONE: pebbles of silcrete, partly ferruginized, m. grained to >5cm v.p. sorted, Qz<1 cm, subangular-w. rounded, minor $CaCO_3$ cement (partly pisolithic)
SAND: gy, m-v. crs grained, subangular-subrounded m. sorted, fragments of ironstone, v.p. indurated
20
SAND & CLAYSTONE: wh, gy, pk, yel; sand as above, with clay, v.p. indurated, clay & sand interbedded & mixed
v. crs grained Qz more abundant
30 granule sized Qz, subrounded
CONGLOMERATIC SANDSTONE: wh, buff, yel, f. grained-pebble size mostly v. crs-granule sized, p. sorted, angular-rounded, Qz & rock fragments partly ferruginized, p. indurated minor clay
40
CLAYSTONE: gy, plastic, soft; containing Qz grains and minor lithic fragments
50
m. gy
Qz f.-v. crs grained, subangular-subrounded, minor ferruginized rock fragments
Core 1 cored 56.39-59.44m 100% recovery
205 x
206 x
369a, 207 ● x
208 x
369b, 209 ● x
CLAYSTONE & minor SANDSTONE: gy-grn, laminated, Qz v.f.-f. grained, laminations
60 1-3mm thick; at 58.52 change to red, angular lumps of ? ironstone or ferruginized sandstone, p. indurated. Contains decomposed lithic fragments
CLAYSTONE & minor SANDSTONE: as above containing pebbles and lithic fragments
70
bl.-grn claystone
74.76 T.D.

BMR NEALE 2

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

γ RAY

Sensitivity : 0·01 mR/hr
Time constant : 3 sec
Logging speed : 9·14 m/min

Aeolian sand

Calcrete & laterite

PATERSON

Silcrete

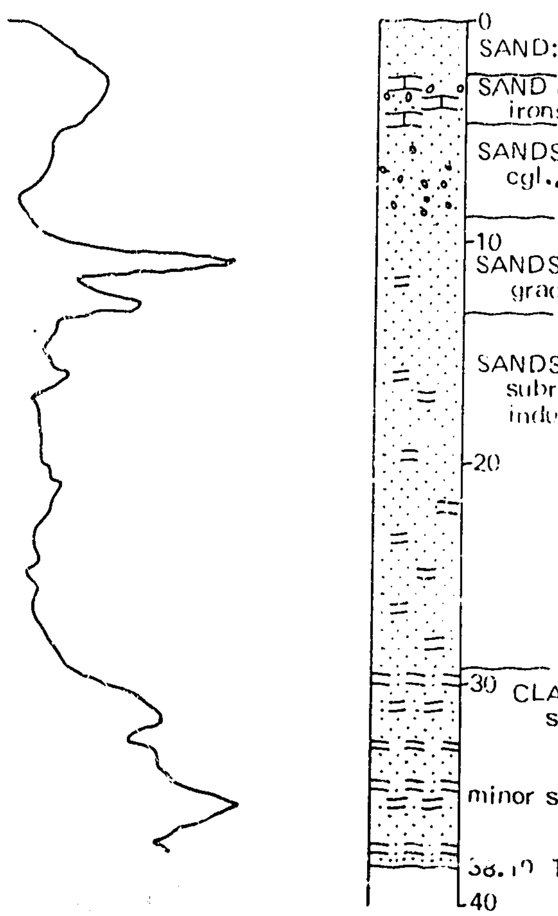
FORMATION

(Fluviatile)

PATERSON

FORMATION

(Lacustrine)



SAND: red-brn, f.-m. grained, subrounded-rounded, m.-p. sorted, uncons.

SAND & LIMESTONE: red-brn, f.-v. crs grained, subrounded-rounded, p. sorted, minor ironstone pellets; discontinuously cemented with calc; m. indurated

SANDSTONE: rusty-brn, m-granule sized, subrounded, m. sorted (bimodal), partly cgl., Ø ≤ 2cm Qz, Qtz, m. indurated.

SANDSTONE: yel.-grn, f.-v.crs grained, angular, p. sorted (bimodal-clay mtx), si, gradational base, sharp top, v. indurated

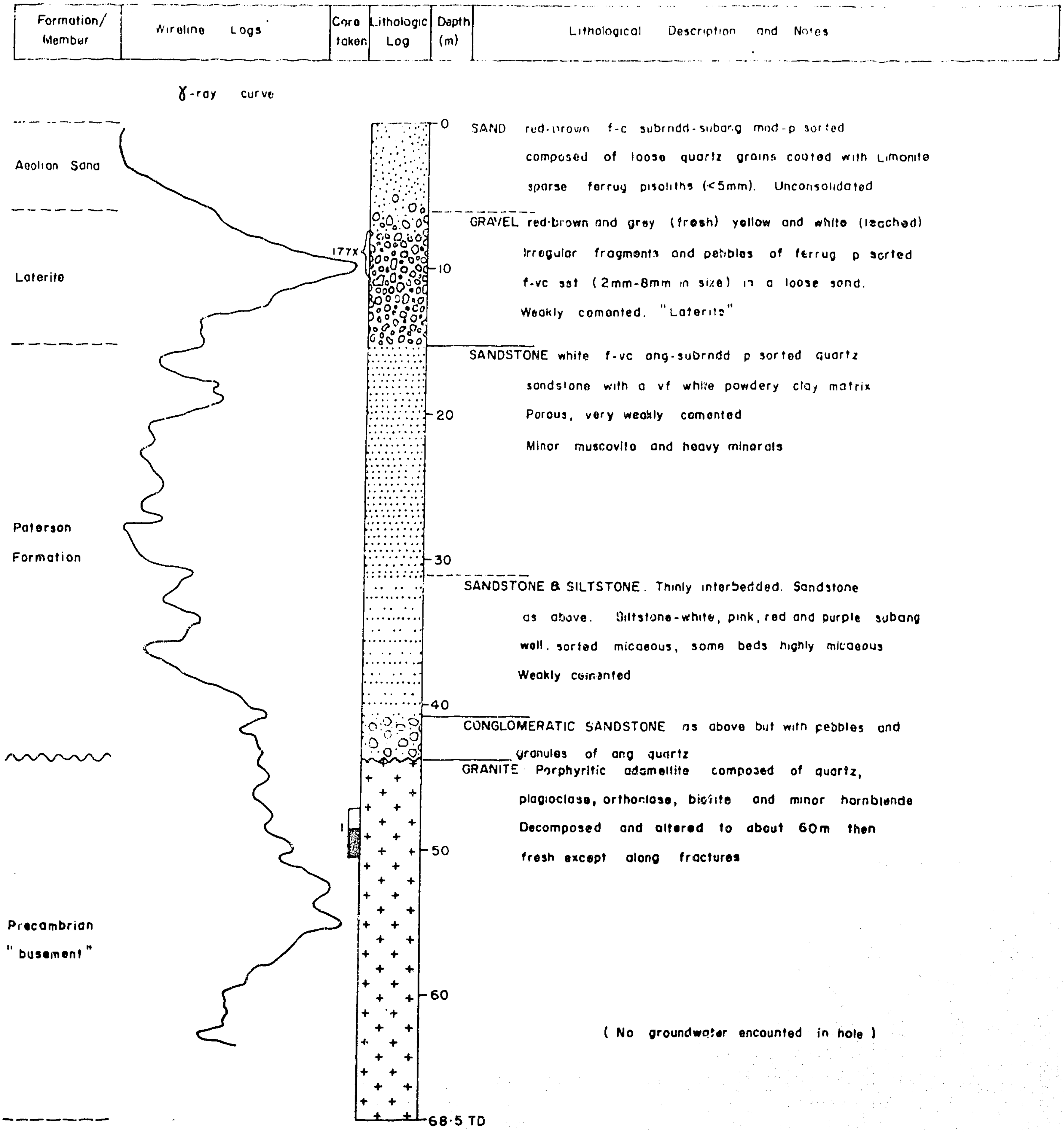
SANDSTONE: lt. pk-wh. f-m. grained, minor crs & v. crs grained Qz; subangular-subrounded, bimodal sorted, Qz w.-v.w. sorted, clay mtx, Qz wacke, p.-m indurated, cuttings mostly loose grains

CLAYSTONE & SANDSTONE: interbedded claystone, siltstone & sandstone, sandstone ditto as above but better sorted (Qz arenites)

minor seepage of water

BMR NEALE 3

M(S)337

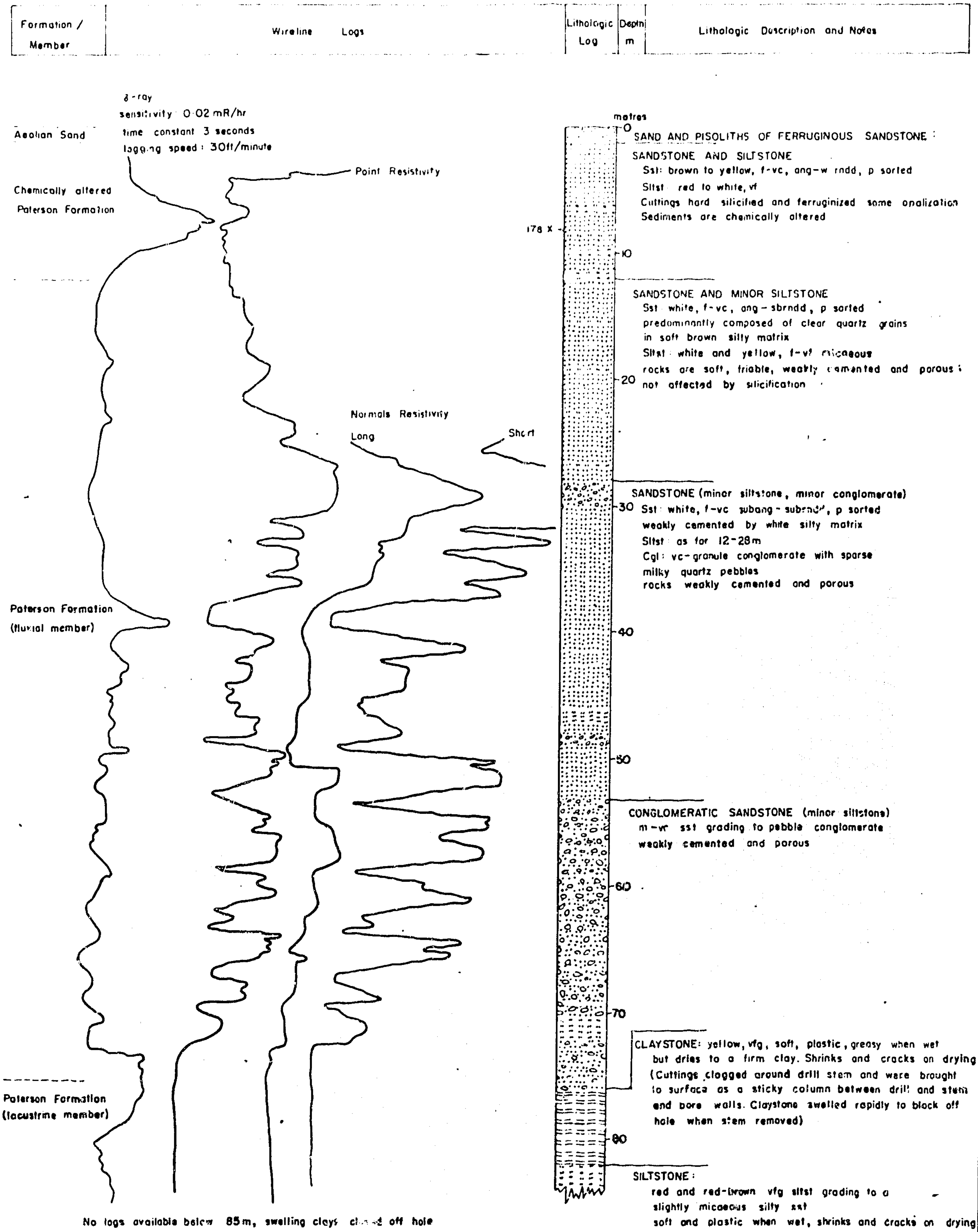


B M R RASON I

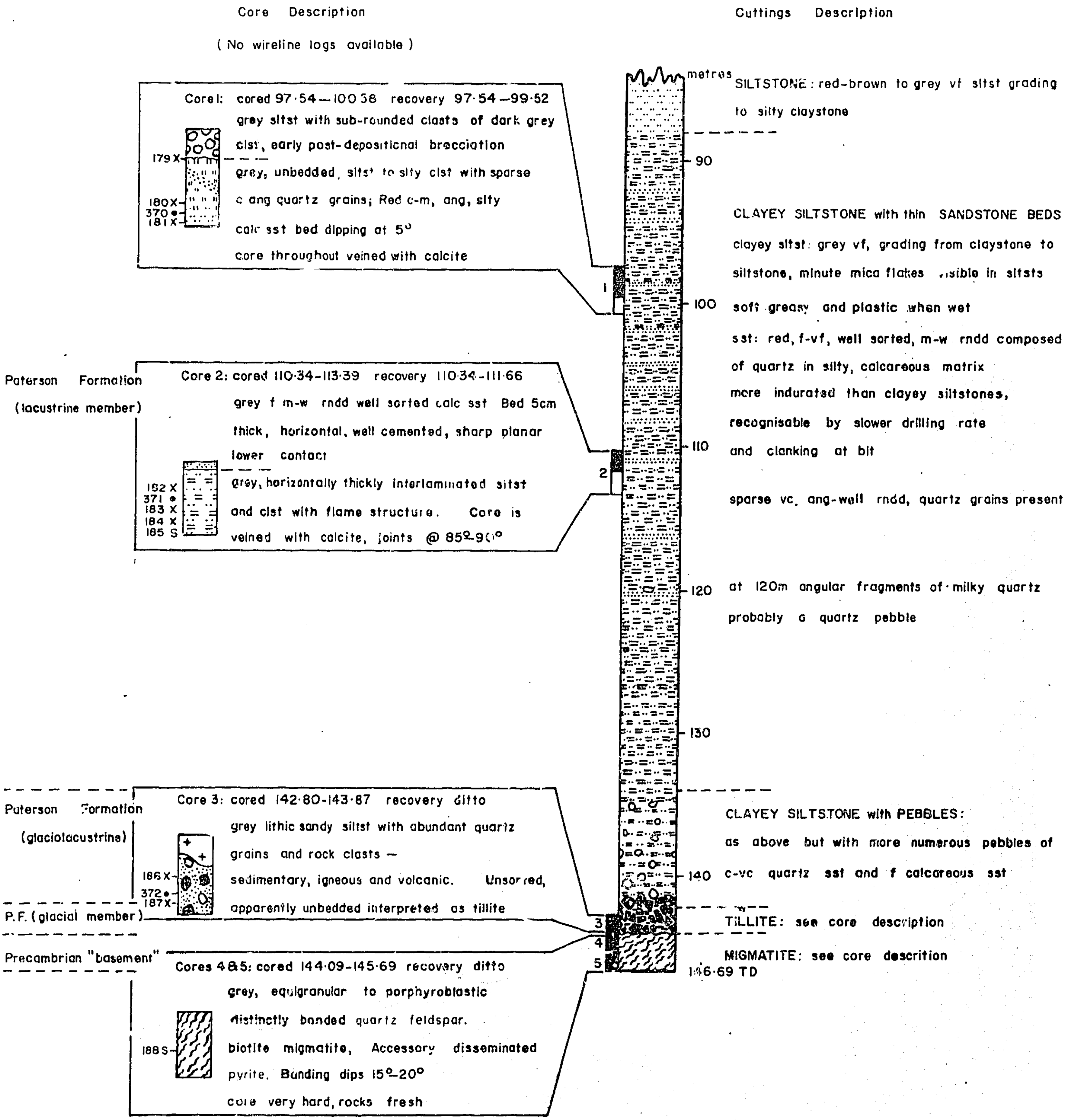
Reference for work done on samples

x *Chemical analysis*	P *Permeability & Porosity*
+ *X-ray diffraction analysis*	◊ *Detail petrology*
T *Thin section*	□ *Examined for conodonts*
• *Palynology*	∘ *Sample taken, not submitted*
S *Slabbing*	*N.B. number to left of symbol refers to BMR sample submission catalogue* (See Appendix 6)

M(S)211-1



BMR RASON 2 (0-85m)



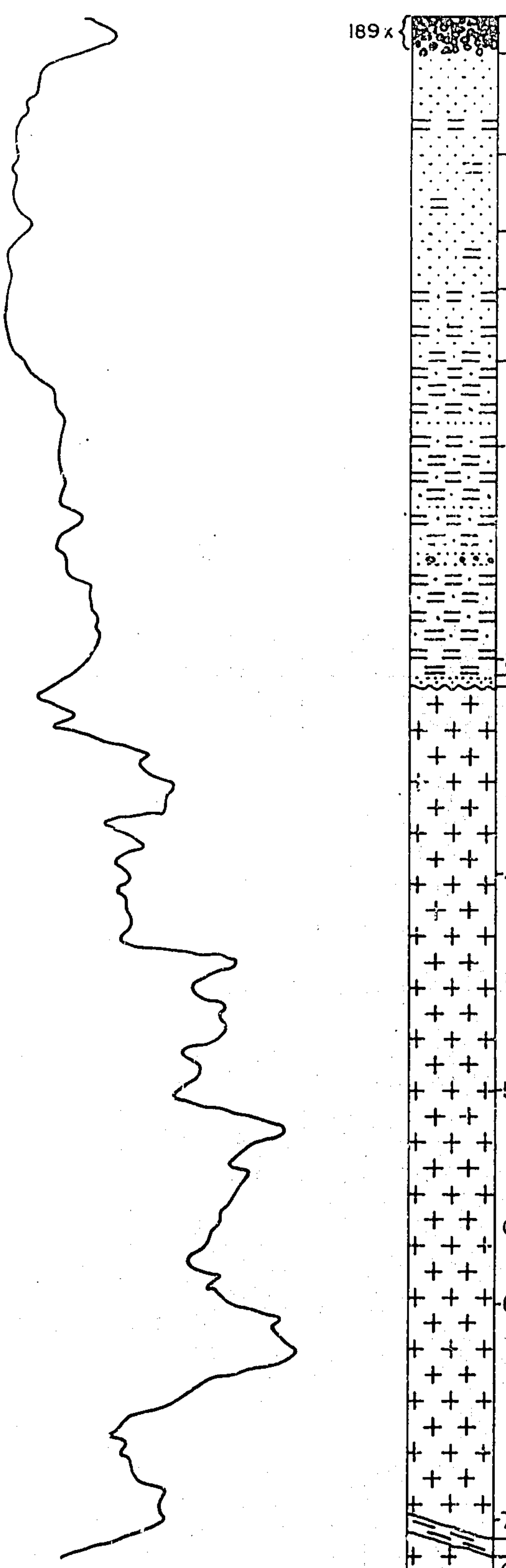
BMR RASON 2 (85–146·69m)

M(S)213

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

γ RAY

Sensitivity: 0·05 mR/hr
Time constant: 3 sec
Logging speed: 9·14 m/min



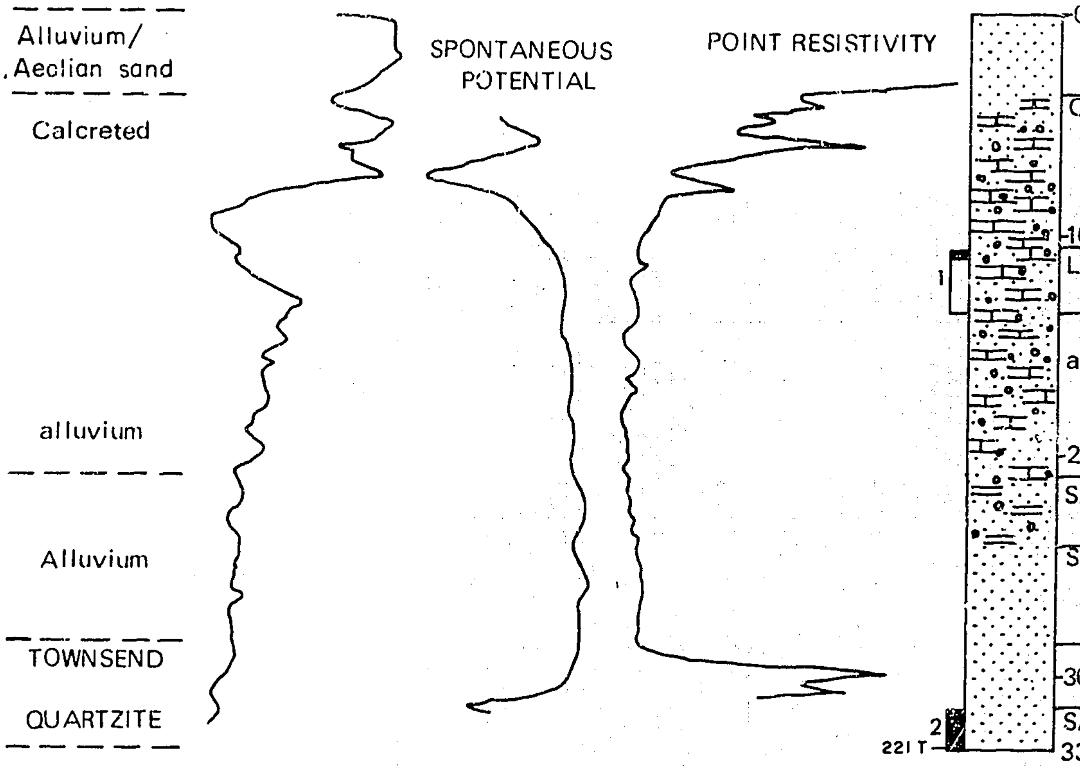
Formation/member/lithological unit	Depth (m)	Lithological descriptions and notes
Laterite	0	IRONSTONE GRAVEL: dk brn-rusty brn-dk gy-bl. gy, ferruginized Qz sand, pellets closely packed, Qz m-crs grained, pellets spherical to irregular
Silcrete		SANDSTONE: wh. rusty yel, kidney red, bimodal sorted, m-crs grained Qz, clay mtx, subrounded-subangular, v.w. indurated, minor claystone streaks; colours mottled
		gradational upper and lower boundaries-silcrete
PATERSON FORMATION (Fluvial)		SANDSTONE: wh.-lt. gy, f-v. crs grained, subangular-rounded, v.p. sorted (bimodal) clay mtx, p. indurated- layers of rusty brn to kidney red or pink coloured sandstone
		SANDSTONE, SILTSTONE & CLAYSTONE: wh.-lt. gy, sandstone as above intercalated with claystone & siltstone p. indurated
PATERSON FORMATION (Lacustrine)		CLAYSTONE, SILTSTONE & SANDSTONE: interbedded, wh. lt. gy, pk sandstone as above, claystone contains 'floating' Qz Ø 250-500μ Clay plastic when washed, p. indurated
		Ø Qz 0.5 cm
	30	SANDSTONE: wh.-lt.gy, m.-v. crs grain-granule sized, p. indurated
PRECAMBRIAN BASEMENT		GRANITE: intensely weathered; Qz, feldspar; Qz very coarse to granule sized
		first appearance of mica
		first appearance of orthoclase
		GRANITE: slightly weathered; Qz, plagioclase, orthoclase, minor biotite; m-v. crsly crystalline, probably porphyritic
	70	'SCHIST': highly micaceous fracture zone; weathered; minor flow of water; 6Ω/m ≈1600p.p.m. Water rose to 64m after 2 days
		GRANITE: as above
	74.68	T.D.

BMR RASON 3

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

γ RAY

Sensitivity : 0·01 mR/hr
Time constant : ·3 sec
Logging speed : 9·14 m/min



SAND & SILT: v.f.-m. grained, m. sorted, subrounded-w. rounded, scattered crs-v. crs grained Qz, ironstone, igneous rocks

CONGLOMERATIC SAND & SANDY LIMESTONE: Sand-as above, with pebbles of Qz, Qzt, ferruginized sandstone, igneous rocks, irregularly cemented by $CaCO_3$, minor $CaSO_4$ at 6 m

Core 1 cored 10.67–13.56m
recovered 10.67–10.98m

LIMESTONE: wh. spongy, Qz f.-crs grained angular-subrounded, black impurities m. indurated, pebbles of Townsend Qzt & dk gy porphyritic rock Ø ≤ 15cm

as above

SANDSTONE, minor SILTSTONE & CLAYSTONE: rare pebbles of Town. and Qzt, wh.-grn-gy

SANDSTONE: wh.-grn, f.-crs grained, rare v. crs grained Qz, subangular-subrounded m. sorted p.-m. indurated

Core 2 cored 31.39–33.06 100% recovery

SANDSTONE: grn-gy, f.-m. grained, w. sorted v.w. indurated

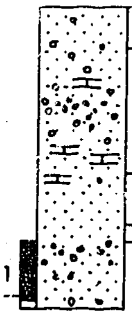
33.06 T.D.

BMR TALBOT 1

M(S)341

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

Calcareous alluvium



0

SAND: f.grained-granule sized, p. sorted, subangular-w. rounded, v.p. indurated

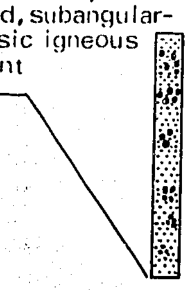
CONGLOMERATIC SANDSTONE: pebbles & granules of:- ironstone, Qz, Qzt, dark, f. grained igneous rocks. Sand as above; v.p. sorted p. indurated subangular-subrounded, minor & irregular cementation with $CaCO_3$

SANDSTONE: gy, v.f.-f. grained, m-p sorted, subangular-subrounded, $CaCO_3$ v.w. indurated

10 Core 1 cored 10.66-13.72 m recovered 10.66-13.41m

CONGLOMERATIC SANDSTONE: Sandstone, f.-crs grained, streaks & pockets of v. crs grained to pebble sized gravels, sands m.-w. sorted, subangular-subrounded; pebbles Qz, ferruginized sandstone, basic igneous rocks, Ø ≤ 1.5cm p.-v.w. indurated, minor $CaCO_3$ cement

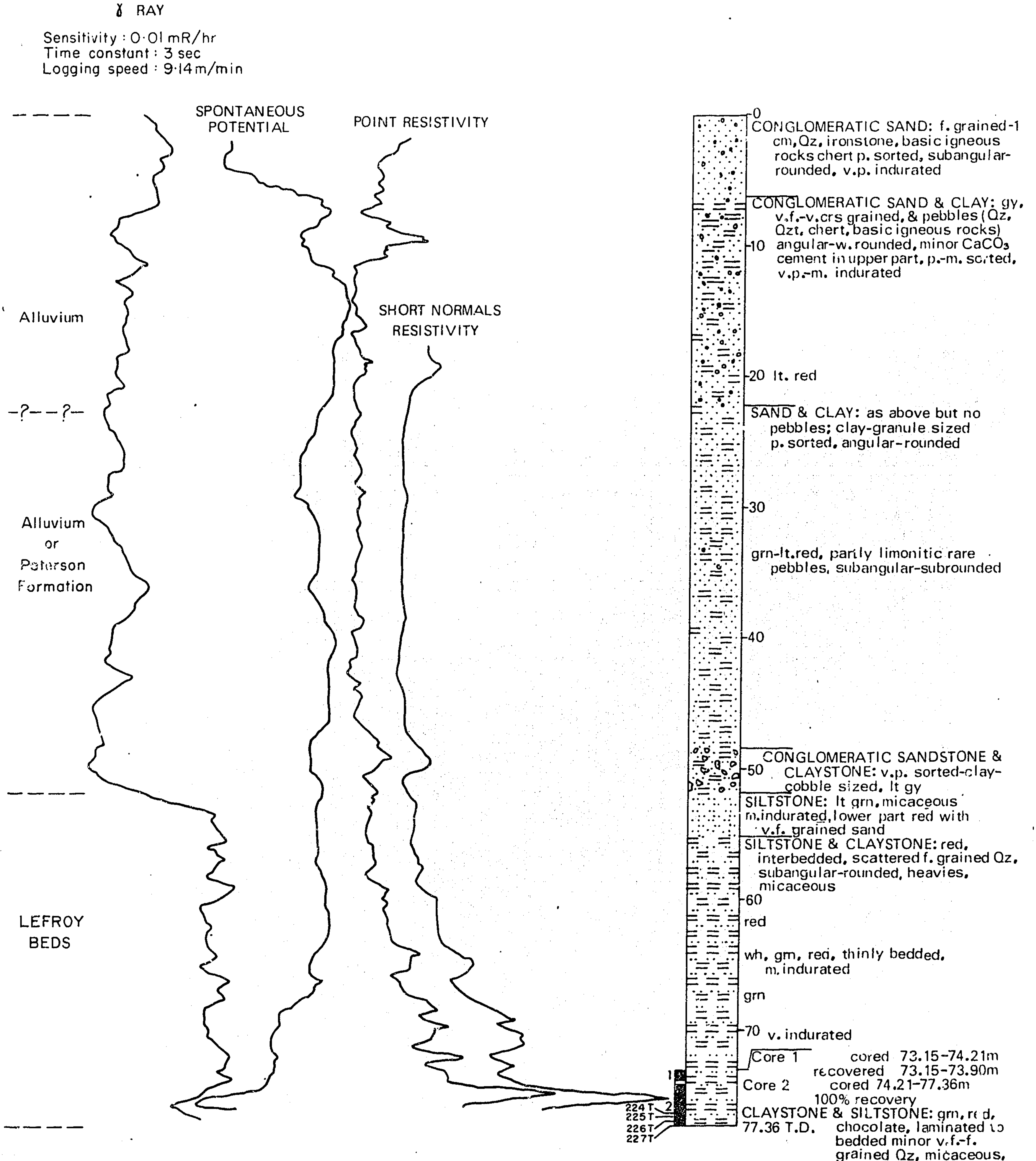
13.72 T.D.



BMR TALBOT 2

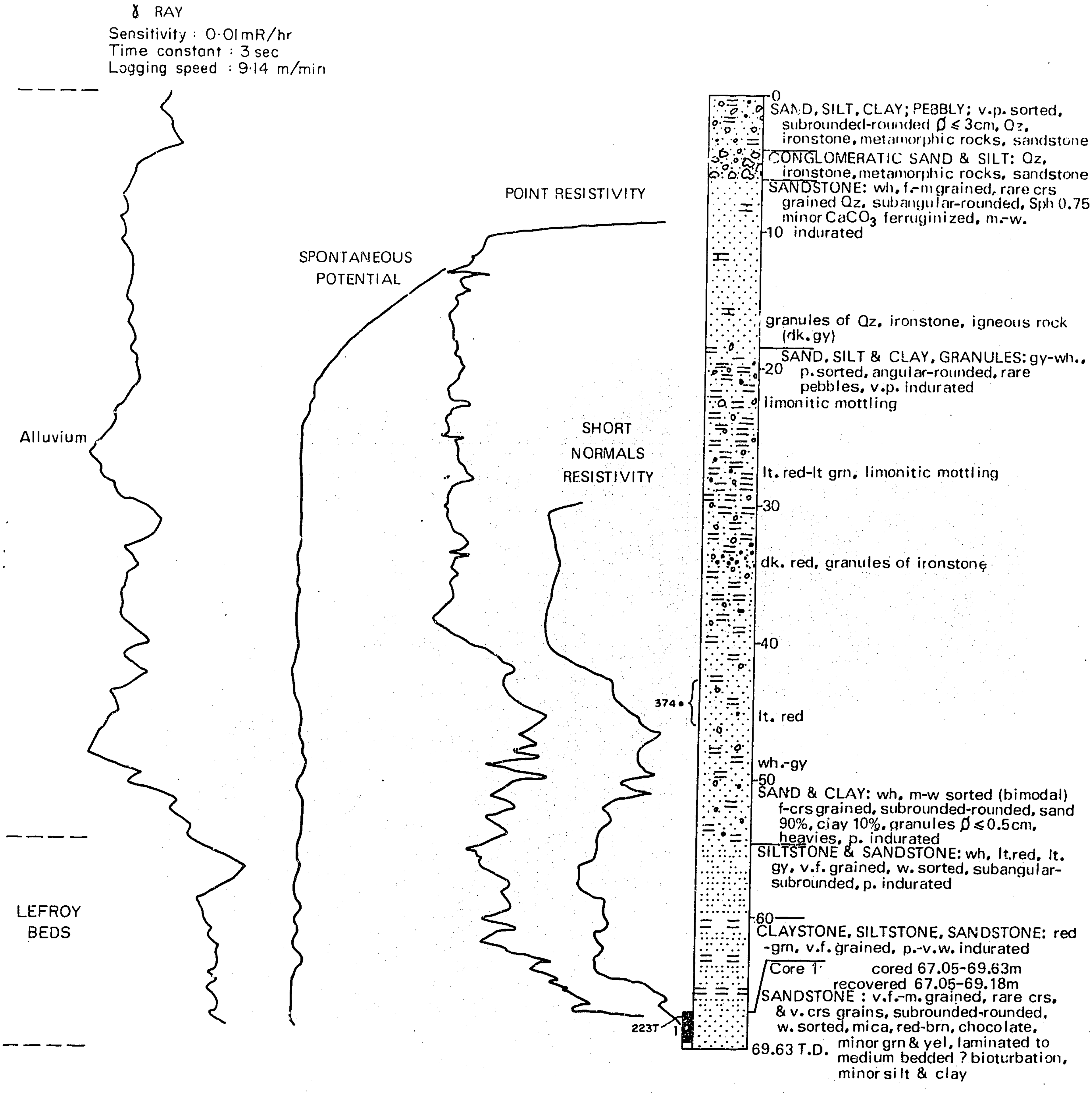
M(S)342

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

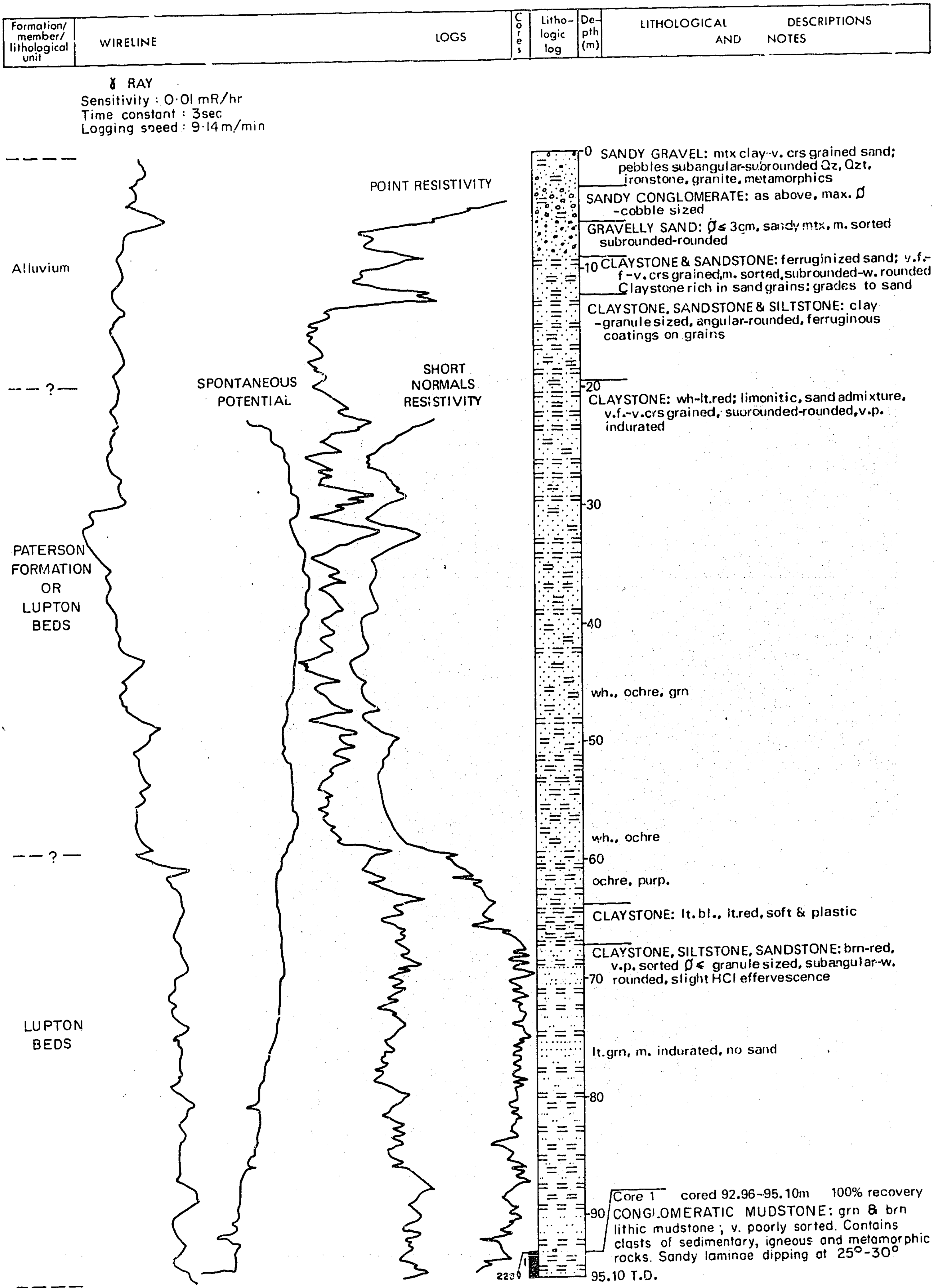


BMR TALBOT 3

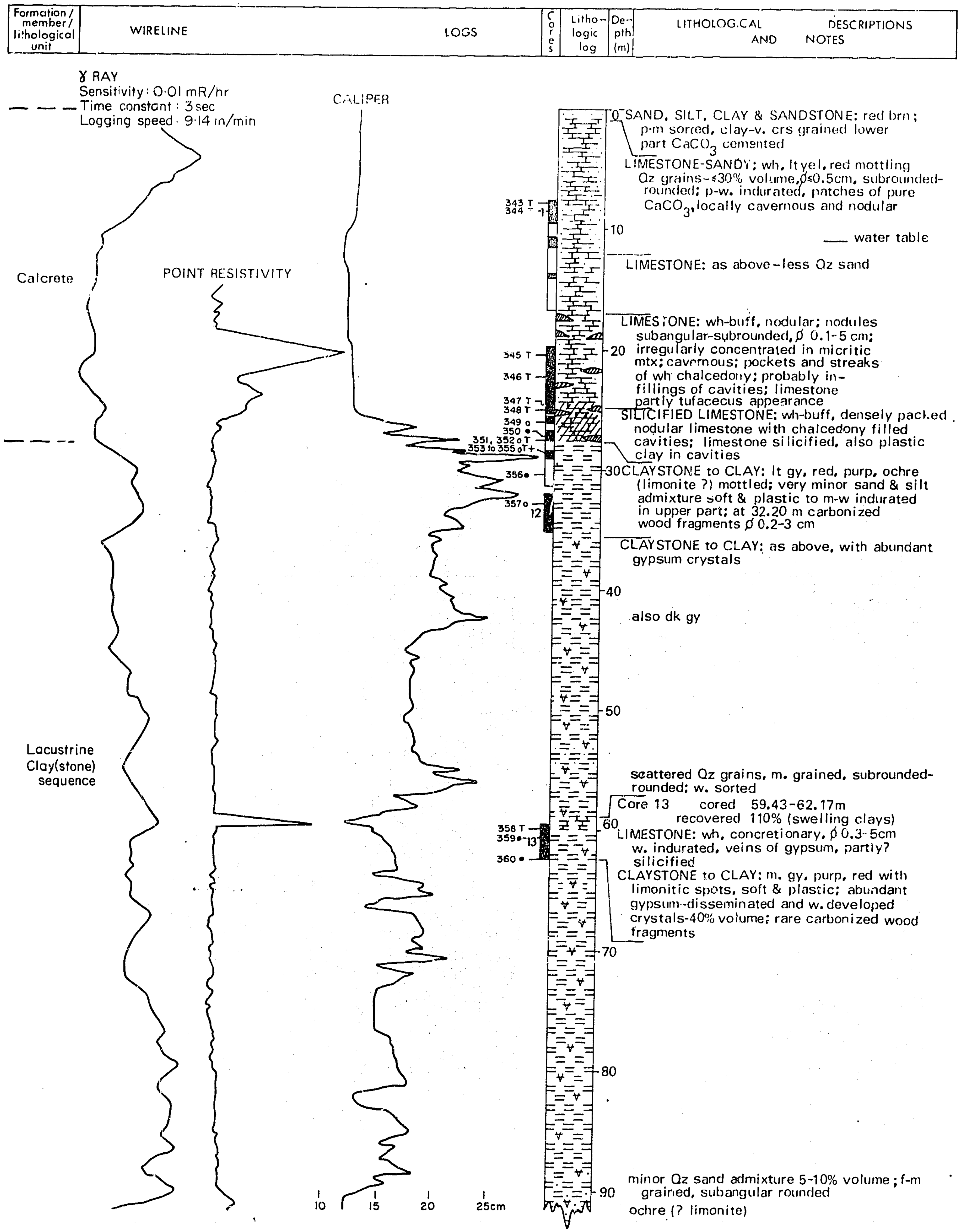
Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES



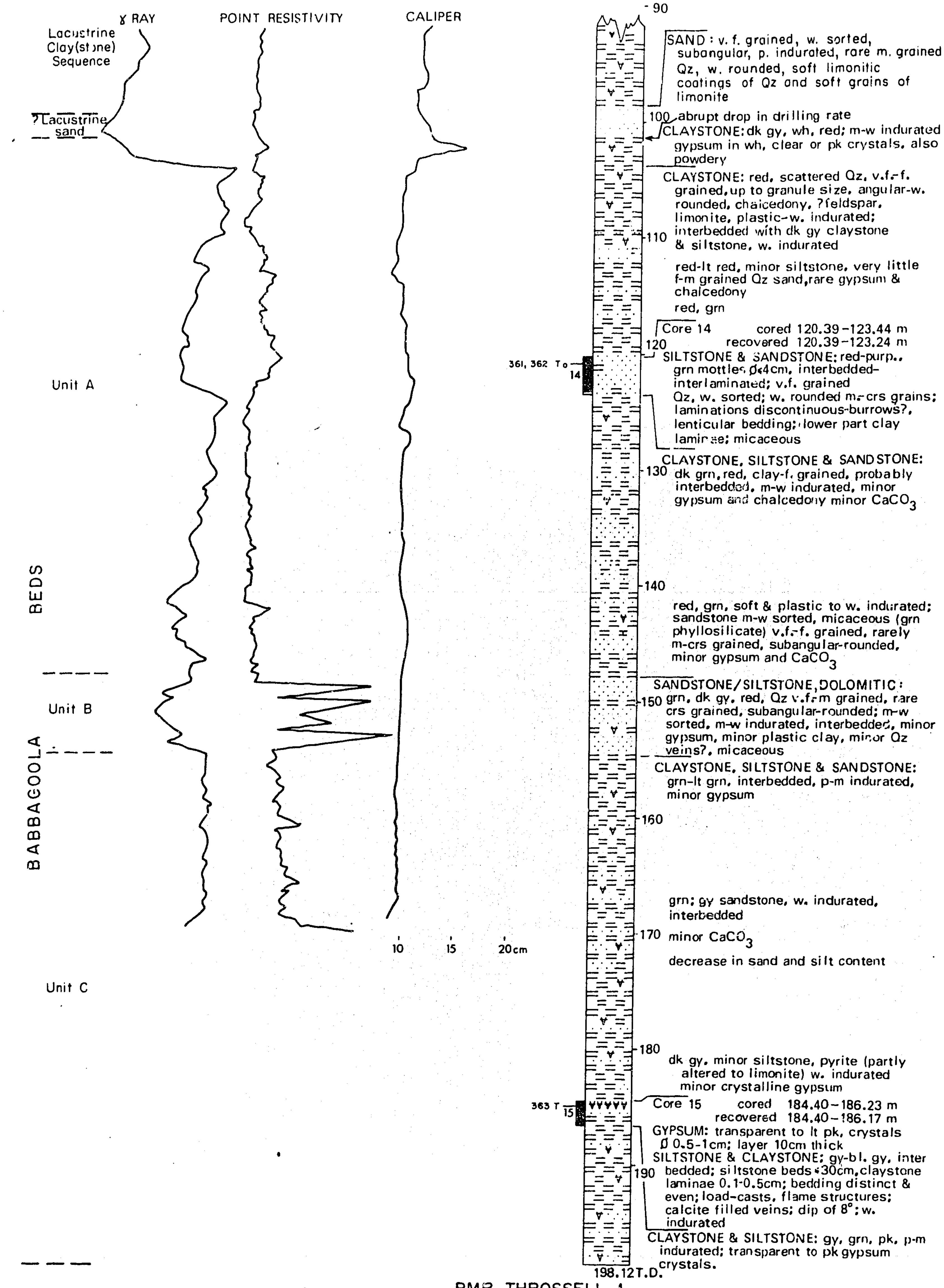
BMR TALBOT 4


Formation/ member/ lithological unit
WIRELINE
LOGS
Cores
Litho- logic log
De- pth (m)
LITHOLOGICAL DESCRIPTIONS AND NOTES
γ RAY
Sensitivity : 0·01 mR/hr
Time constant : 3sec
Logging speed : 9·14 m/min
POINT RESISTIVITY
SPONTANEOUS POTENTIAL
SHORT NORMALS RESISTIVITY
Alluvium
PATERSON FORMATION OR LUPTON BEDS
LUPTON BEDS
?
?
0 SANDY GRAVEL: mtx clay-v. crs grained sand; pebbles subangular-subrounded Qz, Qzt, ironstone, granite, metamorphics
SANDY CONGLOMERATE: as above, max. Ø -cobble sized
GRAVELLY SAND: Ø ≤ 3cm, sandy mtx, m. sorted subrounded-rounded
10 CLAYSTONE & SANDSTONE: ferruginized sand; v.f.-f-v. crs grained, m. sorted, subrounded-w. rounded Claystone rich in sand grains; grades to sand
CLAYSTONE, SANDSTONE & SILTSTONE: clay-granule sized, angular-rounded, ferruginous coatings on grains
20 CLAYSTONE: wh-lt.red; limonitic, sand admixture, v.f.-v.crs grained, subrounded-rounded, v.p. indurated
30
40
wh., ochre, grn
50
wh., ochre
60
ochre, purp.
CLAYSTONE: lt. bl., lt.red, soft & plastic
CLAYSTONE, SILTSTONE, SANDSTONE: brn-red, v.p. sorted Ø ≤ granule sized, subangular-w. rounded, slight HCl effervescence
70
lt.grn, m. indurated, no sand
80
Core 1 cored 92.96–95.10m 100% recovery
90 CONGLOMERATIC MUDSTONE: grn & brn lithic mudstone; v. poorly sorted. Contains clasts of sedimentary, igneous and metamorphic rocks. Sandy laminae dipping at 25°-30°
1
2230
95.10 T.D.

BMR TALBOT 5



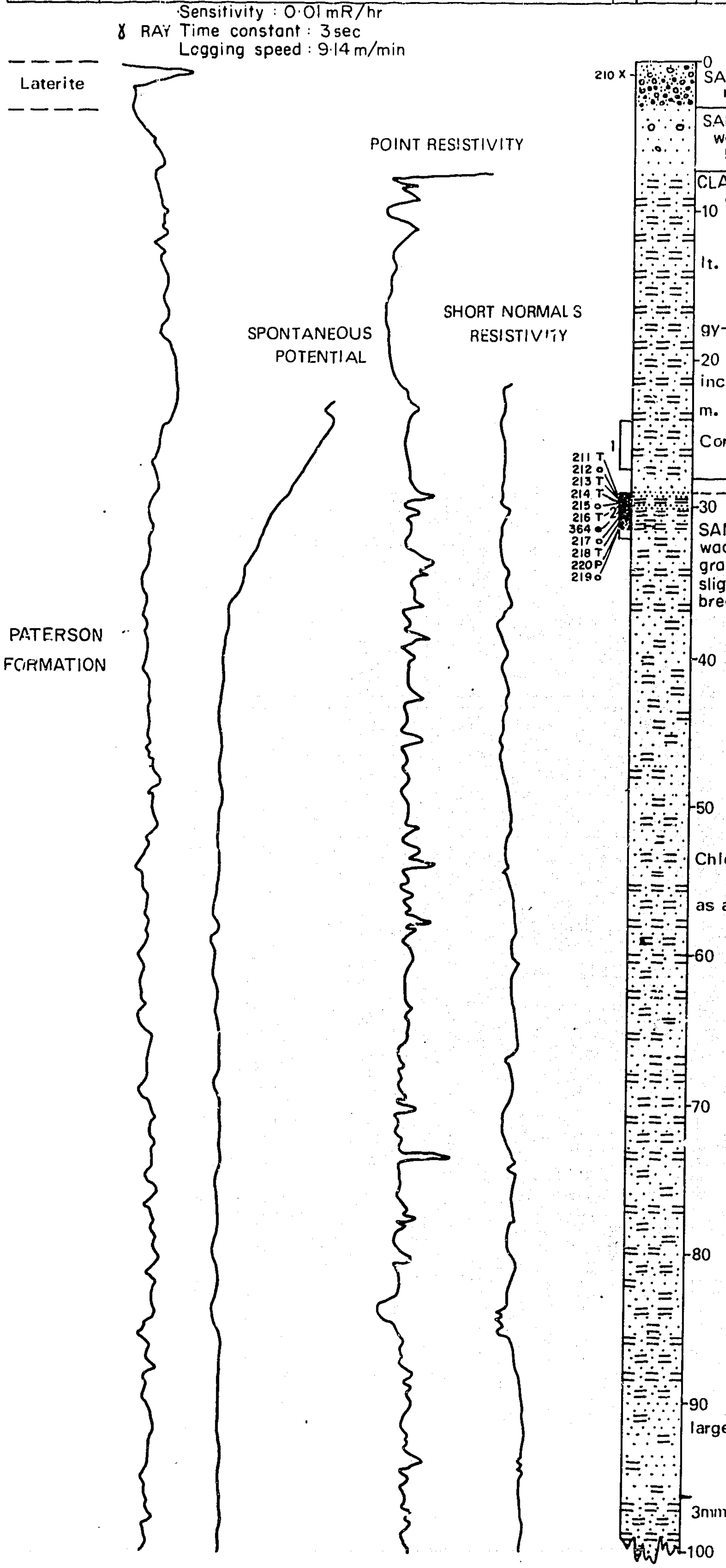
BMR THROSSELL 1



BMR THROSSELL 1

M(S)351-1

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES



SAND & IRONSTONE: Sand: f.-m. grained subangular-w. rounded, Sph 0.75; ironstone mostly pisolithic

SANDSTONE: lt. pk, lt grn-wh., f-m grained, subangular-well rounded, minor muscovite, pebbles Qz, granite Ø≤ 5cm. Partly ferruginized and silicified

CLAYEY SANDSTONE: buff-yel. scattered Qz m-v. crs grained, subangular-subrounded, p. indurated

lt. gy-pk

gy-grn

increase in amount of sandstone

m. gy

Core 1 cored 24.38-27.43 m; No recovery

Core 2 cored 28.95-32.00m recovered 28.95-31.29

SANDSTONE: lt. gy to brn gy silty lithic carbonaceous wacke; f-m grained, well rounded to spherical Qz grains present, minor feldspar. Slightly calcareous and slightly micaeous beds. Bedding indistinct some breccias and slumps sparse wood fragments

Chlorite, rare rounded crs grains

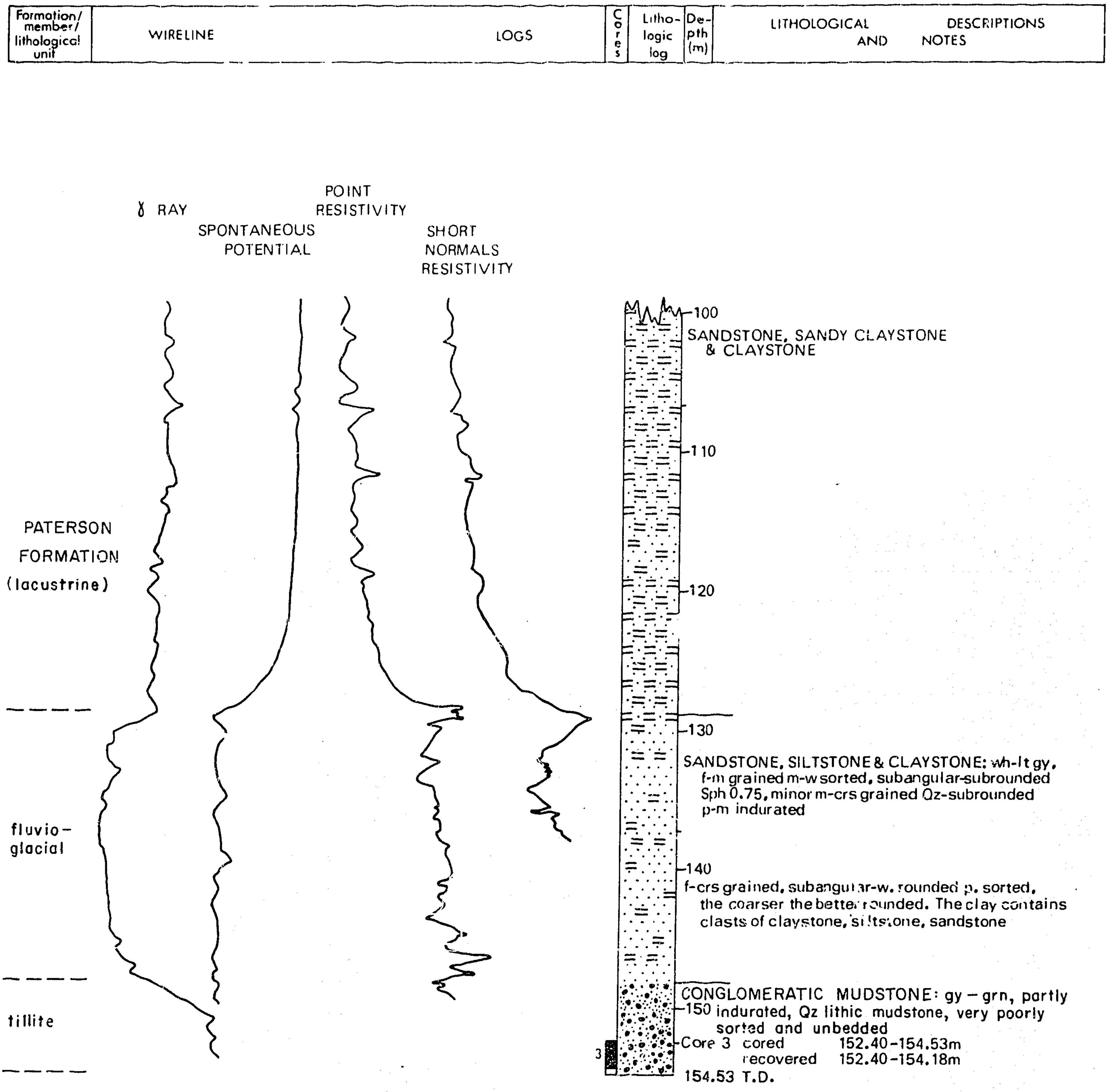
as above

larger proportion of sandstone

3mm thick gypsum veins

BMR WANNA 1

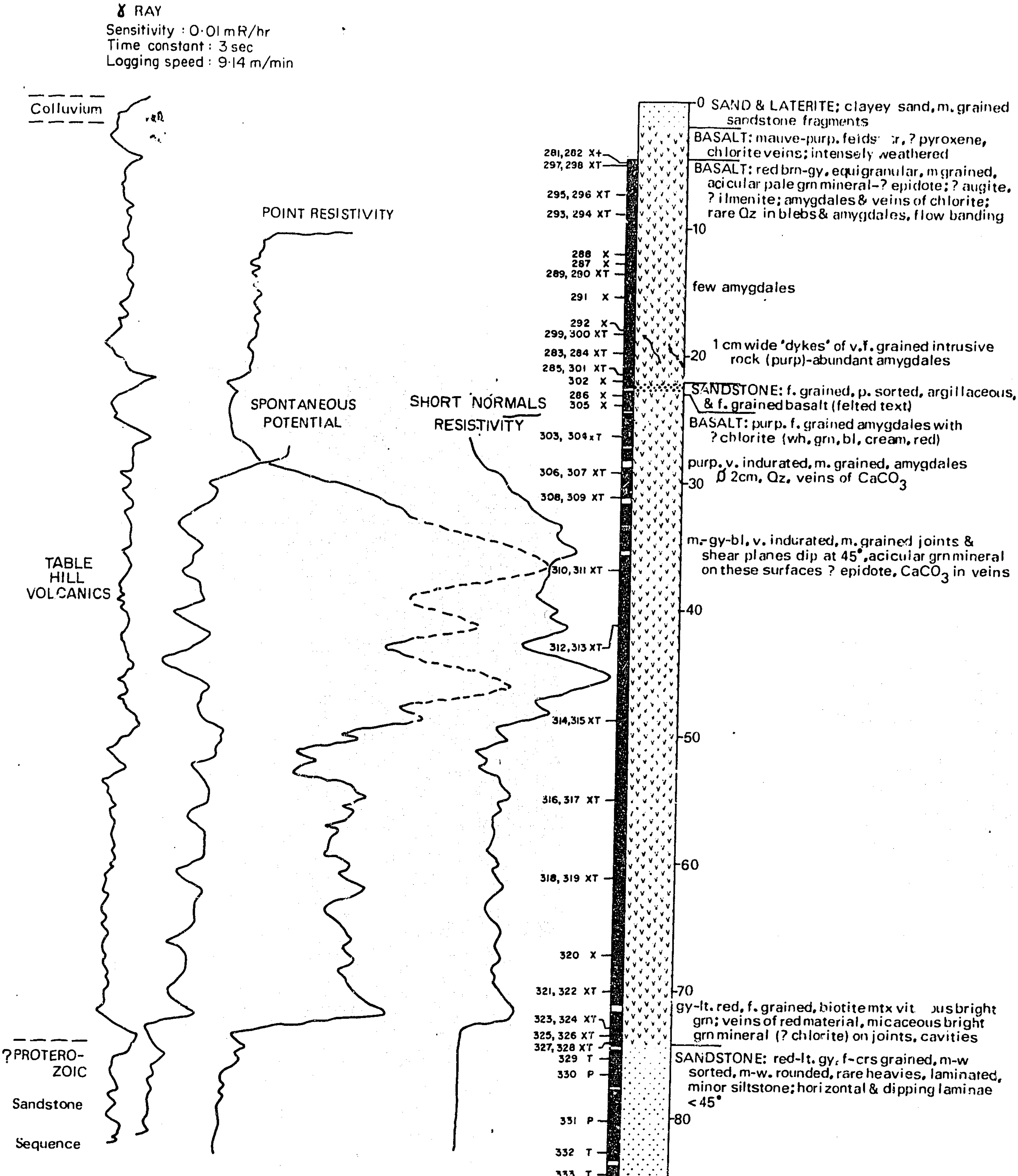
M(S)338



BMR WANNA 1

M(S)339-I

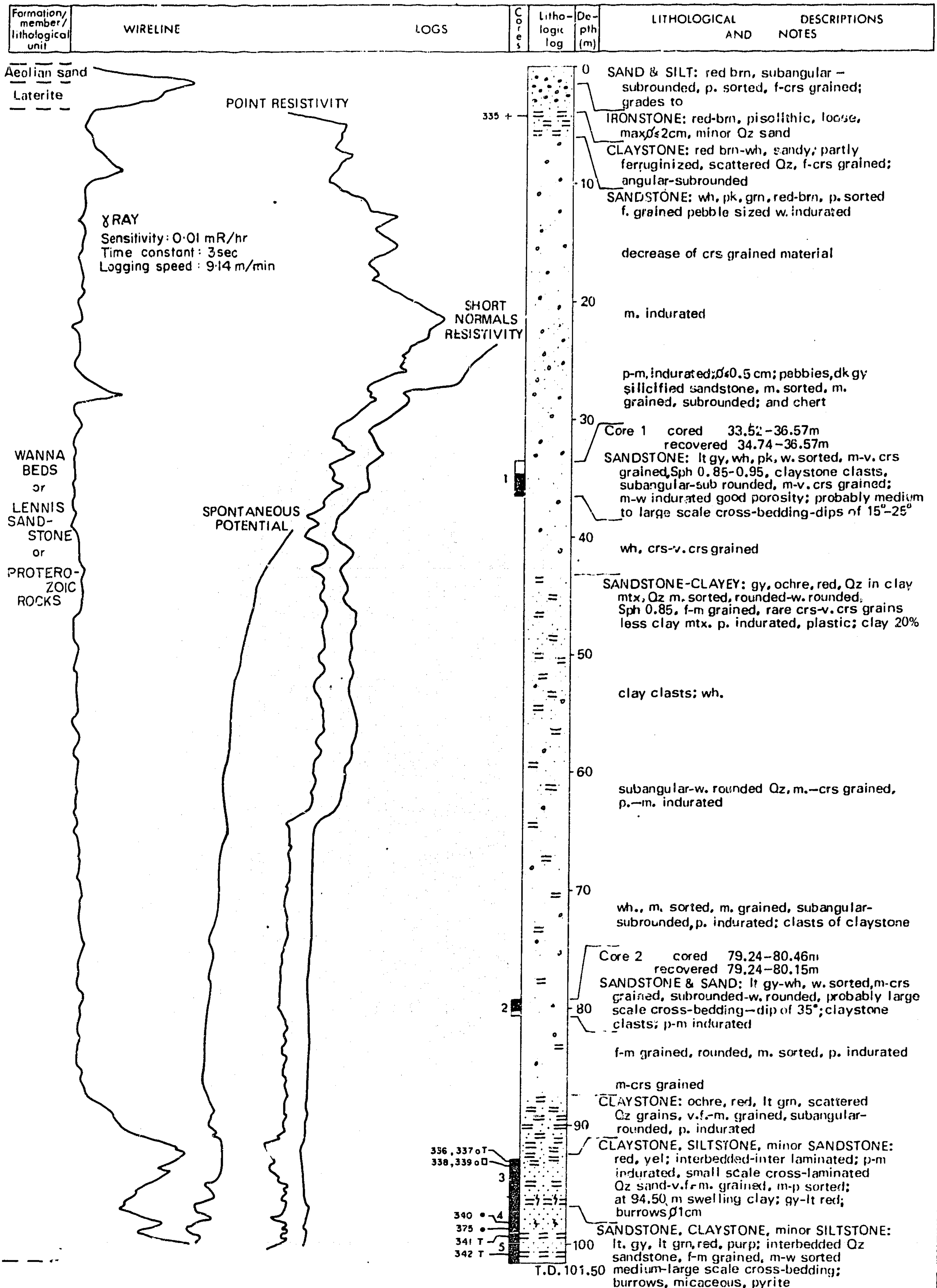
Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES



N.B. Very short intervals of lost core not indicated

BMR WESTWOOD 1

M(S)346

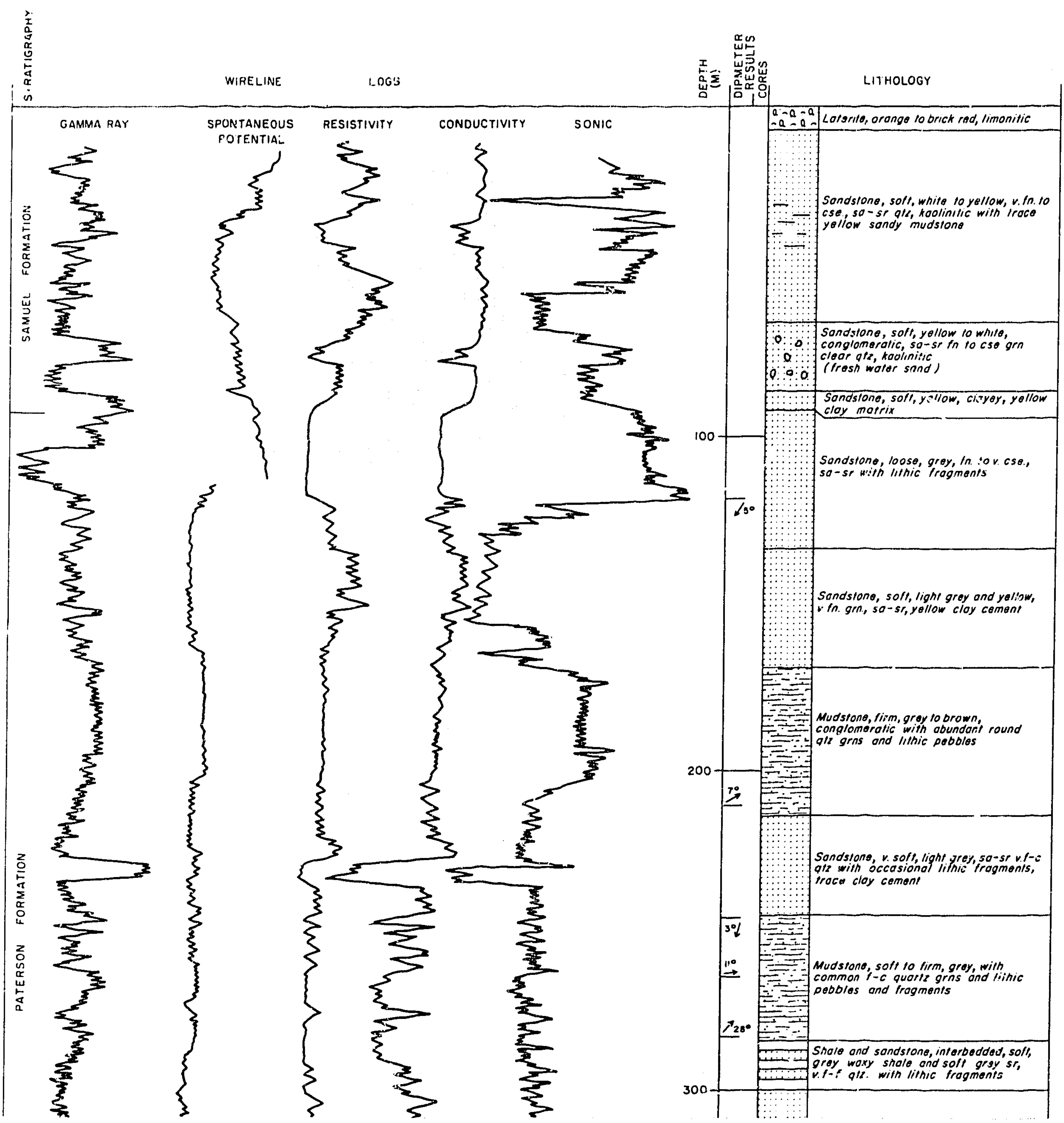


BMR WESTWOOD 2

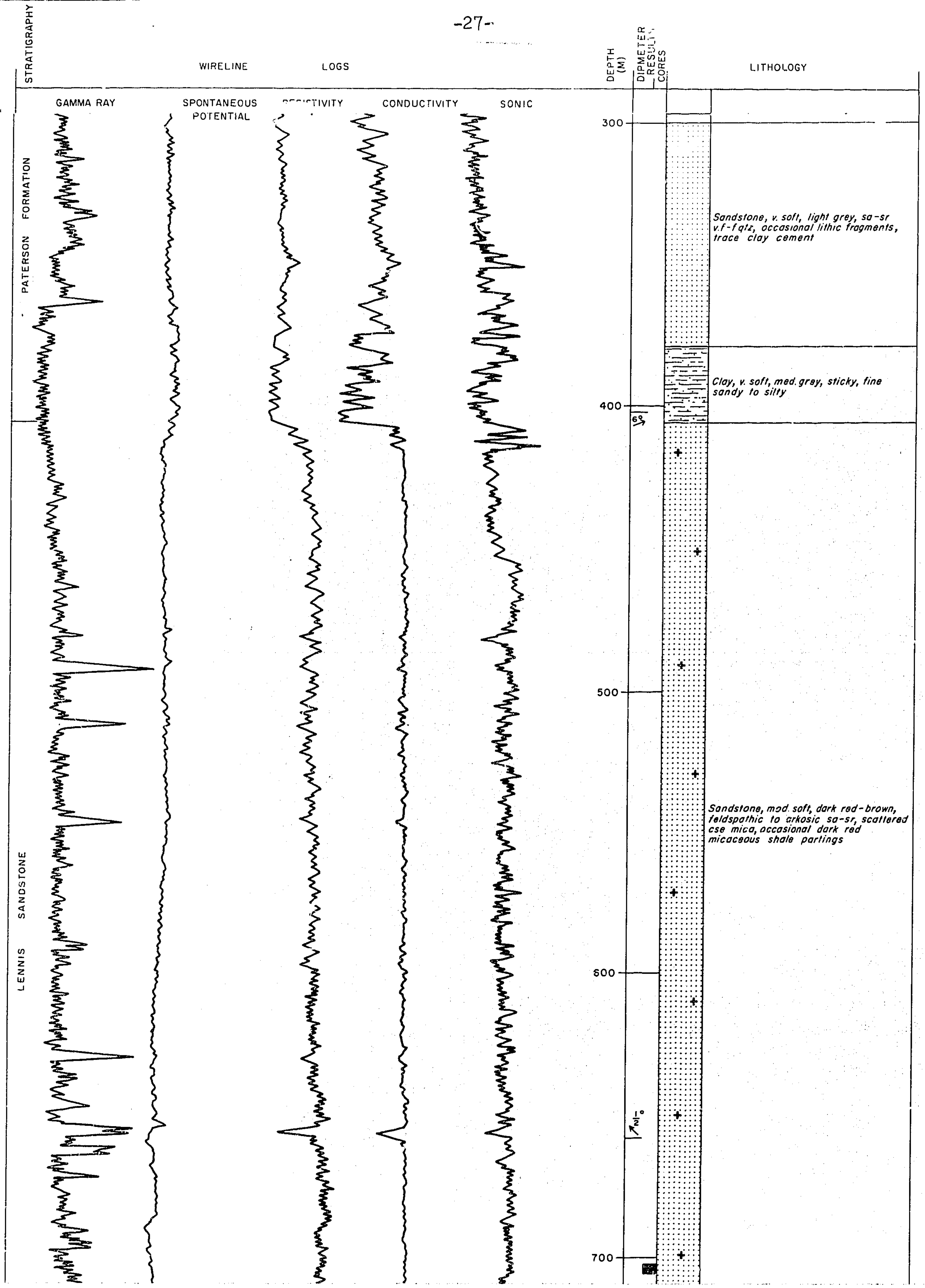
M(S)349

LOCATION Lat 26° 10' 12" S Long 125° 58' 00" E LOGGED BY Schlumberger Seaco Inc DATE SPUDDED 1st March 1966

TOTAL DEPTH : Driller 989.38m E Log 985.11m ELEVATION GL 472.49m DATE COMPLETED: 22nd March 1966

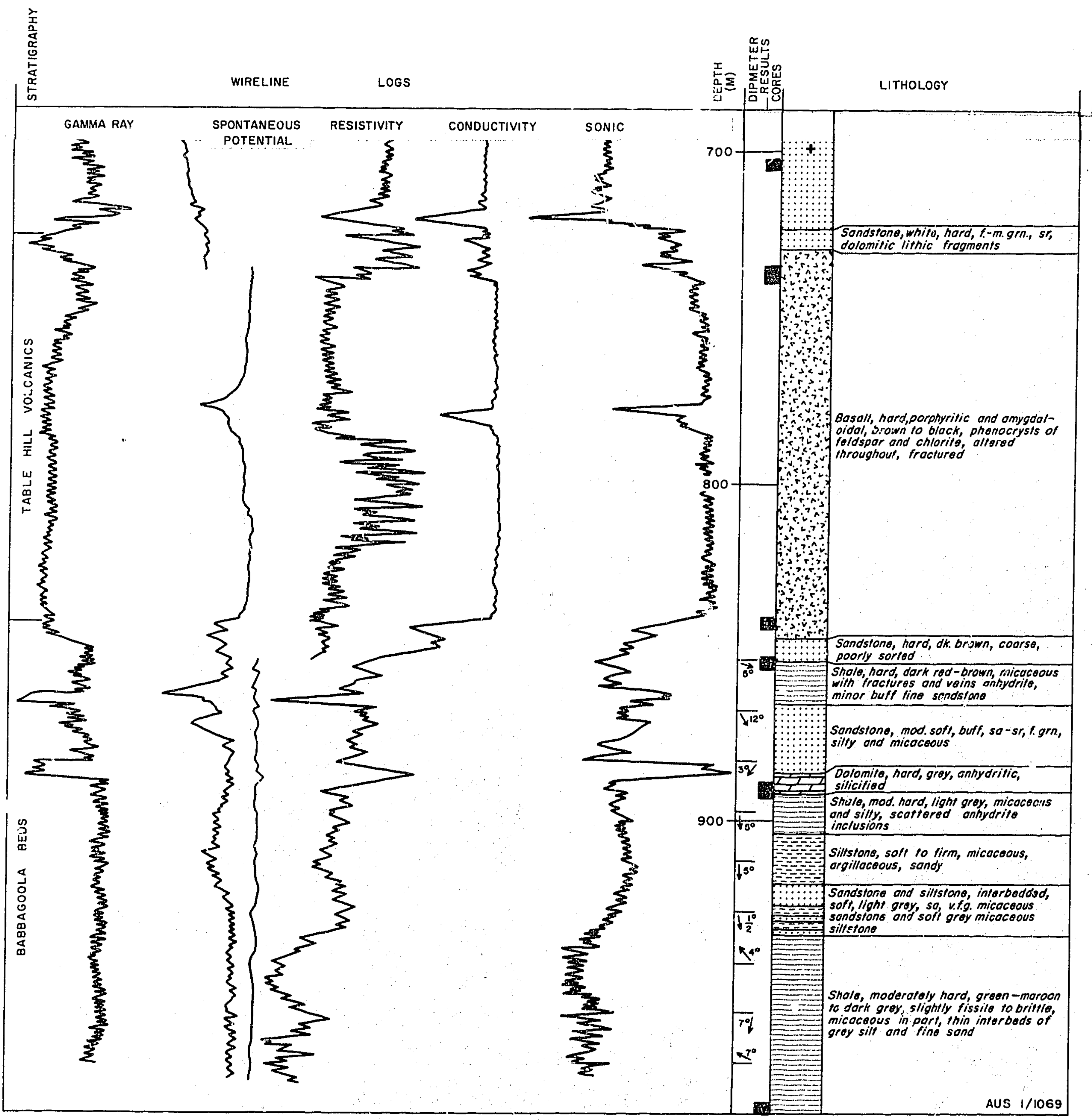


HUNT OIL YOWALGA 2 (0 to 300)
(modified, after Jackson 1966a)



HUNT OIL YOWALGA 2 (300 to 700)

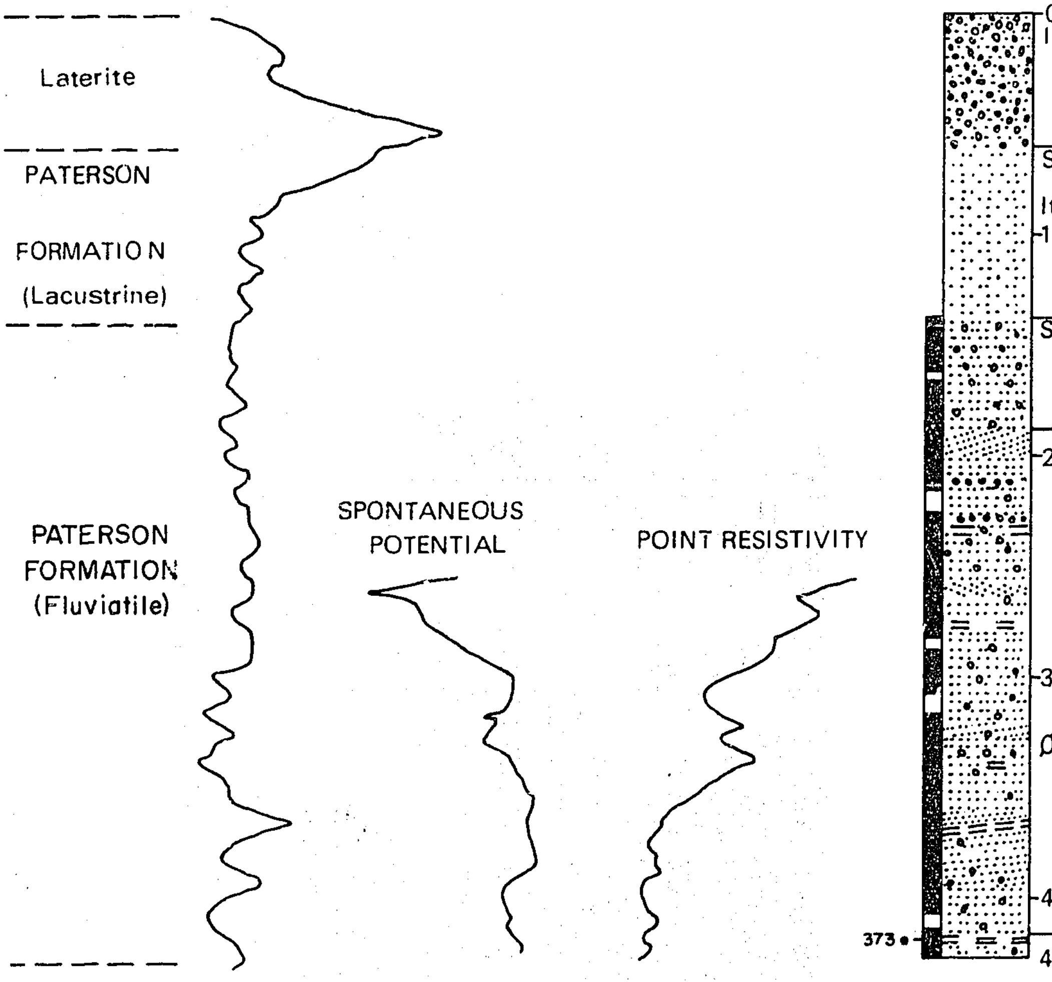
(modified, after Jackson 1966a)



HUNT OIL YOWALGA 2 (700 to END)
(modified, after Jackson 1966a)

Formation/ member/ lithological unit	WIRELINE LOGS	Cores	Litho-logic log	Depth (m)	LITHOLOGICAL DESCRIPTIONS AND NOTES

γ RAY
Sensitivity: 0·02 mR/hr
Time constant: 3 sec
Logging speed: 9·14 m/min



IRONSTONE, SAND & SILT: pisolithic ironstone, mostly densely packed; ferruginized sandstone Qz f-m grained, p. sorted minor crs-v. crs grained, subangular-subrounded. Lower part richer in siltstone & claystone

SILTSTONE: gy-red; v.f.-f. grained Qz in silty mtx, minor micas
lt. gy, pk, purp.

SANDSTONE: wh, red & yel. mottled; f. grained-granule sized, subangular-w. rounded Qz; discontinuous streaks of siltstone, also siltstone clasts Ø ≤ 3cm, irregular & lenticular beds, m-w indurated

SANDSTONE: wh, red, yel, purp, f. grained (rare) -granule sized, scattered pebbles, subangular-rounded, m. sorted, m-w indurated, partly cross bedded-15°-20°, 30°-40°, pebble; oolitic chert minor siltstone & claystone streaks reworked siltstone & clay clasts

Ø ≤ 3cm Qz

42.97 T.D. CLAYSTONE, SILTSTONE & SANDSTONE: wh.-purp., interlaminated

N.B. Short intervals of lost core not indicated

BMR YOWALGA 4

M(S)340

APPENDIX 2 - LOCALITIES OF PLACES & DRILLHOLES MENTIONED IN TEXT

NAME	SHEET	LAT(S)	LONG(E)
Ainslie Gorge	Talbot	26°-14'	126°-38'
Axe Hill	Talbot	26°-22'	126°-47'
Barrow Range	Talbot	26°-14'	127°-27'
Baker Lake	Talbot	26°-47'	126°-02'
Bobbies Point	Neale	28°-59'	124°-40'
Breaden Bluff	Robert	26°-56'	124°-28'
Brown Range	Talbot	26°-10'	126°-35'
Bejah Hill	Runton	23°-46'	124°-09'
Brown 24	Browne	25°-28'	125°-07'
Bullock Bore	Robert	26°-12'	123°-04'
Blackstone Camp	Cooper	26°-01'	128°-22'
BMR Warri 3	Warri	24°-09'	124°-38'
Cooper Creek	Lennis	27°-20'	126°-25'
Clutterbuck Hills	Cobb	24°-35'	126°-19'
Cobb 24	Cobb	24°-53'	127°-21'
Condum Well	Rason	28°-26'	123°-05'
Cundeelee Mission	Cundeelee	30°-43'	123°-25'
Empress Spring	Robert	26°-46'	124°-22'
Dwyer Well	Rason	28°-32'	123°-06'
Deila Well	Rason	28°-05'	123°-06'
Hocking Range	Talbot	26°-21'	127°-26'
Herbert Wash	Yowalga	26°-00'	124°-30'
Hanns Tabletop Hill	Lennis	27°-08'	126°-25'
Homestead Well	Rason	28°-10'	123°-40'
Ida Range	Robert	26°-27'	124°-00'
Jubilee 1	Jubilee	29°-05'	126°-27'
Kapi Kempa	Talbot	Exact Location	
" Papul	Talbot	of Water Holes	
" Narratha	Talbot	Unknown	
Kanandah No. 95	Cundeelee	30°-52'	124°-25'
Lake Wells	Throssell	27°-10'	123°-25'
Lake Hancock	Warri	24°-37'	124°-52'
Lilian Creek Gorge	Talbot	26°-19'	126°-57'

NAME	SHEET	LAT(S)	LONG(E)
Liversey Range	Cooper	26°-40'	127°-32'
Lennis 1	Lennis	27°-06'	126°-03'
" 10	"	27°-13'	127°-25'
" 18	"	27°-13'	127°-16'
" 38	"	27°-13'	127°-16'
" 25	"	27°-21'	126°-26'
" 39	"	27°-09'	126°-25'
Lake Throssell	Throssell	27°-35'	124°-10'
Lake Cohen	Warri	24°-27'	125°-02'
Lake Minigwal	Minigwal	29°-35'	123°-15'
Lake Gruszka	Browne	25°-19'	125°-54'
Lake Keene	Herbert	25°-01'	123°-35'
Lilian Creek Well	Talbot	26°-13'	126°-58'
Limestone Well	Throssell	27°-55'	123°-10'
Lupton Hills	Cooper	26°-30'	128°-00'
Mt Smith	Robert	26°-09'	124°-25'
Mt Beadell	Browne	25°-32'	125°-16'
Mt Venn	Rason	28°-05'	123°-31'
Mt Cumming	Throssell	27°-45'	123°-21'
Mt Elizabeth	Robert	26°-33'	123°-01'
Miller Soak	Rason	28°-09'	124°-16'
Munjil Soak	Rason	28°-13'	123°-40'
Mt Samuel	Browne	25°-46'	125°-56'
Mt Charles	Bentley	25°-44'	126°-11'
Mt Archie	Herbert	25°-33'	123°-15'
Madley 20	Madley	24°-27'	123°-33'
Mason 7	Mason	29°-12'	127°-41'
Mungilli Claypan	Herbert	25°-23'	124°-15'
Midnight Bore	Robert	26°-35'	123°-01'
Mt Everard	Browne	25°-11'	125°-04'
Neale 28	Neale	28°-17'	125°-14'
" 29	Neale	28°-20'	125°-14'
" 7	Neale	28°-42'	126°-52'
NMF 23	Browne	25°-11'	124°-07'
Naries Point	Neale	28°-52'	124°-50'
Neale 14	Neale	28°-52'	124°-49'
Neale Junction	Neale	28°-18'	125°-49'

NAME	SHEET	LAT(S)	LONG(E)
Notabilis Hill	Browne	25°-40'	125°-34'
Neale Junction Well	Vernon	28°-18'	126°-02'
Neale 2	Neale	28°-47'	125°-46'
Ponton Creek	Cundeelee	30°-53'	123°-10'
Point Salvation	Rason	28°-12'	123°-39'
Packhorse Bore	Robert	26°-20'	123°-10'
Plumridge 4	Plumridge	29°-10'	124°-52'
Pink Eye Corner	Seemore	30°-53'	124°-42'
Robert 24	Robert	26°-46'	124°-27'
Rason Lake	Rason	28°-45'	124°-25'
Rason 1	Rason	28°-33'	123°-47'
" 3	Rason	28°-33'	123°-29'
Rabbit Range	Waigen	27°-17'	127'-50'
Robert 69 (Parsons Bluff)	Robert	26°-47'	123°-04'
Rason 12	Rason	28°-50'	123°-29'
" 11	Rason	28°-46'	123°-45'
Rason 2	Rason	28°-33'	124°-02'
Sulphur Knob (Lennis 38)	Lennis	27°-13'	127°-16'
Snake Well	Talbot	26°-13'	126°-52'
Squeakers Hill	Rason	28°-34'	123°-09'
Streich Mound	Cundeelee	30°-28'	123°-41'
Skirmish Hill	Cooper	26°-22'	128°-27'
Stony Point	Rason	28°-06	124°-12'
Salt Creek	Plumridge	29°-28'	125°-06'
Simms Shaft	Talbot	26°-10'	126°-37'
Scrubby Tank	Seemore	30°-43'	124°-47'
Talbot 21	Talbot	26°-12'	126°-35'
" 27	Talbot	26°-16'	126°-38'
" 35	Talbot	26°-22'	126°-47'
Table Hill	Talbot	26°-28'	126°-55'
Traeger Hills	Morris	23°-50'	124°-37'
Townsend Ridges	Talbot	26°-19'	127°-02'
Warburton Mission	Talbot	26°-08'	126°-35'
" Range	Talbot	26°-07'	126°-40'
Woolnough Hills	Warri	24°-00'	124°-35'
Westwood 1	Westwood	27°-48'	125°-51'
" 9	Westwood	27°-55'	123°-36'

NAME	SHEET	LAT(S)	LONG(E)
" 22	Westwood	27°-04'	124°-32'
" 23	Westwood	27'-53'	124°-35'
" 2	Westwood	27°-51'	125°-39'
" 4	Westwood	27°-54'	125°-33'
Waigen 10	Waigen	27°-25'	128°-41'
Wanna Lakes	Wanna	28°-40'	128°-23'
Wanna 3	Wanna	28°-49'	128°-16'
" 7	Wanna	28°-21'	127°-51'
Waigen 6	Waigen	27°-25'	128°-18'
Wingellina Camp	Cooper	26°-04'	128°-57'
Wort Native Well	Throssell	Unknown	
Wanna 1	Wanna	28°-59'	128°-23'
Westwood Bluff	Westwood	27°-47'	125°-31'
Warri 3	Warri	24°-09'	124°-38'
" 11	Warri	24°-06'	124°-53'
Wharton Bore	Robert	26°-29'	123°-10'
Warburton Mission 1	Talbot	26°-07'	126°-35'
" " 2	"	" "	" "
" " 3	"	" "	" "
" " 4	"	" "	" "
" " 5	"	" "	" "
" " 6	"	" "	" "
" " 7	"	" "	" "
" " 8	"	" "	" "
" " 9	"	" "	" "
Watertree Bore	Herbert	25°-43'	123°-06'
Weston Minning 1	Talbot	26°-09'	126°-37'
" " 2	Talbot	" "	" "
Wilkinson Range	Neale	28°-00'	124°-45'
Yamarna (Homestead)	Rason	28°-09'	123°-40'
Young Range	Warri	24°-55'	125°-05'
BMR Browne 1	Browne	25°-32'	125°-16'
BMR Madley 1	Madley	24°-14'	124°-21'
BMR Neale 1	Neale	28°-18'	125°-57'
BMR Neale 2	Neale	28°-48'	125°-46'
BMR Neale 3	Neale	28°-19'	125°-49'

NAME	SHEET	LAT(S)	LONG(E)
BMR Rason 1	Rason	28°-33'	123°-47'
BMR Rason 2	Rason	28°-33'	124°-02'
BMR Rason 3	Rason	28°-33'	123°-30'
BMR Throssell 1	Throssell	27°-16'	124°-24'
BMR Wanna 1	Wanna	28°-22'	127°-38'
BMR Warri 20	Warri	24°-05'	124°-34'
BMR Yowalga 4	Yowalga	26°-50'	125°-38'
Hunt Browne 1	Browne	25°-51'	125°-49'
Hunt Browne 2	Browne	25°-56'	125°-58'
Hunt Lennis 1	Lennis	27°-17'	126°-21'
Hunt Yowalga 1	Yowalga	26°-10'	125°-58'
" " 2	Yowalga	26°-10'	125°-58'
BMR Westwood 1	Westwood	27°-03'	124°-49'
BMR " 2	Westwood	27°-07'	124°-43'

APPENDIX 3

Catalogue of Registered Specimens from the Officer Basin, held at the Bureau of Mineral Resources, Canberra.

Specimens are grouped according to formations, which are arranged alphabetically. The locality listed is the locality shown on the 1:250 000 published map that accompanies the Explanatory Note for that sheet area (only maps covered by this project have these numbers).

Registered No.	Rock type	Formation	Locality
70880013	Claystone	Bejah Claystone	Browne 6
72880074	Sandstone	Bejah Claystone	Madley 23
72880075	Claystone	Bejah Claystone	Herbert 35
72880076	Claystone	Bejah Claystone	Madley 17
72880077	Siltstone	Bejah Claystone	Madley 22
72880079	Claystone	Bejah Claystone	Herbert 24
72880080	Claystone	Bejah Claystone	Browne 11
72880081	Claystone	Bejah Claystone	Browne 15
72880082	Claystone	Bejah Claystone	Browne 25
72880083	Claystone	Bejah Claystone	Browne 24
72880084	Claystone	Bejah Claystone	Robert 28
72880085	Claystone	Bejah Claystone	Robert 53
72880001	Calcedony	Cainozoic unit	Warri 2
72880002	Sandstone	Cainozoic unit	Warri 2
72880003	Chalcedony	Cainozoic unit	Warri 2
72880004	Breccia	Cainozoic unit	Warri 2
72880005	Calcrete	Cainozoic unit	Waigen 15b
72880006	Chalcedony	Cainozoic unit	Warri 10
72880007	Calcrete	Cainozoic unit	Wanna 9
72880008	Chalcedony	Cainozoic unit	Warri 2
72880009	Calcrete	Cainozoic unit	Westwood 15
72880010	Calcrete	Cainozoic unit	Warri 10
72880020	Laterite	Cainozoic unit	Stanley 2
72880021	Laterite	Cainozoic unit	Yowalga 10
72880022	Laterite	Cainozoic unit	Throssell 35
72880023	Laterite	Cainozoic unit	Stanley 2
72880024	Laterite	Cainozoic unit	Birksgate 5
72880025	Laterite	Cainozoic unit	Browne 20

Registered	Rock Type	Formation	Locality
72880026	Laterite	Cainozoic unit	Herbert 10
72880027	Laterite	Cainozoic unit	Lennis 23
72880102	Sandstone	Clutterbuck Beds	Cobb 4
72880133	Sandstone	Clutterbuck Beds	Cobb 3
71880008	Basalt	Kulyong Volcanics	Waigen 10
71880009	Basalt	Kulyong Volcanics	Birksgate 4
71880010	Basalt	Kulyong Volcanics	Birksgate 4
72880039	Basalt	Kulyong Volcanics	Cooper 2
72880040	Basalt	Kulyong Volcanics	Cooper 2
72880041	Basalt	Kulyong Volcanics	Cooper 2
72880042	Basalt	Kulyong Volcanics	Cooper 2
72880043	Quartz Vug	Kulyong Volcanics	Cooper 2
72880044	Basalt	Kulyong Volcanics	Robert 27
72880045	Basalt	Kulyong Volcanics	Waigen 10
72880014	Sandstone	Lampe Beds	Herbert 13
72880015	Sandstone	Lampe Beds	Browne 17
72880016	Sandstone	Lampe Beds	Browne 23
72880017	Sandstone	Lampe Beds	Herbert 22
72880018	Breccia	Lampe Beds	Throssell 27
72880019	Sandstone	Lampe Beds	Cobb 17
70880010	Sandstone	Lennis Sandstone	Lennis 10
72880028	Sandstone	Lennis Sandstone	Talbot 12
72880029	Sandstone	Lennis Sandstone	Waigen 9
72880030	Sandstone	Lennis Sandstone	Waigen 7
72880031	Sandstone	Lennis Sandstone	Wanna 11
72880032	Sandstone	Lennis Sandstone	Waigen 21
72880033	Sandstone	Lennis Sandstone	Talbot 12
72880034	Sandstone	Lennis Sandstone	Lennis 31
72880035	Sandstone	Lennis Sandstone	Lennis 31
72880138	Sandstone	Lupton Beds	Cooper 5
72880011	Limestone	Nullarbor Limestone	Waigen 5
72880013	Sandstone	Nullarbor Limestone	Waigen 5

Registered No.	Rock Type	Formation	Locality
70880002	Sandstone	Paterson Formation	Talbot 5
70880004	Siltstone	Paterson Formation	Neale 3
70880005	Sandstone	Paterson Formation	Rason 2
70880009	Sandstone	Lennis Sandstone	Lennis 10
70880011	Siltstone	Samuel Formation	Browne 1
70880014	Sandstone	Paterson Formation	Herbert 4
72880046	Sandstone	Paterson Formation	Madley 14
72880047	Sandstone	Paterson Formation	Madley 14
72880089	Granite Erratic	Paterson Formation	Herbert 20
72880149	Sandstone	Paterson Formation	Madley 3
72880150	Sandstone	Paterson Formation	Trainor 3
72880151	Conglomerate	Paterson Formation	Madley 8
72880152	Sandstone	Paterson Formation	Madley 16
72880153	Claystone	Paterson Formation	Madley 16
72880154	Sandstone	Paterson Formation	Madley 17
72880155	Claystone	Paterson Formation	Madley 19
72880156	Claystone	Paterson Formation	Madley 18
72880157	Claystone	Paterson Formation	Madley 20
72880158	Sandstone	Paterson Formation	Madley 16
72880159	Claystone	Paterson Formation	Madley 18
72880160	Claystone	Paterson Formation	Herbert 12
72880161	Sandstone	Paterson Formation	Herbert 11
72880162	Siltstone	Paterson Formation	Herbert 33
72880163	Tillite	Paterson Formation	Herbert 20
72880164	Sandstone	Paterson Formation	Herbert 21
72880165	Sandstone	Paterson Formation	Herbert 23
72880166	Tillite	Paterson Formation	Herbert 33
72880167	Sandstone	Paterson Formation	Westwood 18
72880168	Tillite	Paterson Formation	Westwood 20
72880169	Siltstone	Paterson Formation	Westwood 20

Registered No.	Rock Type	Formation	Locality
72880170	Sandstone	Paterson Formation	Westwood 20
72880171	Claystone	Paterson Formation	Westwood 21
72880172	Sandstone	Paterson Formation	Westwood 21
72880173	Sandstone	Paterson Formation	Westwood 21
72880174	Sandstone	Paterson Formation	Warri 28
72880175	Tillite	Paterson Formation	Warri 32
72880176	Sandstone	Paterson Formation	Wanna 8
72880177	Sandstone	Paterson Formation	Robert 41
72880178	Sandstone	Paterson Formation	Talbot 16
72880179	Chert Erratic	Paterson Formation	Throssell 22
72880180	Claystone	Paterson Formation	Robert 46
72880181	Chert	Paterson Formation	Robert 50
72880182	Claystone	Paterson Formation	Robert 32
72880183	Sandstone	Paterson Formation	Rason 9
72880184	Claystone	Paterson Formation	Minigwal 3
72880185	Claystone	Paterson Formation	Neale 17
72880186	Claystone	Paterson Formation	Lennis 24
72880187	Sandstone	Paterson Formation	Lennis 24
72880188	Chert Erratic	Paterson Formation	Stanley 2
72880189	Sandstone	Paterson Formation	Cobb 18
72880190	Sandstone	Paterson Formation	Cooper 5
72880191	Sandstone	Paterson Formation	Cooper 5
72880192	Sandstone	Paterson Formation	Cooper 5
72880193	Sandstone	Paterson Formation	Bentley 4
72880194	Fossil Wood	Paterson Formation	Browne 27
72880195	Conglomerate	Paterson Formation	Herbert 12
70880007	Sandstone	Proterozoic unit	Robert 1
70880008	Chert (oolitic)	Proterozoic unit	Robert 6
70880015	Dolomite	Proterozoic unit	Robert 8
70880016	Dolomite	Proterozoic unit	Robert 8
71880004	Basalt	Proterozoic unit	Kingston -
71880005	Basalt	Proterozoic unit	Kingston -
71880006	Basalt	Proterozoic unit	Kingston -
71880007	Basalt	Proterozoic unit	Kingston -
72880091	Sandstone	Proterozoic unit	Trainor -
72880092	Sandstone	Proterozoic unit	Trainor -

Registered No.	Rock Type	Formation	Locality
72880093	Sandstone	Proterozoic unit	Stanley -
72880094	Basalt	Proterozoic unit	Stanley -
72880095	Sandstone	Proterozoic unit	Madley 13
72880096	Dolomite	Proterozoic unit	Madley 13
72880097	Dolomite	Proterozoic unit	Madley 13
72880098	Dolomite	Proterozoic unit	Madley 13
72880099	Dolomite	Proterozoic unit	Trainor -
72880100	Dolomite	Proterozoic unit	Trainor -
72880101	Sandstone	Proterozoic unit	Madley 12
72880103	Sandstone	Proterozoic unit	Trainor -
72880104	Sandstone	Proterozoic unit	Trainor -
72880105	Haematite	Proterozoic unit	Trainor -
72880106	Dolomite	Proterozoic unit	Trainor -
72880107	Dolomite	Proterozoic unit	Trainor -
72880108a	Sandstone	Proterozoic unit	Trainor -
72880108b	Quartzite	Proterozoic unit	Madley 13
72880109	Chalcedony	Proterozoic unit	Madley 5
72880110	Dolomite	Proterozoic unit	Madley 5
72880111	Dolomite	Proterozoic unit	Madley 5
72880112	Dolomite	Proterozoic unit	Madley 5
72880113	Chert	Proterozoic unit	Robert 39
72880114	Dolomite	Proterozoic unit	Robert 39
72880115	Shale	Proterozoic unit	Robert 39
72880116	Siltstone	Proterozoic unit	Robert 39
72880117	Chert	Proterozoic unit	Robert 40
72880118	Siltstone	Proterozoic unit	Robert 42
72880119	Siltstone	Proterozoic unit	Robert 44
72880120	Sandstone	Proterozoic unit	Robert 21
72880121	Chert	Proterozoic unit	Robert 22
72880122	Chert	Proterozoic unit	Robert 58
72880123	Quartzite	Proterozoic unit	Madley 12
72880124	Dolomite	Proterozoic unit	Madley 13
72880125	Siltstone	Proterozoic unit	Madley 13
72880126	Dolomite	Proterozoic unit	Madley 13
72880127	Dolomite	Proterozoic unit	Madley 13
72880128	Shale	Proterozoic unit	Kingston -

Registered No.	Rock Type	Formation	Locality
72880129	Chert	Proterozoic unit	Kingston -
72880130	Sandstone	Proterozoic unit	Robert 12
72880131	Dolomite	Proterozoic unit	Robert 12
72880132	Sandstone	Proterozoic unit	Robert 12
72880134	Chert	Proterozoic unit	Birksgate -
72880135	Conglomerate	Proterozoic unit	Birksgate -
72880136	Siltstone	Proterozoic unit	Birksgate -
72880140	Dolomite	Proterozoic unit	Throssell 27
72880141	Dolomite	Proterozoic unit	Throssell 27
72880142	Dolomite	Proterozoic unit	Throssell 27
72880143	Dolomite	Proterozoic unit	Warri 16
72880144	Siltstone	Proterozoic unit	Warri 18
72880145	Gypsum	Proterozoic unit	Warri 18
72880146	Sandstone	Proterozoic unit	Warri 20
72880147	Siltstone	Proterozoic unit	Waigen 13
72880148	Shale	Proterozoic unit	Robert 40
70880001	Sandstone	Samuel Formation	Yowalga 6
70880003	Sandstone	Samuel Formation	Westwood 1
70880012	Siltstone	Samuel Formation	Browne 5
72880056b	Sandstone	Samuel Formation	Westwood 13
72880057	Sandstone	Samuel Formation	Westwood 13
72880058	Chalcedony	Samuel Formation	Herbert 21
72880059	Siltstone	Samuel Formation	Herbert 16
72880060	Sandstone	Samuel Formation	Herbert 16
72880061	Siltstone	Samuel Formation	Herbert 21
72880062	Sandstone	Samuel Formation	Bentley 1
72880063	Siltstone	Samuel Formation	Browne 23
72880064	Claystone	Samuel Formation	Madley 19
72880065	Siltstone	Samuel Formation	Bentley -
72880066	Siltstone	Samuel Formation	Westwood 11
72880067	Sandstone	Samuel Formation	Browne 33
72880068	Sandstone	Samuel Formation	Cobb 14
72880069	Sandstone	Samuel Formation	Browne 16
72880070	Siltstone	Samuel Formation	Browne 22
72880071	Sandstone	Samuel Formation	Yowalga 9
72880072	Sandstone	Samuel Formation	Browne 22
72880073	Sandstone	Samuel Formation	Bentley 3

Registered No.	Rock Type	Formation	Locality
70880006	Basalt	Table Hill Volcanics	Robert 2
71880001	Basalt	" " "	Robert 33a
71880002	Basalt	" " "	Robert 33a
71880003	Basalt	" " "	Robert 33a
72880036	Basalt	" " "	Robert 21
72880037	Sandstone	" " "	Robert 21
72880038	Sandstone	" " "	Robert 21
71880011	Basalt	" " "	Talbot 19
71880012	Basalt	" " "	Talbot 19
72880137	Quartzite	Townsend Quartzite	Cooper 1
72880139	Quartzite	Townsend Quartzite	Talbot 9
72880012	Sandstone	Wanna Beds	Waigen 7
72880048	Sandstone	Wanna Beds	Wanna 1
72880049	Sandstone	Wanna Beds	Wanna 5
72880050	Sandstone	Wanna Beds	Waigen 1
72880051	Sandstone	Wanna Beds	Waigen 2
72880052	Sandstone	Wanna Beds	Waigen 4
72880053	Sandstone	Wanna Beds	Lennis 17
72880054	Sandstone	Wanna Beds	Lennis 17
72880055	Sandstone	Wanna Beds	Waigen 18
72880056a	Sandstone	Wanna Beds	Waigen 6
72880086	Dolerite	Yilgarn Block	Minigwal 1
72880087	Granite	Yilgarn Block	Minigwal 2
72880088	Granite	Yilgarn Block	Minigwal 3
72880090	Gneiss	Yilgarn Block	Throssell 12

APPENDIX 4

Results of X-ray Diffraction Analyses of Selected Samples

(For accurate locations refer to Appendix 3).

Sample No.	Rock Type	Mineralogy	Formation if available
71880003	Basalt	Feldspar, diopside, quartz, kaolinite.	Table Hill Volcanics
72880001	Calcrete	Opal C-T	Unnamed (Cainozoic)
72880003	Chalcedony	Kaolinite, quartz.	" "
72880004	Breccia	Quartz, kaolinite, mica.	" "
72880005	Calcrete	Calcite, quartz, dolomite	" "
72880006	Chalcedony	Quartz, kaolinite, calcite	" "
72880007	Calcrete	Dolomite, quartz, kaolinite	" "
72880008	Chalcedony	Kaolinite, quartz, opal C-T	" "
72880009	Calcrete	Calcite, quartz	" "
72880010	Calcrete	Calcite, quartz, kaolinite	" "
72880015	Sandstone	Quartz, hematite, anatase	Lampe Beds
72880016	Sandstone	Quartz, kaolinite	" "
72880017	Sandstone	Quartz, anatase	" "
72880018	Breccia	Quartz	" "
72880019	Sandstone	Quartz, goethite, kaolinite	" "
72880020	Laterite	Quartz, goethite, kaolinite	Unnamed (Cainozoic)
72880021	"	Quartz, lithiophorite, kaolinite	" "
72880022	"	Quartz, goethite, hematite, kaolinite	" "
72880023	"	Quartz, goethite, hematite	" "
72880024	"	Quartz, goethite, anatase	" "
72880025	"	Goethite, kaolinite, quartz	" "
72880026	"	Kaolinite, goethite, quartz	" "
72880027	"	Hematite, goethite, kaolinite	" "
72880028	Sandstone	Kaolinite, quartz, mica, hematite	Lennis Sst
72880029	"	Quartz, goethite	" "
72880039	"	Quartz, mica, feldspar, hematite	" "
72880040	Basalt	Feldspar (Sanidine?), hematite, montmorillonite	Table Hill Volcanics
72880043	Quartz Vug	Quartz, hematite	" " "
72880045	Basalt	Feldspar, quartz, diopside.	" " "
72880048	Sandstone	Quartz, feldspar, mica, kaolinite, diopside.	Wanna Beds
72880049	"	Quartz, goethite, kaolinite.	" "
72880058	Chalcedony	Opal C-T, kaolinite, quartz.	Samuel Formation
72880059	Siltstone	Quartz, kaolinite, opal C-T, mica.	" "
72880060	Sandstone	Quartz, opal C-T, kaolinite, mica	Samuel Formation
72880061	Siltstone	Opal C-T, quartz, kaolinite	" "
72880062	Sandstone	Quartz, opal C-T,	" "
72880063	Siltstone	Opal C-T, quartz	" "
72880064	Claystone	Opal C-T, kaolinite, quartz	" "
72880065	Siltstone	Opal C-T, quartz, kaolinite	" "
72880066	Siltstone-Lateratised	Kaolinite, hematite, goethite	" "
72880073	Sandstone	Quartz, hematite, kaolinite	" "
72880074	Sandstone	Quartz, kaolinite	Bejah Claystone
72880075	Claystone	Opal C-T, quartz, kaolinite	" "
72880076	"	Opal C-T, kaolinite, quartz, bementite	" "
72880078	"	Quartz, kaolinite, mica	" "
72880080	"	Opal C-T, quartz, kaolinite	" "
72880082	"	Opal C-T, quartz, kaolinite	" "
72880083	"	Opal C-T, quartz, kaolinite	" "
72880084	"	Quartz, opal C-T, kaolinite	" "
72880085	"	Opal C-T, quartz, kaolinite, mica	" "

Sample No.	Rock Type	Mineralogy	Formation (if available)
72880087	Granite	Kaolinite, quartz, halite, mica	Yilgarn Block
72880088	"	Kaolinite, quartz, mica	" "
72880089	"	Kaolinite, quartz, feldspar, mica	Paterson Formation
72880094	Basalt	Feldspar, quartz, magnetite, mica	(Unnamed) Proterozoic Unit
72880096	Dolomite	Quartz, dolomite	" " "
72880099	"	Dolomite, quartz, calcite, feldspar, mica	" " "
72880105	Haematite	Goethite, quartz	" " "
72880106	Dolomite	Dolomite, quartz	" " "
72880110	"	Dolomite, quartz, calcite	" " "
72880115	Shale	Quartz, kaolinite, mica	" " "
72880116	Siltstone	Quartz, kaolinite, mica	" " "
72880118	"	Quartz, kaolinite, mica, feldspar	" " "
72880119	"	Quartz, kaolinite, mica.	" " "
72880125	"	Quartz, feldspar, opal $^{C-T}$, mica, diopside.	" " "
72880128	Shale	Quartz, hematite, mica.	" " "
72880131	Dolomite	Calcite, quartz, garnet (almandine?), mica.	" " "
72880136	Siltstone	Quartz, kaolinite, mica, anatase	" " "
72880148	Shale	Quartz, kaolinite, feldspar, mica, hematite.	" " "
72880153	Claystone	Quartz, kaolinite, mica.	Paterson Formation
72880155	Claystone	Quartz, kaolinite, mica.	" "
72880156	Claystone	Quartz, kaolinite, mica	Paterson Formation
72880157	"	Quartz, opal $^{C-T}$, kaolinite	" "
72880159	"	Quartz, kaolinite, mica	" "
72880160	"	Kaolinite, quartz, mica	" "
72880162	Siltstone	Quartz, feldspar, kaolinite, halite.	" "
72880165	Claystone	Quartz, kaolinite, mica	" "
72880168	Tillite	Quartz, kaolinite, mica	" "
72880171	Claystone	Quartz, kaolinite, halite, mica	" "
72880174	Sst. Ironst.	Goethite, quartz	" "
72880180	Claystone	Quartz, opal $^{C-T}$, kaolinite, halite, mica	" "
72880184	"	Kaolinite, quartz, opal $^{C-T}$, mica	" "
72880185	"	Goethite, quartz	" "
72880189	Sandstone	Quartz, hematite	" "

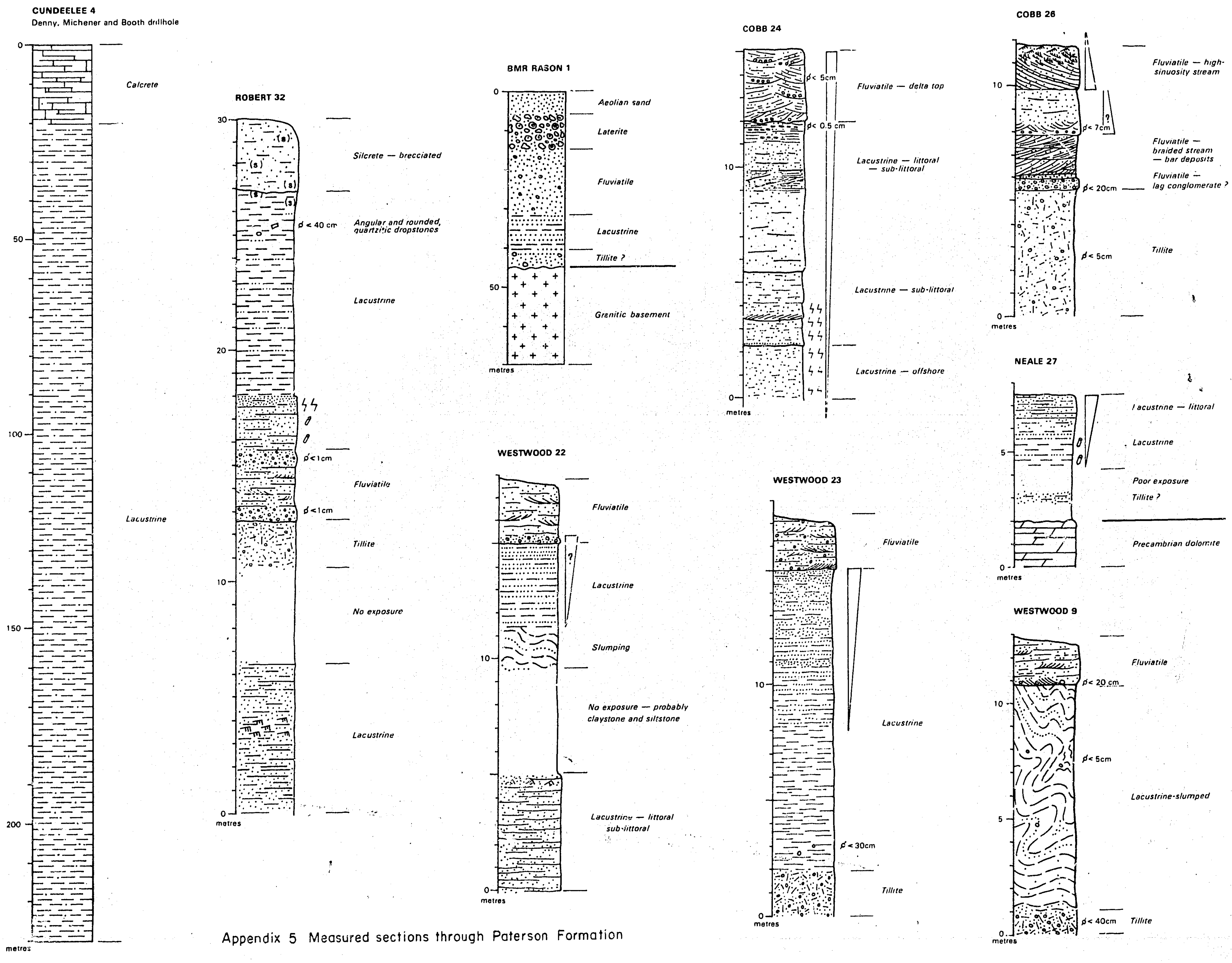
<u>Note:</u> Anatase ' TiO_2

Bementite $H_{10}Mn8\ Si_7\ O_{27}$

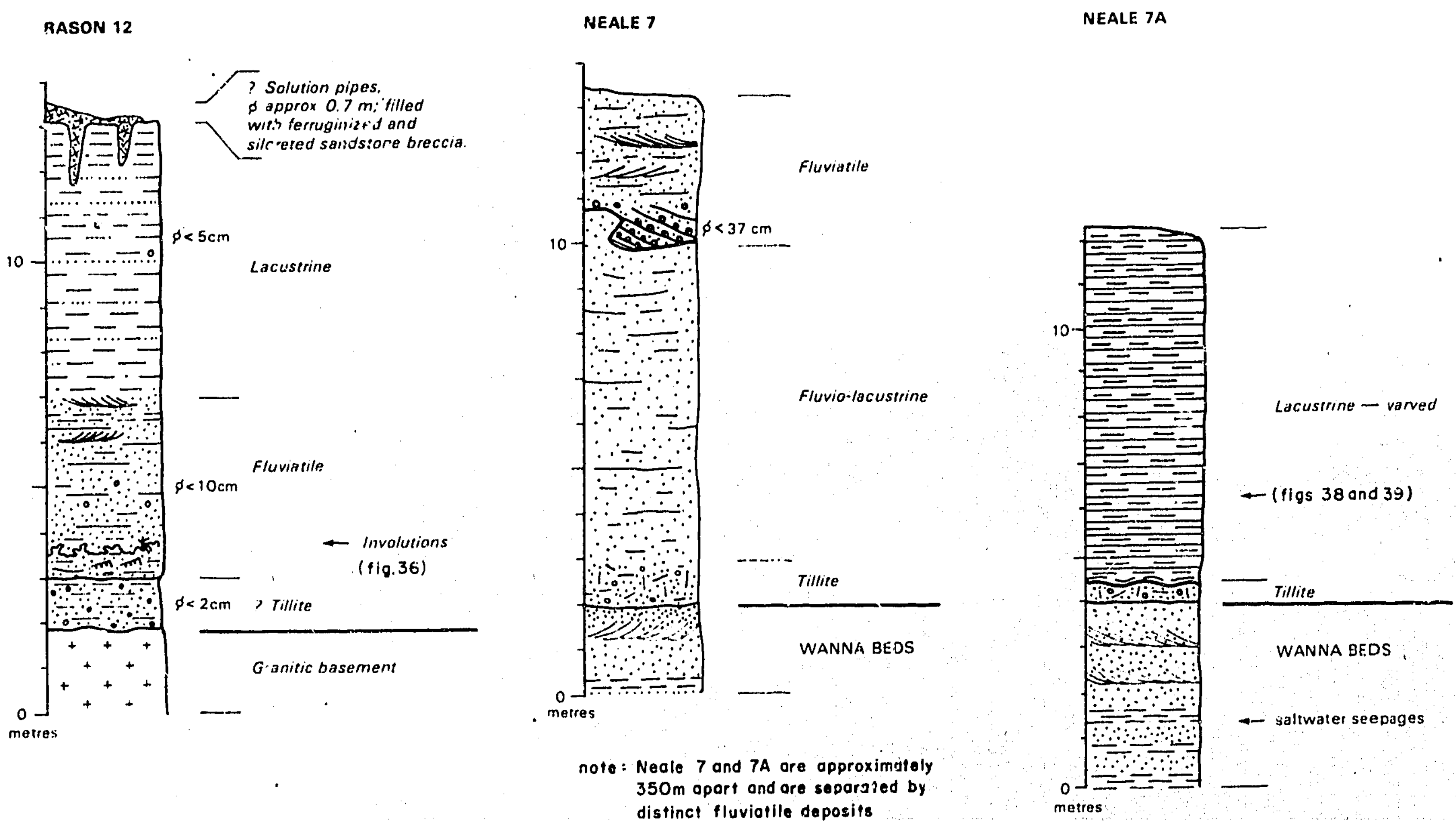
Lithiophorite $(Li, Al) MnO_2 (OH)_2$

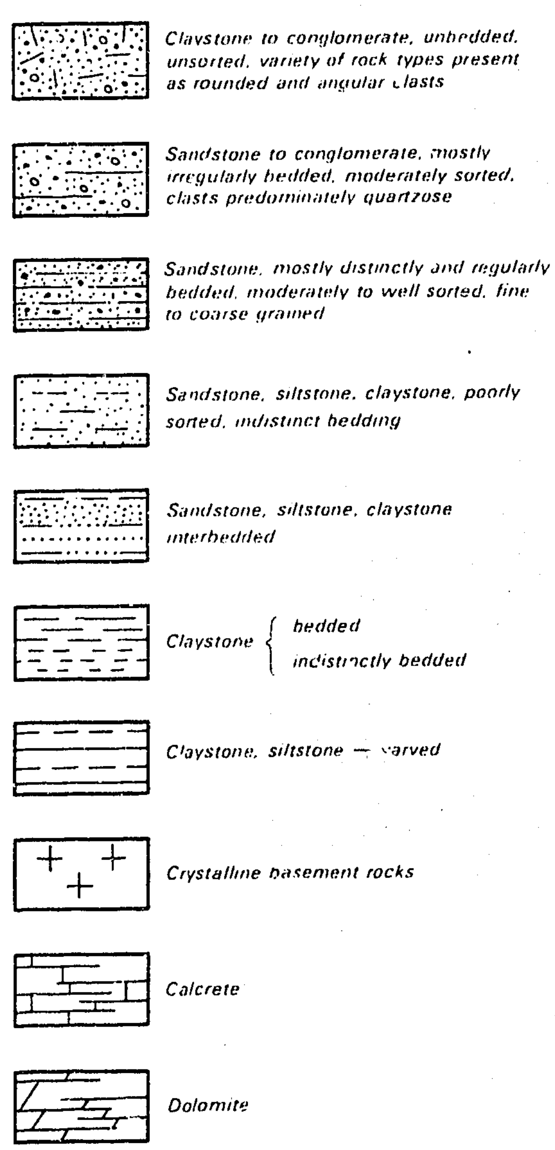
Opal $^{C-T}$ $SiO_2 \times H_2O$ (Jones & Segnit, 1971)

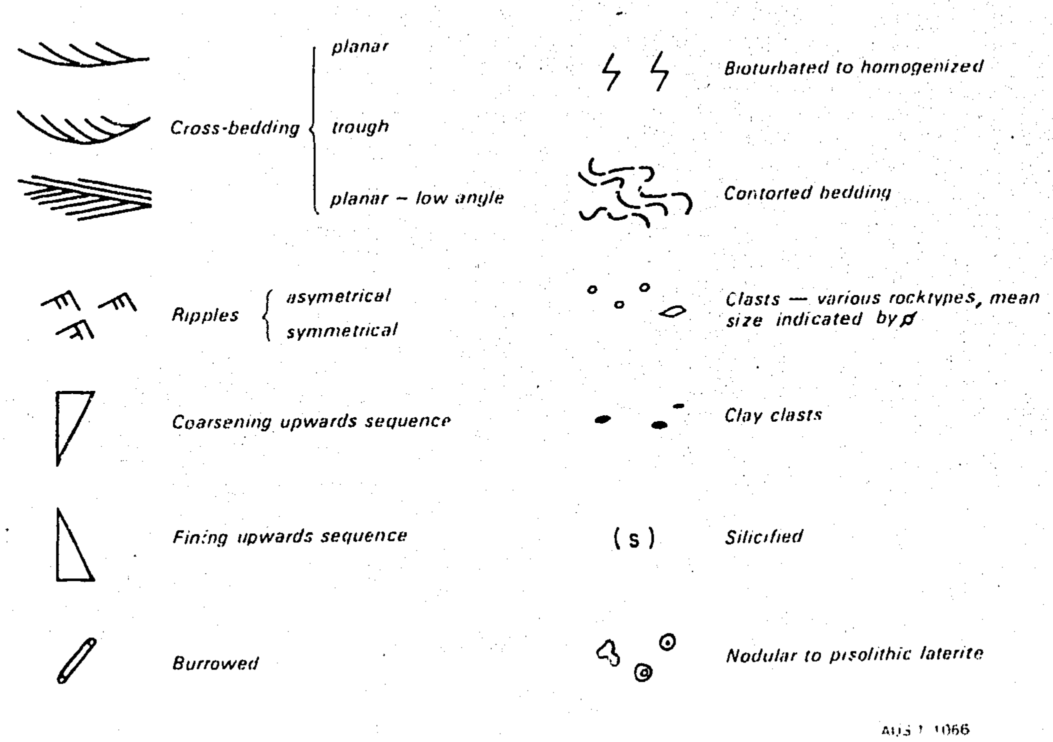
Analyses by G. Berryman



Appendix 5 Measured sections through Paterson Formation







Appendix 5 Measured sections through Paterson Formation

APPENDIX 6 CATALOGUE OF DRILL HOLE SAMPLES ANALYSED OR EXAMINED IN CANBERRA

The specimens listed below were selected for additional examination following the finish of the drilling program. The samples are listed in numerical order under the BMR sample registration number. All the samples listed below have been cross-indexed with the drill hole logs (Figs. 2-19); on the logs they are shown immediately to the left of the lithological column by a symbol (see Fig. 2) and the registered number (excluding the first five digits). All samples are from cores unless otherwise indicated. The depth shown is for the midpoint of the core piece. Registered numbers are bracketed together where the sample was taken from the case core specimen. ND - indicated work not done.

REGISTERED NUMBER	DRILLHOLE	DEPTH (metres)	FORMATION OR ROCK TYPE	REASON SAMPLE TAKEN	REMARKS/RESULTS ETC.
73880177	Rason 1	7.62 to 10.67	Laterite (cuttings)	chem. analysis for U, Th, Al_2O_3, Fe_2O_3 SiO_2.	see Table 2 for results
178	Rason 2	8.00	Laterite (cuttings)	"	
179	"	98.15	Paterson Fm (grey clayey siltstone)	chem. analysis for Th, U,	
180	"	99.06	" "	Ca, B, Ga, Cu, Li, K, Sr,	
181	"	99.37	" "	Fe, Mn, Mi (clay fraction only)	see Table 3 for results
182	"	110.92	" "		
183	"	111.20	" "		
184	"	111.63	" "		
185	"	111.10	" "	slabbing for photography	
186	"	143.63	" (lithic sandstone; tillitic)	chem. analysis as 179	
187	"	143.75	" "	" " "	see Table 3 for results
188	"	145.00	" "	slabbing	
189	Rason 3	0 to 1.50	Laterite (cuttings)	chem. analysis as 177	see Table 2 for results
190	Neale 1	67.40	Wanna Beds (grey fine sst)	thin section	
191	"	67.80	" "	permeability/porosity	see Table 4
192	"	68.00	" "	sieve analysis	N.D.
193	"	111.94	" "	thin section	
194	"	112.58	" "	permeability/porosity	see Table 4
195	"	113.07	" "	thin section	
196	"	113.39	" "	sieve analysis	N.D.
197	"	114.18	" "	permeability/porosity	see Table 4
198	"	179.96	Lennis Sandstone (red fine quarzt sst)	thin section	
199	"	180.40	" "	seive analysis	N.D.
200	"	202.96	" "	thin section	
201	"	203.27	" "	permeability/porosity	see Table 4
202	"	203.36	" "	thin section	
203	"	203.77	" "	permeability/porosity	see Table 4
204	"	203.97	" "	thin section	
205	Neale 2	56.63	Paterson Fm (laminated grey claystone)		
206	"	56.93	" "		
207	"	57.51	" "	chem. analysis as for 179	see Table 3 for results
208	"	58.02	" "		
209	"	58.95	" "		
210	Wanna 1	2.00	Laterite (cuttings)	chem. analysis as for 177	see Table 2 for results
211	"	28.98	Paterson Fm (lithic silty carbonaceous wacke)	thin section	
212	"	29.03	" "	sieve analysis	N.D.
213	"	29.44	" "	thin section	
214	"	29.46	" "	thin section	
215	"	29.52	" "	sieve analysis	N.D.
216	"	29.90	" "	large thin section	
217	"	30.63	" "	sieve analysis	N.D.
218	"	30.93	" "	thin section	
219	"	31.25	" "	palynology	N.D.
220	"	30.85	" "	permeability/porosity	see Table 4
221	Talbot 1	33.06	Townsend Quartzite (sandstone)	thin section	
222	Talbot 2	13.10	Alluvial conglomerate	mineralogy	XRD - Goethite
223	Talbot 4	67.20	Lefroy Beds (fine brown sst)	large thin section	

REGISTERED NUMBER	DRILLHOLE	DEPTH (metres)	FORMATION OR ROCK TYPE	REASON SAMPLE TAKEN	REMARKS/RESULTS ETC.
73880224	Talbot 3	76.20	Lefroy Beds (" " ")	thin section	
225	"	76.32	Lefroy Beds (green silty sst)	"	
226	"	77.03	" (red/brown silty sst)	"	
227	"	77.17	" (" " " ")	"	
228	Talbot 5	93.00	Lupton Beds (lithic claystone,tillite)	petrology	
229	Browne 1	10.97	Bejah Claystone (pink claystone)	thin section	
230	"	"	" "	mineralogy	XRD - Quartz, kaolinite (~2:1)
231	"	"	" "	chem. analysis	
232	"	"	" "	palynology	N.D.
233	"	13.69	" (pale purple claystone)	mineralogy	XRD - Quartz, kaolinite (~5:1)
234	"	"	" "	palynology	Barren
235	"	20.40	" (pink claystone)	chem. analysis	
236	"	"	" "	palynology	N.D.
237	"	"	" "	mineralogy	XRD - Quartz, kaolinite (~2:1)
238	Browne 1	22.53	Bejah Claystone (white claystone)	thin section	
239	"	"	" "	palynology	N.D.
240	"	25.90	" (white/purple mottled claystone)	thin section	
241	"	"	" "	palynology	N.D.
242	"	"	" "	chem. analysis	
243	"	38.68	Samuel Formation (sandstone)	large thin section	
244	"	8.71	Bejah Claystone (pink sandstone)	palynology	N.D.
245	"	"	" "	mineralogy	XRD - Quartz, kaolinite (~7:1)
246	"	"	" "	chem. analysis	
247	"	"	" "	thin section	
248	"	46.56	Samuel Fm (grey brown claystone)	palynology	N.D.
249	"	48.77	" "	"	N.D.
250	"	52.12	" (yellow/brown siltstone)	"	N.D.
251	"	54.86	" " "	"	N.D.
252	"	58.22	" (micaeous " ")	"	N.D.
253	"	60.66	" (yellow brown silty sandstone)	"	N.D.
254	"	64.01	" (yellow brown siltstone)	palynology	N.D.
255	"	"	" " " "	thin section	
256	"	67.06	Samuel Fm (yellow brown silty sandstone)	palynology	N.D.
257	"	69.19	" (khaki claystone & siltstone)	"	N.D.
258	"	70.41	" (brown silty sandstone)	palynology	Spores,pollen and microplankton abundant.
259	"	"	" " " "	thin section	
260	"	73.46	"(dark grey/brown clayey siltstone)	palynology	Spores, pollen and microplankton abundant Late Aptian.
261	"	78.64	" "	"	"
262	"	82.91	" "	"	N.D.
263	"	84.43	" (micaeous " ")	"	"
264	"	89.00	" "	"	Palynomorphs abundant, but fragmented
265	"	90.83	" (grey micaeous, silty claystone)	"	Palynomorphs abundant, well preserved
266	"	95.71	" "	"	Palynomorphs fragmented
267	"	99.14	" (brown & grey sandy siltstone)	"	Palynomorphs common, fragmented
268	"	100.89	" (fine well sorted grey sst)	"	"
269	"	103.63	" "	"	N.D.
270	"	106.68	" (grey sandy siltstone)	palynology	Palynomorphs common, well preserved
271	"	"	" "	thin section	
272	"	106.00	" (silty sandstone, glauconitic)	large thin section	
273	"	108.20	" (brown clay with sand)	palynology	Palynomorphs common, well preserved
274	"	108.59	" "	"	barren
275	"	108.97	" "	"	Very rare dinoflagellatae, some woody
276	"	109.00	" (hard ferruginous silty sst)	mineralogy	XRD - 276a, Quartz, vermadite (MnO(OH$_2$) (1:1). 276a Quartz, Hematite (~3:1).
277	"	"	" "	thin section	
278	"	109.07	Paterson Fm? (grey quartz sst with clay)	palynology	Barren
279	"	114.08	" (grey silty feldspathic? sandstone)	large thin section	
280	"	114.30	" (grey coarse sandstone)	palynology	N.D.
281	Westwood 1	4.67	Table Hill Volcanics (white zeolite?)	mineralogy	XRD - Muscovite, kaolinite (~1:1). White clayey band/vein near top of upper flow.
282	"		" "	chem. analysis	282 to 327 see Table 5
283	"	19.81	" (purple basalt)	chem. analysis	massive basalt from middle of up flow.
284	"	"	" "	thin section	

REGISTERED NUMBER	DRILLHOLE	DEPTH (metres)	FORMATION OR ROCK TYPE	REASON SAMPLE TAKEN	REMARKS/RESULTS ETC.
73880285	Westwood 1	21.34	Table Hill Volcanics (purple basalt)	chem. analysis	amygdaloidal and vesicular basal from top of lower flow.
286	"	23.16	" (amygdaloidal basalt)	"	
287	"	12.80	" (medium-grained greenish purple basalt)	"	
288	"	12.19	" "	"	
289	"	13.72	" "	"	massive basalt from middle part of upper flow.
290	"	"	" "	thin section	
291	"	15.54	" "	chem. analysis	
292	"	17.98	" "	"	
293	"	9.07	" "	"	
294	"	"	" "	thin section	greenish purple basalt from upper part of upper flow, (rare amygdales)
295	"	7.32	" "	chem. analysis	
296	"	"	" "	thin section	
297	"	4.88	" "	chem. analysis	
298	"	"	" "	thin section	
299	"	18.29	" (red spilite? vein)	chem. analysis	red aphanitic vein intruding upper flow.
300	"	"	" "	thin section	
301	"	21.34	" (amygdaloidal basalt)	thin section	amygdaloidal basalt from near base of upper flow.
302	"	21.79	" "	chem. analysis	
303	"	26.37	" "	"	
304	"	"	" "	thin section	altered, amygdaloidal and vesicular basalt from upper part of lower
305	"	24.08	" "	chem. analysis	
306	"	29.26	" "	chem. analysis	
307	"	"	" "	thin section	
308	"	32.00	" "	chem. analysis	
309	"	"	" "	thin section	
310	"	36.58	" (massive basalt)	chem. analysis	
311	"	"	" "	thin section	
312	Westwood 1	42.67	Table Hill Volcanics (massive basalt)	chem. analysis	
313	"	"	" "	thin section	
314	"	48.77	" "	chem. analysis	
315	"	"	" "	thin section	massive, medium to fine-grained, grey to purple basalt from middle of lower flow; rare green and brown discolouration.
316	"	54.86	" "	chem. analysis	
317	"	"	" "	thin section	
318	"	60.96	" "	chem. analysis	
319	"	"	" "	thin section	
320	"	67.06	" "	chem. analysis	
321	"	70.10	" "	"	
322	"	"	" "	thin section	
323	"	72.85	" "	chem. analysis	
324	"	"	" "	thin section	
325	"	73.46	" "	chem. analysis	
326	"	"	" "	thin section	amygdaloidal basalt from lower part of lower flow; red and cream intrusive veinlets included in specimen 326.
327	"	74.07	" "	chem. analysis	
328	"	"	" "	thin section	
329	"	75.16	unknown (coarse red sst)	large thin section	
330	"	76.40	" "	permeability/porosity	see Table 4
331	"	80.13	" "	"	see Table 4
332	"	82.60	" (brown medium sst)	thin section	
333	"	84.43	" (white " ")	"	
334	"	32.00	Table Hill Volcanics	chem. analysis	(identical to 308 check analysis)
335	Westwood 2	4.00	Laterite (cuttings)	chem. analysis	see Table 2
336	"	93.27	unknown (red silty sst)	palynology	N.D.
337	"	"	" "	thin section	
338	"	93.42	" (yellow sst)	palynology	N.D.
339	"	"	" "	conodonts	Barren
340	"	98.45	" (grey-green siltstone)	palynology	Barren
341	"	99.59	" (grey sandstone)	thin section	
342	"	100.89	" (glauconitic? sst & slts)	large thin section	
343	Throssell 1	7.92	Calcrete (brown-cream silicified congl)	large thin section	
344	"	8.53	" "	"	
345	"	20.42	") white to cream mottled	"	
346	"	22.25	") vuggy calcrete - range	"	
347	"	24.38	") of rock types represented	"	
348	"	24.99	")	"	
349	"	26.00	" (fawn claystone with calc. blebs)	palynology	N.D.
350	"	27.12	" "	"	Barren

REGISTERED NUMBER	DRILLHOLE	DEPTH (metres)	FORMATION OR ROCK TYPE	REASON SAMPLE TAKEN	REMARKS/RESULTS ETC.
73880351	Throssell 1	27.43	Calcrete (white silty clay)	palynology	N.D.
352	"	"	" "	thin section	
353	"	28.40	" (white clay)	palynology	N.D.
354	"	"	" "	thin section	
355	"	"	" "	mineralogy	XRD - Dolomite, quartz, gypsum, possible $CuSO_4 3H_2O$ (∿70:3:2:1)
356	"	32.91	" (mottled grey/white clay)	palynology	Barren
357	"	30.05	" "	"	N.D.
358	"	59.43	" (grey clay with gypsum)	large thin section	
359	"	60.50	" "	palynology	Barren
360	"	62.48	" "	"	Barren
361	"	121.00	Proterozoic (mottled red/brown/green	large thin section	
362	"	"	" "	palynology	N.D.
363	"	185.50	" (green siltstone)	thin section	
364a	Wanna 1	30.32	Paterson Fm (brown silty sst with woody fragments)	palynology	Recovery sparse, preservation excellent; Sakmarian?
364b	"	30.58	" "	"	"
364c	"	30.78	" "	"	"
365	Neale 1	66.82	Wanna Beds (grey fine sst)	"	Barren
366	"	112.08	" "	"	Barren
367	"	203.00	Lennis Sandstone (red fine sst)	"	Barren
368	"	56.69	Paterson Fm (grey laminated claystone)	"	Sparse, fragmented spores and pollen Sakmarian?
369a	Neale 2	56.99	" "	"	"
369b	"	58.21	" "	"	"
370	Rason 2	99.21	Paterson Fm (grey siltstone)	"	Spores and pollen abundant, well preserved, Sakmarian?
371	"	110.95	" "	"	"
372	"	143.36	" (sandy tillite)	"	Spores and pollen sparse, poorly preserved, Sakmarian?
373	Yowalga 4	41.75	Paterson Fm (pink claystone & siltstone)	"	Barren
374	Talbot 4	42.67 - 45.72	Cainozoic? (red silty sandstone)	"	Barren
375	Westwood 2	98.45	Lennis Sandstone (grey sandy siltstone)	"	Barren

XRD - X-ray diffraction analyses by D. Barnes (BMR) The ratios shown are not absolute, but only give an indication of relative concentrations of minerals in samples.

GEOLOGY OF THE OFFICER BASIN

WESTERN AUSTRALIA

1981

Scale 1:1000 000

0 20 40 60 80 100 KILOMETRES

Lambert Conformal Conic Projection

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Issued under the authority of the Minister for National Development and Energy.
Base map compiled from 1:1000 000 ICAO National Mapping Charts and 1:80 000 scale aerial photographs

Geology 1970-74 by Officers of the Bureau of Mineral Resources and the Geological Survey of Western Australia
Compiled 1975-78 by M. J. Jackson, W. J. E. van de Graaff, I. T. Lamberts, G. Matveev
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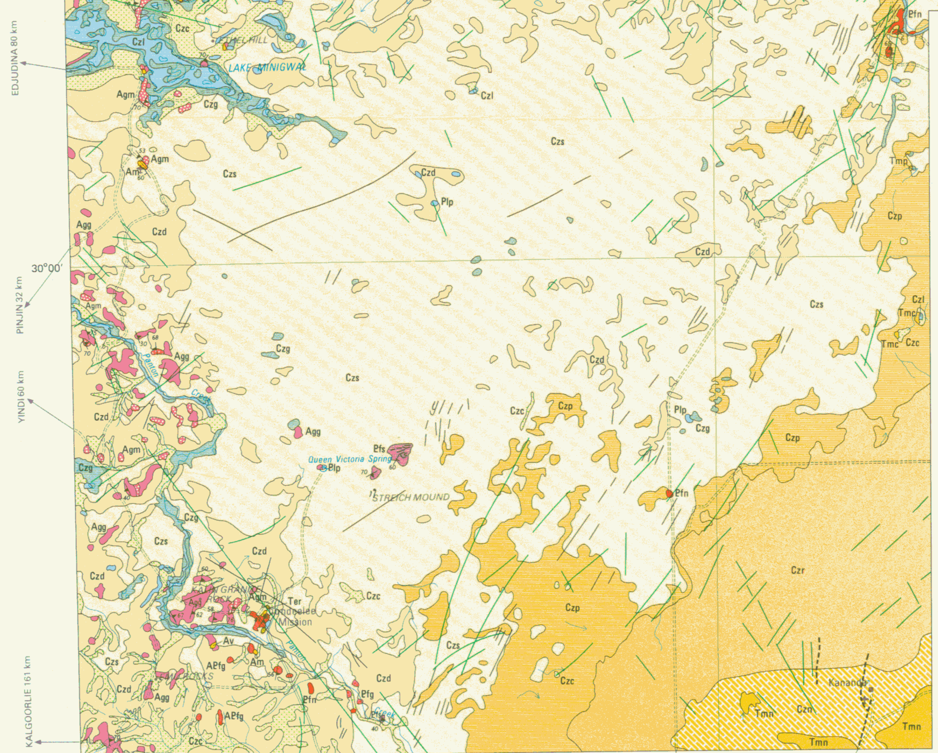
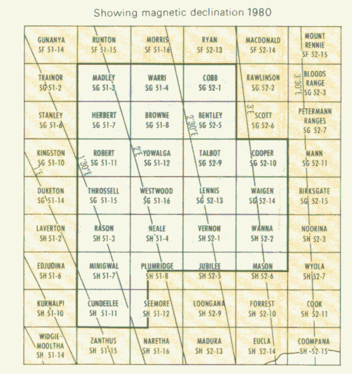


LOCALITY MAP

INDEX TO 1:250 000 SHEETS



OFFICER BASIN

CAINOZOIC — QUATERNARY; TERTIARY (MIOCENE, EOCENE)

- Czl / Czg — Czl – clay, silt, sand, authigenic gypsum and halite: deposited in fresh water and saline playa lakes. Czg – fine gypsum sand or powdery gypsum (kopi); minor quartz sand, silt, clay: aeolian deposits marginal to and derived from saline playa lakes
- Czs — Red-brown and minor yellow sand: aeolian deposits forming longitudinal dunes and sand plains
- Czc — Poorly sorted gravel, sand, silt, clay: colluvial and minor alluvial deposits formed by creep, sheet flood and channel-confined streams
- Czv — Authigenic, nodular to rubbly limestone with minor chalcedony, in clay, silt, sand and gravel: pedogenic calcrete deposits in valleys
- Czd — Ferruginous, nodular, pisolitic laterite crust grading up into pisolitic red sand or intensely silicified, spheroidally-weathering bedrock (silcrete); pedogenic replacement in bedrock

MESOZOIC — CRETACEOUS TO TERTIARY

- KTl — **Lampe beds** Poorly sorted, indistinctly bedded, medium to coarse sandstone, pebble conglomerate, breccia; minor siltstone, claystone; everywhere intensely silicified (silcrete): fluviatile, colluvial

EARLY CRETACEOUS

- Kle — **Bejah Claystone** Indistinctly bedded, white-weathering claystone; minor siltstone, fine sandstone: shallow marine
- Kls — **Samuel Formation** Laminated to thin-bedded micaceous, glauconitic, carbonaceous siltstone, claystone and sandstone: shallow marine

PALAEOZOIC — EARLY PERMIAN

- Plp — **Paterson Formation** Coarse to conglomeratic sandstone, siltstone (fluviatile); laminated and varved claystone, siltstone, fine sandstone (lacustrine); tillite and clastics with dropstones (glacial)
- Pzw — **Wanna beds** Predominantly white-weathering, well-sorted fine to medium quartz arenite with diagenetic clay matrix; minor claystone interbeds; medium to very thick-bedded, mostly large-scale cross-bedded: shallow marine
- Pzl — **Lennis Sandstone** Red-brown micaceous, feldspathic sandstone; micaceous siltstone interbeds; thick-bedded, mostly cross-bedded: shallow marine and terrestrial

EARLY CAMBRIAN

- Ꞓlt — **Table Hill Volcanics** Purple and grey finely crystalline flow-banded tholeiitic basalt, amygdaloidal and vesicular, minor sandstone interbeds: subaerial

570 M.Y.

PROTEROZOIC — LATE PROTEROZOIC

"SOUTHWESTERN"

- Ᵽot — **Turkey Hill beds** Distinctly bedded siltstone and sandstone, minor tillite: marine glacial deposits

"WESTERN"

- Ᵽor — **Robert beds** Thick-bedded, rippled quartz arenite, feldspathic sandstone, minor chert: marine

"NORTHERN"

- Ᵽoo — **Woolnough beds** Gypsum, stromatolitic and brecciated dolarenite to dololutite, laminated siltstone, chert, sandstone: shallow marine, evaporitic
- Ᵽon — **Madley beds** Gypsum, anhydrite, minor halite; diapirically intrudes Ᵽoo: evaporitic

"CENTRAL"

- Ᵽob — **Babbagoola beds** Shale, siltstone, sandstone, with anhydrite and gypsum: marine, at times evaporitic. (Section only)
- Ᵽoe — **Browne beds** Dolomitic limestone, calcareous shale with anhydrite gypsum and halite; diapirically intrudes Ᵽob: evaporitic. (Section only)

"SOUTHERN"

- Ᵽod — **Neale beds** Dolomite, limestone, poorly stromatolitic, minor quartzite: shallow marine
- Ᵽoi — **Ilma beds** Sandstone, stromatolitic and oolitic limestone and dolomite; in places altered to chert: shallow marine

"NORTHEASTERN"

- Ᵽow — **Wirrildar beds** Khaki micaceous sandstone, siltstone, thin flaggy dolomite, coarse arkose and feldspathic sandstone: marine
- Ᵽok — **Punkerri beds** Pink quartzite and feldspathic sandstone, flaggy red sandstone, quartzite, siltstone, minor conglomerate: shallow marine
- Ᵽog — **Lupton beds** Massive pebble to boulder conglomerate (tillite), medium to thick-bedded sandstone, minor siltstone: marine glacial deposits
- Ᵽof — **Lefroy beds** Laminated to thin-bedded siltstone with sandstone intercalations, minor claystone: shallow marine
- Ᵽop — **Wright Hill beds** Siltstone, sandstone, quartzite, minor black oolitic chert: shallow marine (Section only)
- Ᵽos — **Townsend Quartzite** Laminated to very thick-bedded well-sorted medium to coarse quartz arenite and feldspathic arenite, minor conglomerate and shale beds; medium to large-scale cross-bedding: littoral to sublittoral

WESTERN AMADEUS BASIN

- Ᵽac — **Clutterbuck beds** Fine to coarse, well sorted, cross-bedded feldspathic arenite with siltstone and conglomeratic interbeds: marine
- Ᵽay — **Pinyinna beds** Dolomite, limestone, siltstone

1000 M.Y.

EUCLA BASIN

- Czr — Clay with calcrete; pedogenic
- Czn — Recrystallised Nullarbor Limestone
- Czp — Authigenic nodular, rubbly, pisolitic and laminar limestone in clay, silt, sand or bedrock: pedogenic calcrete deposit on plains
- Tmp / Tmc / Tmn — Tmp **Plumridge beds** Fine sandstone, siltstone, claystone, intercalations of conglomeratic sandstone: paralic; Tmc **Colville Sandstone** Sandstone, claystone, minor calcarenite: marine; Tmn **Nullabor Limestone** Foraminiferal calcarenite: marine
- Ter — **Princess Royal Spongolite** Sandstone, siltstone, claystone, spongolite: paralic
- Klm — **Madura Formation** Indistinctly bedded glauconitic and carbonaceous sandstone, siltstone, claystone, shale: marine
- Kll — **Loongana Sandstone** Conglomeratic sandstone with large-scale cross-bedding: marine

BASEMENT

MIDDLE PROTEROZOIC

BANGEMALL BASIN

- Ᵽd — Fine-grained dolerite: intrusive sill (1050 ± 50 my)
- Ᵽb — Thin-bedded stromatolitic dolomite, micaceous siltstone, quartzite, feldspathic sandstone: marine

1770 M.Y.

EARLY PROTEROZOIC

NABBERU BASIN

- Ᵽl — Thick-bedded quartz arenite, thin siltstone and conglomerate beds
- Ᵽn — Quartzose, arkosic and glauconitic sandstone, interbedded fine sandstone, siltstone, stromatolitic dolomite, chert, minor granular ironstone: marine

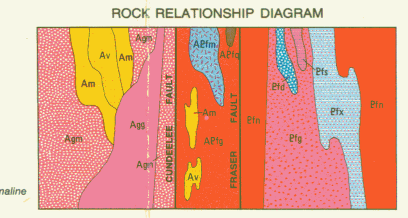
2400 M.Y.

ARCHAEAN

YILGARN BLOCK AND ALBANY — FRASER PROVINCE

- Ᵽfx — **Fraser Complex** Mafic granulite with minor felsic granulite, gneiss, granite and metagabbro (Rock relationship diagram only)
- Ᵽfg — Granite, adamellite, felsic porphyry, granitic gneiss
- Ᵽfs — Quartzite, orthoquartzite and minor kyanite: metasediments
- Ᵽfd — Serpentine-tremolite rock, pyroxenite: (Rock relationship diagram only) ultramafic intrusives
- Ᵽfn — Garnetiferous gneiss and migmatite, mafic gneiss
- AᵽfG — Granite, adamellite, migmatite; minor hybrid rocks-adamellite to gabbro, in part strongly sheared
- Aᵽfq — Quartzite, partly cross-bedded, quartz-mica schist, tourmaline quartzite, quartz conglomerate: metasediments
- Aᵽfm — Gabbro, tonalite, hornblendite; partly metamorphosed: mafic intrusives
- Agg — Granite, adamellite, granodiorite; in part strongly foliated
- Agm — Banded and folded granitic migmatite, nebulitic and schlieric-structured granitic and migmatitic rocks
- Av — Felsic extrusives and intrusives, pyroclastics, clastic sediments, chert, minor banded-iron formation: felsic association
- Am — Basalt, amphibolite, dolerite, hornfels, ultramafic rocks, minor banded-iron formation: mafic association

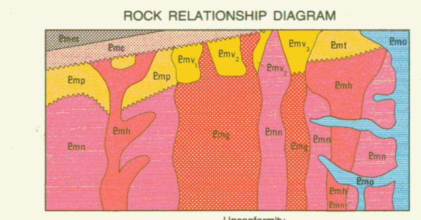
ROCK RELATIONSHIP DIAGRAM



WESTERN MUSGRAVE BLOCK

- Ᵽmm — **Mission Group** Conglomerate, sandstone, shale, basalt, minor tuff, dolomite and quartzite
- Ᵽmc — **Cassidy Group** Rhyolite, basalt; minor sandstone, siltstone shale, tuff
- Ᵽmv₁ — **Scamp Volcanic Association** *Acid volcanic rocks, felsite, breccia, basic lava and agglomerate
- Ᵽmv₂ — **Palgrave Volcanic Association** *Acid volcanic rocks, agglomerate, tuff, obsidian, minor quartzite
- Ᵽmv₃ — **Skirmish Hill Volcanic Association** *Acid volcanic rocks, minor basic volcanics
- Ᵽmg — Granitic and adamellitic gneiss, migmatite, relict granulite
- Ᵽmo — **Giles Complex** Gabbro, norite, troctolite, anorthosite, contaminated gabbroic rocks, ultramafic rocks, dolerite dykes and sills
- Ᵽmp — **Pussy Cat Group** Basic lavas, tuff, shale, siltstone, dolomite, ignimbrite
- Ᵽmt — **Tollu Group** Basic volcanics, rhyolite, conglomerate, sandstone
- Ᵽmh — Granophyre, granite, aplite, quartzite
- Ᵽmn — Granulite

ROCK RELATIONSHIP DIAGRAM



Unconformity

*Informal Lithostratigraphic unit (as used by J. Daniels, Bulletin, 123 of the Geological Survey of Western Australia)

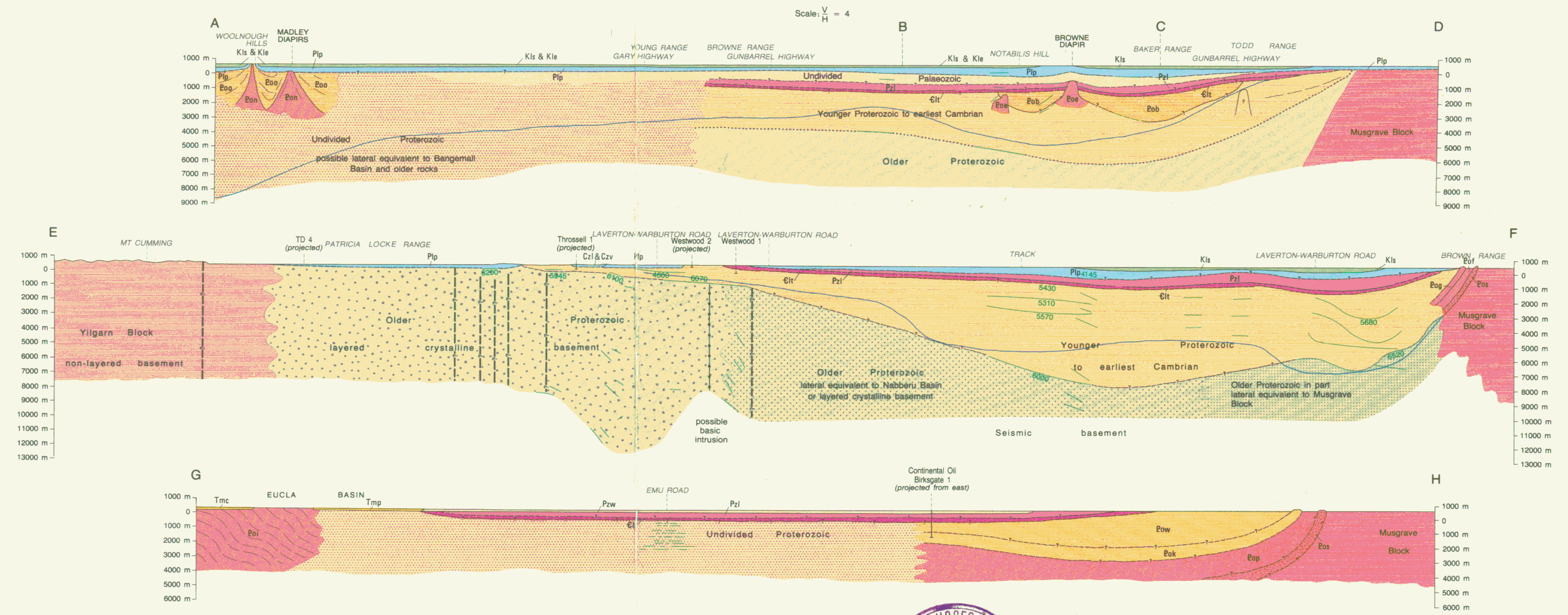
Unconformity — Disconformity — Facies change

- Geological boundary
- Fault
- Where location of boundaries and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries are dotted, faults are shown by short dashes
- Shear zone
- Strike and dip of strata
- Strike and dip of strata, unmeasured
- Strike and dip of foliation
- Strike and dip of foliation; dip not measured
- Trend-line } airphoto interpretation
- Lineament } airphoto interpretation
- Lineaments from interpretation of LANDSAT images
- BMR drillhole
- BHP drillhole
- Oil well, abandoned
- Dyke or vein; q-quartz, g-granite
- Bore
- Well
- Windpump
- Ephemeral stream
- Highway or road
- Vehicle track
- Kananda Homestead
- Landing ground
- Seismic horizon with refraction velocity shown (m/sec) if available } section only
- Hunt Oil Co. depth to magnetic basement } section only
- Gravity basement (Lonsdale and Flavelle, 1963) } section only

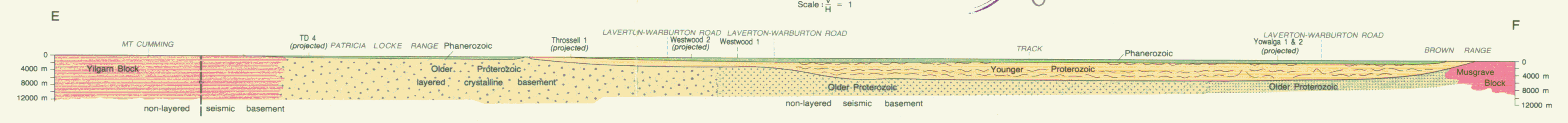
SECTIONS

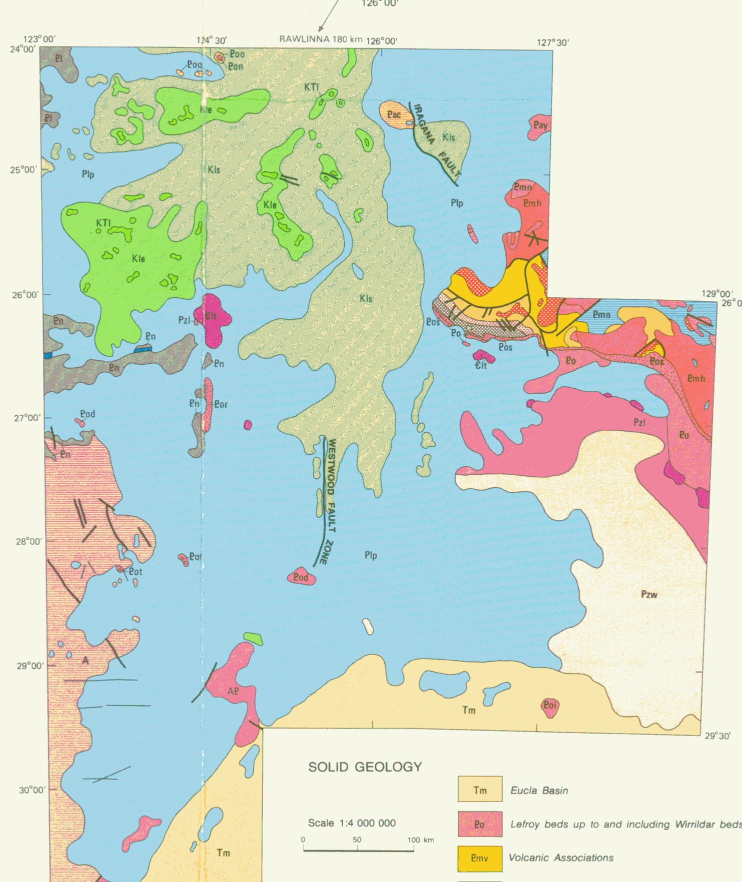
SUPERFICIAL CAINOZOIC UNITS OMITTED

Scale: $\frac{V}{H} = 4$



Scale: $\frac{V}{H} = 1$



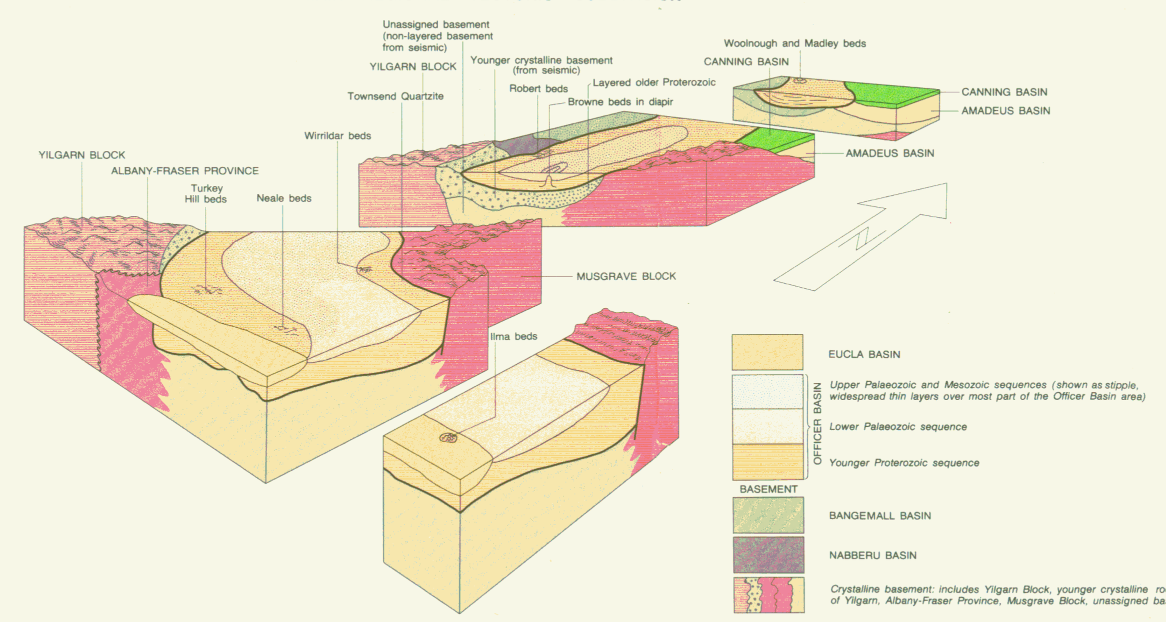


SOLID GEOLOGY

Scale 1:4 000 000

- Tm — Eucla Basin
- Ᵽo — Lefroy beds up to and including Wirrildar beds
- Ᵽmv — Volcanic Associations
- Ᵽmp — Pussy Cat and Tollu Groups
- Ᵽf — Albany-Fraser Province
- A — Yilgarn Block

MAIN REGIONAL TECTONIC SUBDIVISION



- EUCLA BASIN
- Upper Palaeozoic and Mesozoic sequences (shown as stipple, widespread thin layers over most part of the Officer Basin area)
- Lower Palaeozoic sequence
- Younger Proterozoic sequence
- BASEMENT
- BANGEMALL BASIN
- NABBERU BASIN
- Crystalline basement includes Yilgarn Block, younger crystalline rocks east of Yilgarn, Albany-Fraser Province, Musgrave Block, unassigned basement

PLATE 2

PHYSIOGRAPHY OF THE OFFICER BASIN WESTERN AUSTRALIA 1980

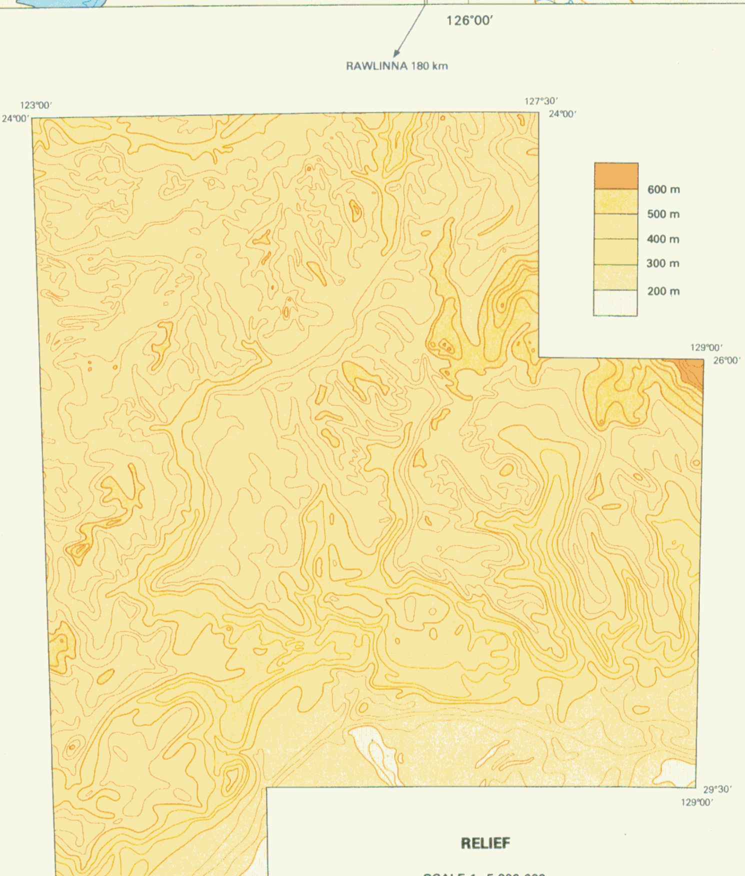
SCALE 1:1000 000

Lambert Conformal Conic Projection

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy, in conjunction with the Geological Survey of Western Australia. Issued under the joint authority of the Minister for National Development and Energy and the Minister for Mines, Western Australia. Base map compiled from 1:1000 000 ICAO National Mapping Charts and 1:80 000 scale aerial photographs

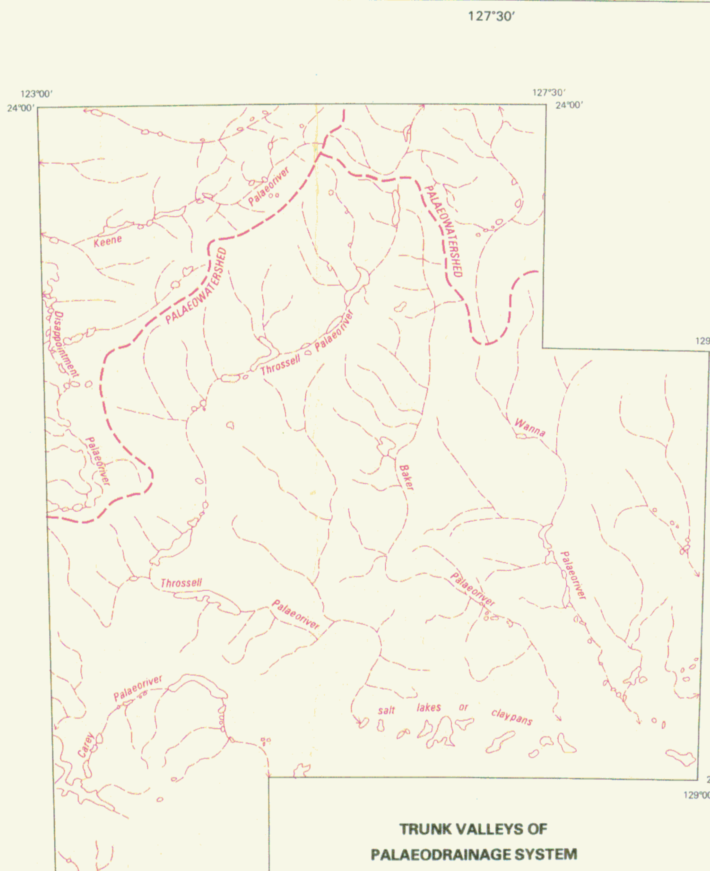
Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT, or the Geological Survey of Western Australia, Perth

Physiography by M.J. Jackson, P.J. Kennewell, BMR; W.J.E. van de Graaff, GSWA
Compiled by M.J. Jackson, W.J.E. van de Graaff
Design and Drafting by Cartography Section, BMR
Drawn by Cartoscope Sydney
Printed by Mercury-Walch, Hobart, Australia



RELIEF

SCALE 1: 5 000 000



TRUNK VALLEYS OF PALAEODRAINAGE SYSTEM

SCALE 1: 5 000 000

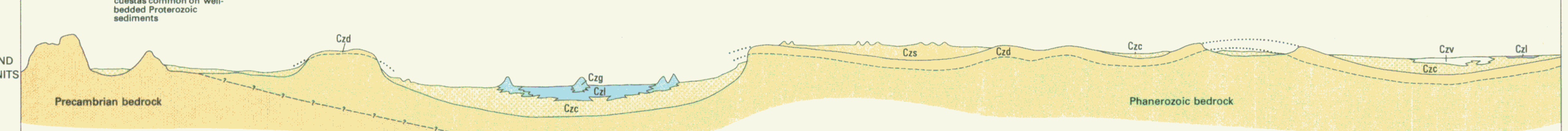
Symbol	Division	Description
D	DURICRUST PLAIN	gently undulating peneplain, commonly with small breakaways and well preserved dendritic palaeodrainage system
M	MESAS	steep or undercut cliffs with siliceous or ferruginous cappings, flanked by scree
P	PLAYAS	salt lakes and claypans
H	LOW HILLS	rubbly rises and colluvial flats
R	RANGES	prominent elongated ridges, high rocky rises
V	MAJOR VALLEYS	flat areas of colluvial, silt and clay
C	CALCRETE-FLOORED VALLEYS	mound and karst topography
CP	CARLISLE PLAIN	flat plain with depressions
NP	NEALE PLATEAU	flat sandy plain
S	SAND PLAINS AND DUNES	mainly longitudinal dunes with intervening sand plain

Physiographic boundary
Geological boundary (section only)
Where location of geological boundary is approximate, line is broken; where inferred, queried

Form lines in metres
Facies boundary (section only)
Section line (refers to Bulletin text figure)
Sand dunes
Relict drainage
Ephemeral stream
Bore
Well
Windpump
Salt lake or claypan
Highway or road
Vehicle track
Homestead
Landing ground

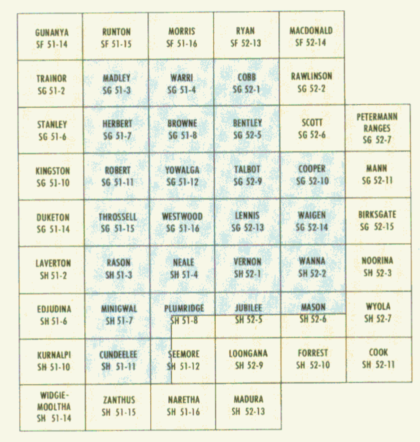
SCHEMATIC SECTION SHOWING RELATION BETWEEN PHYSIOGRAPHY AND GEOLOGY

PHYSIOGRAPHIC DIVISIONS SHOWN ON MAP	Ranges	Low hills	Mesas	Major valleys	Playas	Mesas	Sand plains and dunes	Duricrust plain	Major valleys, calcrete-floored in part
DESCRIPTION OF MAJOR PHYSIOGRAPHIC FEATURES	Prominent elongated ridges and steep-sided rocky hills, commonly lacking vegetation. Rugged topography	Discontinuous low hills and strike ridges flanked by boulder-strewn scree and separated by rubble and colluvium. Rounded exfoliated monadnocks common on granitic rocks, cuestas common on well-bedded Proterozoic sediments	Flat-topped, duricrust-capped buttes with scree apron. Mottled and weathered rocks exposed in cliff faces. Sides commonly incised by heavily vegetated short ephemeral creeks. Grades laterally into outwash fans	Gently sloping areas of colluvium and alluvium infilling broad depressions	Flat, bare, featureless expanses of salt and gypsum containing "islands" of, and commonly flanked by, white gypsiferous dunes	Steep to undercut mesa or breakaway with siliceous or ferruginous capping, flanked by scree apron grading into colluvial valley	Flat, featureless sand plain with spinifex and sparse trees containing symmetrical longitudinal sand dunes up to about 30 m high and tens of kilometres long	Gently undulating duricrust plains. Composed of smooth rounded pisolite-strewn rises separated by narrow sandy depressions. Commonly contains low breakaways of laterite where the duricrust has been breached. Headward erosion of these small cliffs leads to incipient development of mesas and buttes. The depressions in the plain form an integrated dendritic pattern	Low, smooth, elongated depressions, commonly several kilometres wide. Contains small areas of karst topography (calcrete) and claypans
TOPOGRAPHIC PROFILE AND SUPERFICIAL CAINOZOIC UNITS									
ORIGIN OF PHYSIOGRAPHY	Erosion and dissection of resistant Precambrian rocks. Character of individual ranges depends largely on variations in lithology		Mainly by extensive headward erosion of the undulating duricrust peneplain by ephemeral creeks. Collapse of undercut cliff faces and downslope movement of debris forms wide scree aprons grading out into outwash fans	Deposition of silt, clay and sand in the major depressions in the topography. Evaporation of standing bodies of water forms salt and gypsum crusts. Gypsum dunes are formed by accumulation of material deflated from lake surface. Represents the major trunk valleys of the early Tertiary palaeodrainage		As before	Aeolian deposition of sand and minor finer material. Especially extensive in broad depressions in the undulating duricrust plains	A well-preserved, relict, gently undulating Late Cretaceous to Early Tertiary peneplain formed under a more humid climate than the present. Essentially unmodified since formation except for breaching and erosion into rises forming small lateritic breakaways with concomitant deposition of colluvium and alluvium in depressions. Axes of depressions mark courses of palaeodrainage system. Part of Jutson's "Old Plateau"	Broad hollows filled with slope wash material. Precipitation of carbonates in soil profile leads to development of valley calcretes. Small claypans may also form



- Czl — Clay, silt, sand; authigenic gypsum and halite; deposited in fresh water and saline playa lakes
- Czg — Fine gypsum sand or powdery gypsum (kopi); minor quartz sand, silt, clay: aeolian deposits marginal to and derived from saline playa lakes
- Czs — Red-brown and minor yellow sand: aeolian deposits forming longitudinal dunes and sand plains
- Czc — Poorly sorted gravel, sand, silt, clay: colluvial and minor alluvial deposits formed by creep, sheet flood and channel-confined streams
- Czv — Authigenic, nodular to rubbly limestone with minor chalcedony, in clay, silt, sand and gravel; calcrete: pedogenic deposits in valleys
- Czd — Duricrust: ferruginous, nodular, pisolitic, laterite crust grading into pisolitic red sand or intensely silicified, spheroidally weathered bedrock (silcrete): pedogenic replacement in bedrock

INDEX TO 1: 250 000 SHEETS



LOCALITY MAP

PHYSIOGRAPHY OF THE OFFICER BASIN 1:1 000 000

FIRST EDITION 1980

BOUGUER ANOMALY CONTOURS AND TOTAL MAGNETIC INTENSITY CONTOURS OF THE OFFICER BASIN

WESTERN AUSTRALIA

1980

Scale 1:1 000 000

10 0 20 40 60 80 100 KILOMETRES

LAMBERT CONFORMAL CONIC PROJECTION

Design and Drafting by Cartography Section, BMR

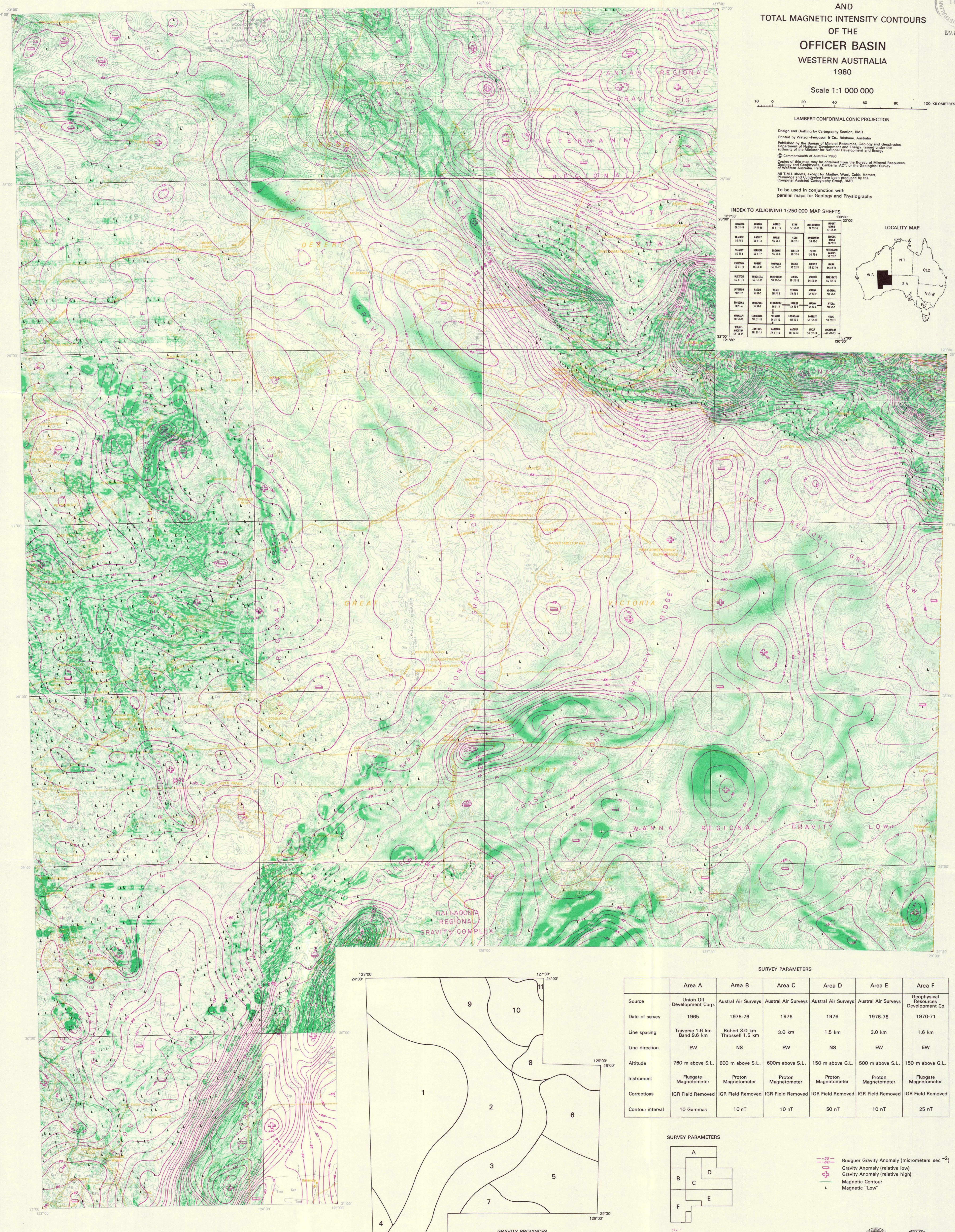
Printed by Watson-Ferguson & Co., Brisbane, Australia

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development and Energy. Issued under the authority of the Minister for National Development and Energy

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT, or the Geological Survey of Western Australia, Perth

All T.M.I. sheets, except for Madley, Warri, Cobb, Herbert, Plumridge and Cundeelee have been produced by the Computer Assisted Cartography Group, BMR

To be used in conjunction with parallel maps for Geology and Physiography



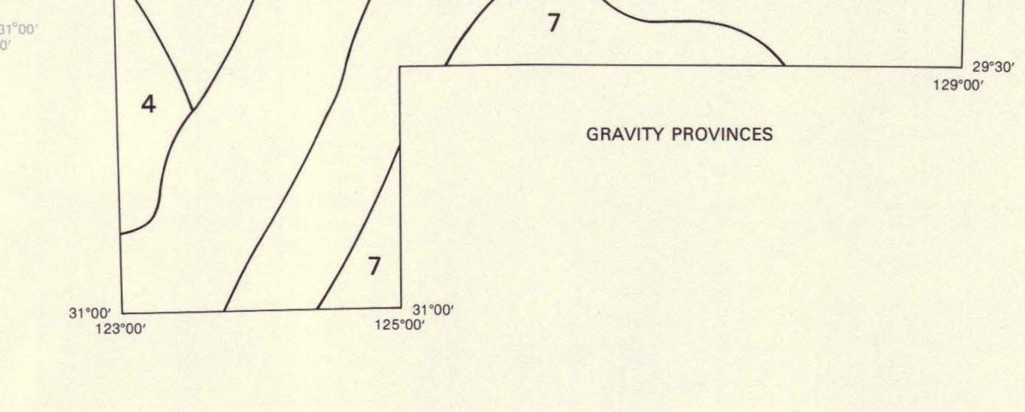
INDEX TO ADJOINING 1:250 000 MAP SHEETS

121°30' 23°00' — 130°30' 23°00' — 32°00' 121°30' — 32°00' 130°30'

GUNANYA SF 51-14	RUNTON SF 51-15	MORRIS SF 51-16	RYAN SF 52-13	MACDONALD SF 52-14	MOUNT RENNIE SF 52-15
TRAINOR SG 51-2	MADLEY SG 51-3	WARRI SG 51-4	COBB SG 52-1	RAWLINSON SG 52-2	BLOODS RANGE SG 52-3
STANLEY SG 51-6	HERBERT SG 51-7	BROWNE SG 51-8	BENTLEY SG 52-5	SCOTT SG 52-6	PETERMANN RANGES SG 52-7
KINGSTON SG 51-10	ROBERT SG 51-11	YOWALGA SG 51-12	TALBOT SG 52-9	COOPER SG 52-10	MANN SG 52-11
DUKETON SG 51-14	THROSSELL SG 51-15	WESTWOOD SG 51-16	LENNIS SG 52-13	WAIGEN SG 52-14	BIRKSGATE SG 52-15
LAVERTON SH 51-2	RASON SH 51-3	NEALE SH 51-4	VERNON SH 52-1	WANNA SH 52-2	NOORINA SH 52-3
EDJUDINA SH 51-6	MINIGWAL SH 51-7	PLUMRIDGE SH 51-8	JUBILEE SH 52-5	MASON SH 52-6	WYOLA SH 52-7
KURNALPI SH 51-10	CUNDEELEE SH 51-11	SEEMORE SH 51-12	LOONGANA SH 52-9	FORREST SH 52-10	COOK SH 52-11
WIDGIE-MOOLTHA SH 51-14	ZANTHUS SH 51-15	NARETHA SH 51-16	MADURA SH 52-13	EUCLA SH 52-14	COOMPANA SH 52-15

LOCALITY MAP

WA
NT
QLD
SA
NSW



GRAVITY PROVINCES

GRAVITY PROVINCES

1 Yeo Regional Gravity Shelf
2 Rason Regional Gravity Low
3 Fraser Regional Gravity Ridge
4 Carey Regional Gravity Complex
5 Wanna Regional Gravity Low
6 Officer Regional Gravity Low
7 Balladonia Regional Gravity Complex
8 Blackstone Regional Gravity Ridge
9 Anketell Regional Gravity Ridge
10 Petermann Regional Gravity Low
11 Angas Regional Gravity High

SURVEY PARAMETERS

	Area A	Area B	Area C	Area D	Area E	Area F
Source	Union Oil Development Corp.	Austral Air Surveys	Austral Air Surveys	Austral Air Surveys	Austral Air Surveys	Geophysical Resources Development Co.
Date of survey	1965	1975-76	1976	1976	1976-78	1970-71
Line spacing	Traverse 1.6 km Band 9.6 km	Robert 3.0 km Throssell 1.5 km	3.0 km	1.5 km	3.0 km	1.6 km
Line direction	EW	NS	EW	NS	EW	EW
Altitude	760 m above S.L.	600 m above S.L.	600m above S.L.	150 m above G.L.	500 m above S.L.	150 m above G.L.
Instrument	Fluxgate Magnetometer	Proton Magnetometer	Proton Magnetometer	Proton Magnetometer	Proton Magnetometer	Fluxgate Magnetometer
Corrections	IGR Field Removed	IGR Field Removed	IGR Field Removed	IGR Field Removed	IGR Field Removed	IGR Field Removed
Contour interval	10 Gammas	10 nT	10 nT	50 nT	10 nT	25 nT

SURVEY PARAMETERS

A
B
C
D
E
F

- -55 / -60 — Bouguer Gravity Anomaly (micrometers sec $^{-2}$)
- Gravity Anomaly (relative low)
- Gravity Anomaly (relative high)
- Magnetic Contour
- L Magnetic "Low"

BOUGUER ANOMALY DATA REFERENCE

Bouguer gravity anomalies are based on the May 1965 observed gravity values at Isogal gravity base stations in and near the area.
For the calculation of Bouguer gravity anomalies, 2.2 g cm^{-3} has been adopted as an average rock density.
The gravity data are preliminary only : refer to BMR gravity maps for more recent data

GRAVITY AND MAGNETIC CONTOURS
OF THE OFFICER BASIN
1:1 000 000