COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN NO. 60

THE GEOLOGY OF THE CANNING BASIN, WESTERN AUSTRALIA

BY

J. J. VEEVERS and A. T. WELLS

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Director: J. M. RAYNER

This Bulletin was prepared in the Geological Branch

Chief Geologist: N. H. FISHER

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SUMMARY

The Canning Basin is the largest sedimentary basin in Western Australia, and the second largest basin in Australia. Excluding the seaward extension of the basin on the Rowley Shelf, and the southern part of the basin, south of Lat. 24° S, which are unknown, its area is 175,000 square miles, roughly the size of Spain. The sediments overlie a Precambrian basement, which in most areas consists of crystalline rock (gneiss, schist), and in the north-eastern part of unaltered sedimentary rocks.

The Palaeozoic sediments consist of about 3000 feet of widespread Ordovician marine limestone, dolomite, shale, and sandstone; about 5000 feet of Devonian marine organic reefs and associated sediments, conglomerate, sandstone, siltstone, calcilutite, and limestone breccia, all confined to the northern part of the basin, called the Fitzroy Basin; Devonian plant-bearing sandstone in the north-eastern part of the basin; at least 7000 feet of Carboniferous marine calcarenite, sandstone, and siltstone, also confined to the Fitzroy Basin; and widespread Permian marine quartz greywacke, conglomerate, sandy limestone, and shale, and freshwater sandstone, 14,000 feet thick in the Fitzroy Basin, and much thinner elsewhere.

The Mesozoic sediments consist of about 1000 feet of Triassic estuarine shale and siltstone, and freshwater sandstone; and about 2500 feet of Jurassic and Cretaceous marine sandstone, conglomerate, glauconitic siltstone, and shale, and freshwater sandstone.

Cainozoic sediments are superficial, and consist of coastal aeolianite and other coastal sediments, desert sand, travertine, black soil, alluvium, river gravels, freshwater limestone, and evaporites.

The Canning Basin is asymmetrical, and contains about 20,000 feet of sediments in the Fitzroy Basin; these thick sediments, which are folded into three anticlinal belts, are bounded by hinges (the Pinnacle, Dampier, and Fenton Faults); whether these hinges are major faults, the edge of buried ridges, or a combination of both, is a major tectonic problem not yet solved. Immediately south of the Fitzroy Basin, at Frome Rocks, rock-salt intrudes Devonian and Permian rocks, and at Woolnough Hills, on the southern margin of the known part of the basin, a dome in Cretaceous and Permian rocks is attributed to salt intrusion. The thickest known rocks outside the Fitzroy Basin are those in a structural depression, about 10,000 feet deep, that underlies Samphire Marsh; between this depression and the Fitzroy Basin, the sediments are only about 5000 to 7000 feet thick. Sediments in the north-eastern part of the basin may be thicker than 10,000 feet, as indicated by aeromagnetic survey, but this estimate is uncertain.

In the later Precambrian, the crystalline floor of the Canning Basin was probably high land that shed sediment into surrounding areas. Probably before the end of the Precambrian, the sediments were folded and uplifted, the crystalline rocks were depressed, and, with these movements, the Canning Basin was initiated. Except perhaps at Samphire Marsh, no Cambrian rocks have yet been found in the basin.

Starting at the latest in the lowermost Ordovician, and continuing to Llanvirnian-Llandeilian times, a shallow sea covered at least half of the basin, and in it were deposited limestone, dolomite, shale, and sandstone. The sea retreated in the Upper Ordovician, and did not return to the greater part of the basin until the Permian. In the upper part of the Middle Devonian (Givetian), sandstone and limestone were deposited in a sea that covered the Fitzroy Basin. The sea-floor was broken into blocks of varying height in the early Upper Devonian; reefs grew along the edges of high-standing blocks, and conglomerate was deposited at the basin margin; sandstone was deposited in lakes in the north-eastern part of the basin. Most of the Devonian rocks were probably gently folded and eroded before Lower Carboniferous calcarenite and siltstone were deposited in the northern part of the Fitzroy Basin. In the Upper Carboniferous, thick siltstone and sandstone were deposited in a shallow bay in the western part of the Fitzroy Basin, and in the early Permian, thick marine glacial rocks were deposited over the entire Canning Basin. This alternate deposition of marine and estuarine or freshwater sediments was repeated two and a half times during the rest of the Permian and during the Lower Triassic. The sea then retreated, and the rocks were folded and eroded. During the interval Middle Jurassic to lowermost Cretaceous, the sea slowly advanced over the land, and in the upper part of the Lower Cretaceous, slowly retreated; coarser-grained rocks (sandstone, conglomerate) were deposited along the shifting shore, and finer-grained rocks (glauconitic siltstone, fine sandstone) offshore. From the Upper Cretaceous to the Recent, the basin has been land except for local intermittent submergence of the present coast.

A good deal of work has already been published on the Fitzroy Basin; this work has now been extended into the rest of the Canning Basin, and has culminated in the 20-mile geological map (Plate 1). The Devonian rocks of the Fitzroy Basin have been restudied by Rattigan & Veevers, who describe the organic reefs and associated sediments, and present evidence indicating a diastrophism in the early Upper Devonian.

We recognize a rhythmic alternation of marine and freshwater or estuarine sediments in the Upper Carboniferous to Lower Triassic succession, and follow Crespin & Condon (1956, unpubl.) in interpreting the main part of the Grant Formation as marine. The Jurassic and Cretaceous rocks are grouped into coarser-grained rocks, which were deposited inshore, and finer-grained rocks, which were deposited offshore. The synthesis of all data, geological, geophysical, and those from drilling, results in eight structural subdivisions being recognized.

The hinge areas are probably the best petroleum prospect in the basin. Outside these areas, the sediments were folded and faulted long after deposition, so that petroleum, if generated in the sediments, probably migrated before reservoirs were formed. In the hinge areas, movement during deposition, and lateral change from deeper-water source rocks to shallower-water reservoir rocks, favour the accumulation of petroleum. The intrusion of salt along the Fenton Hinge at Frome Rocks increases the prospects.

INTRODUCTION

The Bureau started field work in the Canning Basin in 1947 and continued every year up to 1958. This work was carried out by geological parties equipped with land vehicles (1947-56) and with a helicopter (1957), by seismic and gravity parties, by an airborne magnetic party, and by a stratigraphical drilling party (1955-58). All work was based on air photographs, at a scale of 1 : 50,000, prepared by the R.A.A.F. This bulletin incorporates the results of all these surveys. The main published material is: Traves, Casey, & Wells (1957),* Guppy, Lindner, Rattigan, & Casey (1958), and Brunnschweiler (1954 and 1957). Geophysical work is described in unpublished records. Fossils collected by Bureau parties in the Fitzroy Basin have been the subjects of several monographs, which have been published by the Bureau. The first study of plant fossils from the Canning Basin is by White (Appendix 6). 4-mile geological series maps and explanatory notes have been published for Derby, Lennard River, Mount Anderson, Noonkanbah, Yarrie, Anketell, Paterson Range, and Tabletop; and maps and explanatory notes of Mount Bannerman, Billiluna, Lucas, Cornish, and Stansmore will be published shortly.

Other major reports on the area are included in McWhae, Playford, Lindner, Glenister, & Balme (1958), Reeves (1951), and the numerous papers published by Teichert (1941, 1947, 1949, and 1950). The first attempt at compiling a geology of the Canning Basin was made by Reeves (1949, unpubl.). Photographic cover extends to 24° S, and the examination of the basin south of 24° S is postponed until air photographs are prepared.† This Bulletin thus deals with the (greater) part of the Canning Basin that lies north of 24° S.

Location and access (Fig. 1)

The Canning Basin lies within the Kimberley, Eastern, and North-western Divisions of Western Australia, and includes 35 4-mile Sheet areas. The northern part of the area is subdivided into cattle, and a few sheep, stations. The southern part is used as a rocket range. Four towns, Derby, Broome, Fitzroy Crossing, and Talgarno, lie within the basin area. Derby and Broome are ports and Broome is also the centre of the north-western Australian pearl shell industry; Fitzroy Crossing is a small centre of the pastoral industry; Talgarno is an outpost of the Weapons Research Establishment. The only highway in the basin is the unsealed Great Northern Highway, which links Port Hedland (30 miles south-west of the basin) with Broome, Derby, Fitzroy Crossing,

* The following abbreviations are used throughout the text:

Guppy et al.	*for* Guppy, Lindner, Rattigan, & Casey (1958)
Traves et al.	*for* Traves, Casey, & Wells (1957)
McWhae et al.	*for* McWhae, Playford, Lindner, Glenister, & Balme (1958)
Wapet	*for* West Australian Petroleum Pty Ltd
Casey & Wells	*for* Casey & Wells (1961).

† At the date of writing (May 1960) part of the area had been flown, but no photographs were available.

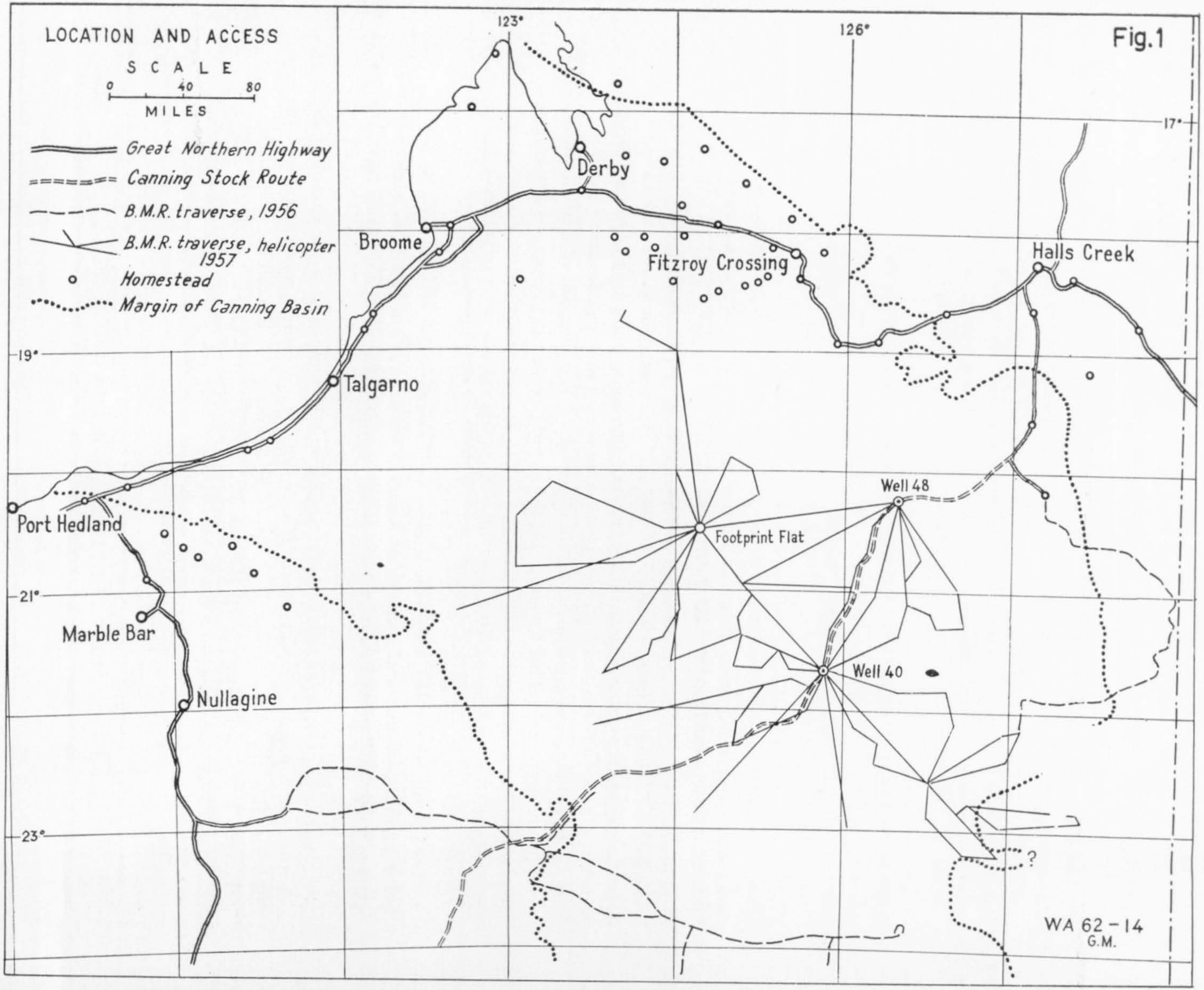

LOCATION AND ACCESS
SCALE
0 40 80
MILES
Great Northern Highway
Canning Stock Route
B.M.R. traverse, 1956
B.M.R. traverse, helicopter 1957
Homestead
Margin of Canning Basin
Fig.1
123°
126°
17°
19°
21°
23°
Derby
Broome
Fitzroy Crossing
Halls Creek
Talgarno
Port Hedland
Marble Bar
Nullagine
Footprint Flat
Well 48
Well 40
?
WA 62 - 14
G.M.

Fig. 1.

and Halls Creek, which lies 50 miles north of the basin. Roads, many of them about 100 miles long, join homesteads to the highway. Bulldozer tracks, made by West Australian Petroleum Pty Ltd, criss-cross the coastal area. The Canning Stock Route, which extends from Billiluna to Wiluna, crosses the Canning Basin. The only settlement near the eastern edge of the basin is the weather station called Giles.

Derby and Broome are served by coastal shipping. An air service links Derby and Broome with Perth and Darwin; most homesteads have at least a fortnightly plane service, and all homesteads are equipped with transceiver wireless sets linked with Royal Flying Doctor base stations at Wyndham, Derby, and Port Hedland for medical calls and telegraphic communication. Only the coastal fringe and the northern and north-eastern parts of the basin are settled; the rest is inhabited by nomadic aborigines, visited by rare explorers, geologists, geophysicists, and rocket research workers, and crossed along the stock route by drovers.

Climate

The Bureau of Meteorology has supplied rainfall data for Warburton Ranges, 100 miles south-west of Giles, for Giles itself, and for the Balgo Hills Mission. Most of the rain falls in heavy showers at long intervals, and the annual totals vary widely. Warburton Ranges has an average annual rainfall of nearly 10 inches, with a dry period from June to October. The highest daily rainfall registered (for 27/3/42) is 398 points. The highest daily rainfall registered during the first two years of operation of Giles was 239 points (29/12/57). Balgo Mission has an average annual rainfall of less than 10 inches, and the highest daily rainfall on record is 413 points (27/12/53); from January 1943 to December 1957, there were 35 occasions when more than 1 inch of rain fell in 24 hours. While supplies were being delivered in preparation for the activities of the 1957 Canning Basin party, Billiluna (the base for the operation) recorded 543 points on the 14th June 1957, and another 243 points on the 19th, out of its annual average total of less than 10 inches. The powerful erosive effect of such downpours on the desert terrain needs no emphasis.

Further features of the climate, in particular temperature and wind, are described on pp. 207-211.

Topography

The surface of the Canning Basin is virtually flat, except in the northern part, where ranges of Devonian limestone and conglomerate, Permian sandstone, and Mesozoic sandstone rise 300 feet or more above the surrounding flat country. South of the Edgar Range lies the Great Sandy Desert, a large dune-covered area without drainage. Typical desert land-forms, such as structural plains, mesas, buttes, and breakways, are found here. These forms are described under Geomorphology (p. 239).

Previous work

Geological work in the Fitzroy Basin dates back to Hardman's work in 1883. Guppy et al. detail this and later work carried out in the Fitzroy Basin. Work in the larger part of the Canning Basin, south of the Fitzroy Basin, started much later, and has hitherto been no more than reconnaissance, except perhaps near the coast. Exploration routes are shown in figure 4 of Traves et al. The desert area is uninviting to the geologist; access is difficult, and outcrops are poor, and deeply weathered; imposing ranges and fertile oases, the lure to geologists in parts of the Sahara, are lacking. Talbot (1910, p. 45), the first geologist to cross the basin, clearly stated the facts:

'From this point (Well 27) north-eastwards to Sturt Creek the country traversed by the stock route is most uninteresting from a geological point of view. There are wide belts of sand ridges, which, however, are broken by patches of good grazing country, and all the hills consist of horizontally bedded sandstones, and in none of the strata examined was any dip detected.'

Kidson (1921) crossed the stock route in 1914 as part of a general magnetic survey of Australia for the Carnegie Institute of Washington. Kidson and party were the first to cross the stock route after the drovers, Shoesmith and Thompson, were killed in 1911 by aborigines at Well 37.

One of the members of L. J. Jones' party, which crossed the stock route, met the same fate as Shoesmith and Thompson. Jones collected fossils near Well 27, and W. S. Dun determined them as Permo-Carboniferous. Fossils collected by a BMR party from Helen Hill near Well 27 were determined by G. A. Thomas as Permian.

Clapp (1925), another American scientist, was the first to tackle the desert with mechanized transport; he travelled by tractor from Broome to McLarty Hills, and from the coast at Wallal to Mount Phire. The fossils he collected at McLarty Hills were tentatively determined by W. S. Dun as Permo-Carboniferous, but recent work shows that these fossils are Jurassic. Clapp also discovered the tillite near Braeside Homestead, and regarded it as pre-Jurassic, probably Permo-Carboniferous.

Bremner (1942, unpubl.) made an aerial reconnaissance of the south-western part of the basin, and showed that the Devonian limestone in the northern part of the basin did not crop out in the south.

Maddox (1941, unpubl.) carried out the first reconnaissance survey of the north-east Canning Basin as far south as Godfreys Tank.

Reeves (1949, unpubl.) made an extensive survey of the basin in 1947 and 1948 for the Vacuum Oil Company, and his work provided a sound basis for later work. Reeves and his colleagues, H. J. Evans, G. W. Patterson, and C. Teichert, have placed later workers in their debt.

Most of the Fitzroy Basin was aerially photographed by the R.A.A.F. in 1947, and the rest of the Canning Basin to Lat. 24° S in 1953. With the aid of the photographs, the Bureau mapped the Fitzroy Basin between 1947 and 1953 (Guppy et al.) and the rest of the basin between 1954 and 1957. The Bureau party of 1954, Traves, Casey, and Wells, mapped the south-western part of the basin; in 1955, Casey and Wells of the Bureau and R. M. E. Elliott and D. Roberts of Wapet mapped part of the north-east Canning Basin; in 1956, B. H. Stinear, Wells, and S. Waterlander (geophysicist) of the Bureau mapped the southern and part of the north-east Canning Basin; and in 1957, Veevers and Waterlander mapped the central part of the basin. Various geological parties of Wapet have worked in the basin, in some detail in the Fitzroy Basin and along the coast, since 1953. Wapet made extensive gravity, aeromagnetic, and seismic surveys in the coastal area and in the Fitzroy Basin.*

* Since this Bulletin was written, the Bureau has made an extensive gravity survey to fill in gaps in the gravity data.

Bores

In the Canning Basin, the low topography and near-horizontal strata sharply limit the amount of information that can be derived from surface geological work, and we must finally turn to bores for more information. As can be seen from the list of deep bores given in Table 1, most boring has been carried out since 1954. Since 1954, oil companies, headed by Wapet, and the Bureau have drilled more than 100,000 feet of hole. Since 1958, seven out of the total of nine deep bores drilled by Wapet have received Commonwealth subsidy.

TABLE 1

DEEP BORES IN THE CANNING BASIN

NAME	COMPANY OR AUTHORITY	DEPTH (Feet)	DATE
*Barlee	Wapet	8101	1960
Broome Town Nos. 1 to 4	West Australian Government	1459, 1775, 1464, 1476	1905, 07, 19, 26
Dampier Downs 1	Wapet	3028	1956
Derby Town	West Australian Government	2371	1911
Fraser River 1	Wapet	10144	1955/56
Fraser River Structure Hole 1	Wapet	1202	1955
*Frome Rocks 1	Wapet	4003	1958
*Frome Rocks 2	Wapet	7504	1959
Goldwyer 1	Wapet	4720	1958
Grant Range 1	Wapet	12915	1954/55
Jurgurra Creek BMR 1	BMR	1680	1955
Laurel Downs BMR 2	BMR	4000	1955/56
*Meda 1	Wapet	8809	1958
Meda 2	Wapet	7628	1959
Mt. Wynne 1	Freney Oil Company	896	1922/23
Mt. Wynne 3	Freney Oil Company	2154	1923/25
Myroodah 1	Associated Freney Oil Fields	6001	1955/56
Nerrima 1 (FKO)	Freney Kimberley Oil Co.	4271	1939/41
Nerrima 1 (AFO)	Associated Freney Oil Fields	9072	1955
Poole Range 3	Freney Kimberley Oil Co.	3264	1927/30
Poole Range 5	Freney Kimberley Oil Co.	1545	1932/33
Prices Creek 1	Freney Kimberley Oil Co.	1008	1922
Prices Creek 2	Freney Kimberley Oil Co.	340	1922/23
Prices Creek 3	Freney Kimberley Oil Co.	809	1923
Prices Creek 4	Freney Kimberley Oil Co.	444	1923
Prices Creek BMR 3	BMR	694	1956
Roebuck Bay 1	Wapet	4000	1956
*Samphire Marsh 1	Wapet	6664	1958
Sisters 1	Associated Freney Oil Fields	9828	1956/57
67-mile Bore	West Australian Government	3012	1906/10
Talgarno 1	Weapons Research Establishment	1324	1959
*Thangoo 1	Wapet	3475	1959
*Thangoo 1A	Wapet	5429	1959/60
Wallal BMR 4	BMR	1410	1958
Wallal BMR 4A	BMR	2223	1958
Wallal Corehole 1	Wapet	1014	1957

* Subsidized by Commonwealth Government.

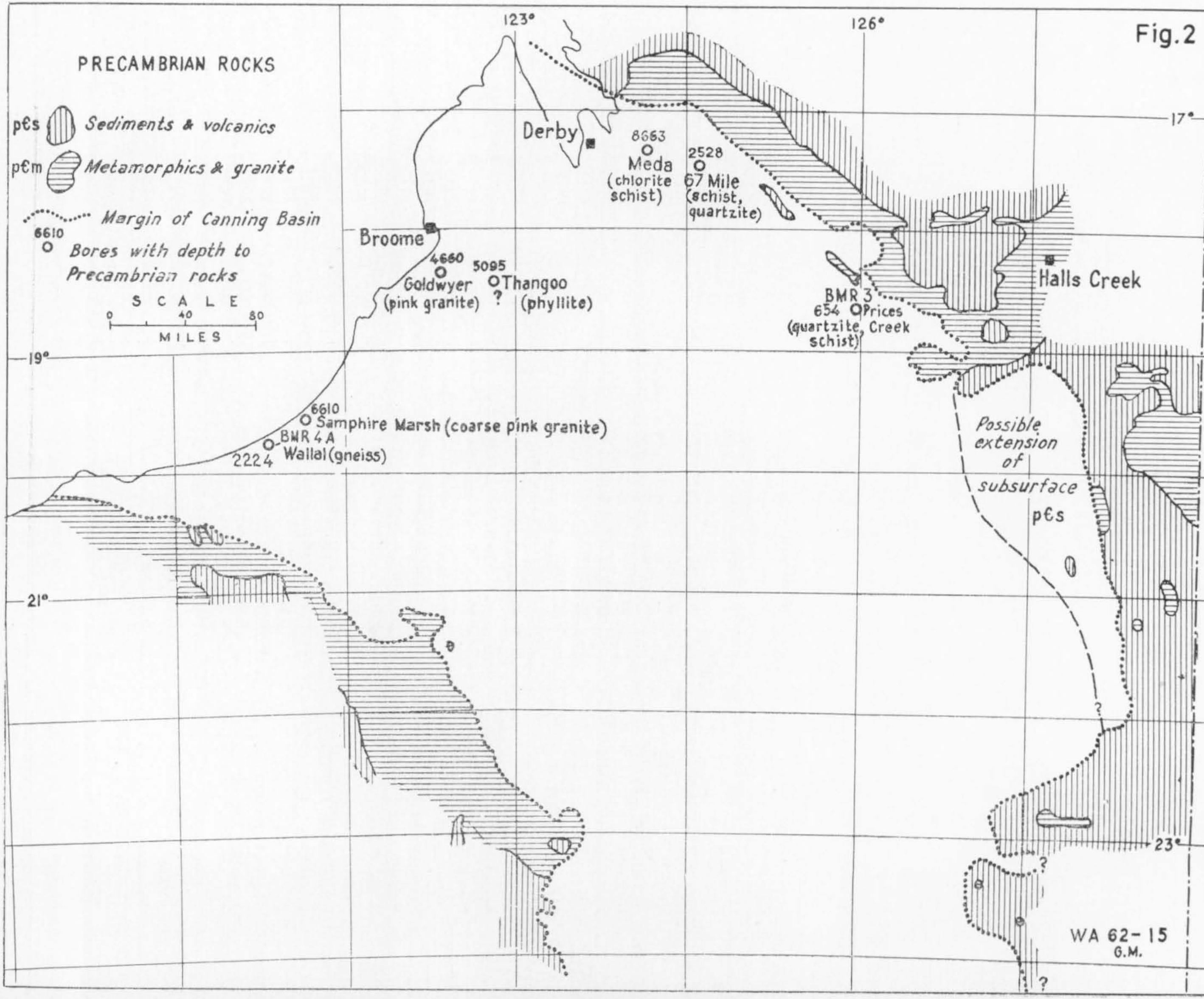


Fig. 2
PRECAMBRIAN ROCKS
p€s Sediments & volcanics
p€m Metamorphics & granite
Margin of Canning Basin
6610
Bores with depth to Precambrian rocks
SCALE
0 40 80
MILES
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
8663
Meda
(chlorite schist)
2528
67 Mile
(schist, quartzite)
4660
Goldwyer
(pink granite)
5095
Thangoo
?
(phyllite)
BMR 3
654
Prices Creek
(quartzite, schist)
6610
Samphire Marsh (coarse pink granite)
BMR 4 A
2224
Wallal (gneiss)
Possible extension of subsurface p€s
?
WA 62-15
G.M.

Fig. 2.

PRECAMBRIAN

Detailed description of the Precambrian rocks that bound the Canning Basin is outside the scope of this Bulletin. The Precambrian rocks of the Sunday Island area of the Buccaneer Archipelago are described by Brunnschweiler (1957), those on the northern margin of the Fitzroy Basin by Guppy et al., those on the margin of the north-east Canning Basin by Casey & Wells (1961), those in part of the northern Pilbara area by Traves et al., and those in the Mount Ramsay Sheet area by Matheson & Guppy (1949, unpubl.). We have investigated the Precambrian rocks on the south-western and south-eastern margins of the basin, and descriptions are given in Appendix 1.

On the basis of gross lithology, the Precambrian rocks are divisible into

(a) sedimentary and volcanic rocks; and

(b) metamorphic rocks and granite.

These divisions are shown in Plate 1 and in Figure 2.

The sedimentary and volcanic rocks, which unconformably overlie the metamorphic rocks and granite, are all gently folded except the contorted Kearney Beds (Casey & Wells), which extend from the Cummins Range to Kearney Range, the quartzite at Corroboree Valley (Appendix 1), and the rocks in the 'King Leopold Mobile Zone' (Traves, 1955) (Fig. 142), which includes the Oscar Range and the King Leopold Ranges.

No attempt is made here to correlate these rocks. The sedimentary rocks on the eastern margin of the Canning Basin resemble some of the lower Palaeozoic rocks of central Australia, and are possibly younger than Precambrian. The oldest well-dated rocks overlying the Precambrian rocks are lowermost Ordovician or uppermost Cambrian in Samphire Marsh No. 1 Bore, and Tremadocian 10 miles west of the Wolf Creek Meteorite Crater. Most outcropping Precambrian rocks are overlain by Permian rocks.

Descriptions of the marginal Precambrian rocks are given in Table 2 on p. 17.

Six, possibly seven, bores in the Canning Basin have penetrated Precambrian rocks. These are shown in Figure 2. The phyllite in Thangoo 1A Bore is Precambrian or Cambrian.

The geological history of the Precambrian rocks, the topography of the subsurface Precambrian basement, and the reasons for extending Precambrian sedimentary rocks below the surface of part of the north-east Canning Basin will be discussed under 'Structure'.

ORDOVICIAN

Ordovician rocks in the Canning Basin (Fig. 3) are known from two areas of outcrop (Prices Creek, and 10 miles west of the Wolf Creek Meteorite Crater), and from five deep bores (from north to south, Roebuck Bay No. 1, Dampier Downs No. 1, Goldwyer No. 1, Thangoo Nos. 1 and 1A, and Samphire Marsh No. 1). The base of the Prices Creek Ordovician succession was penetrated by BMR 3 Prices Creek Bore; FKO Nos. 1 to 3 Prices Creek cut Ordovician rocks, but did not reach basement. These occurrences of Ordovician rocks lie within an area 400 miles long and 100 miles wide.

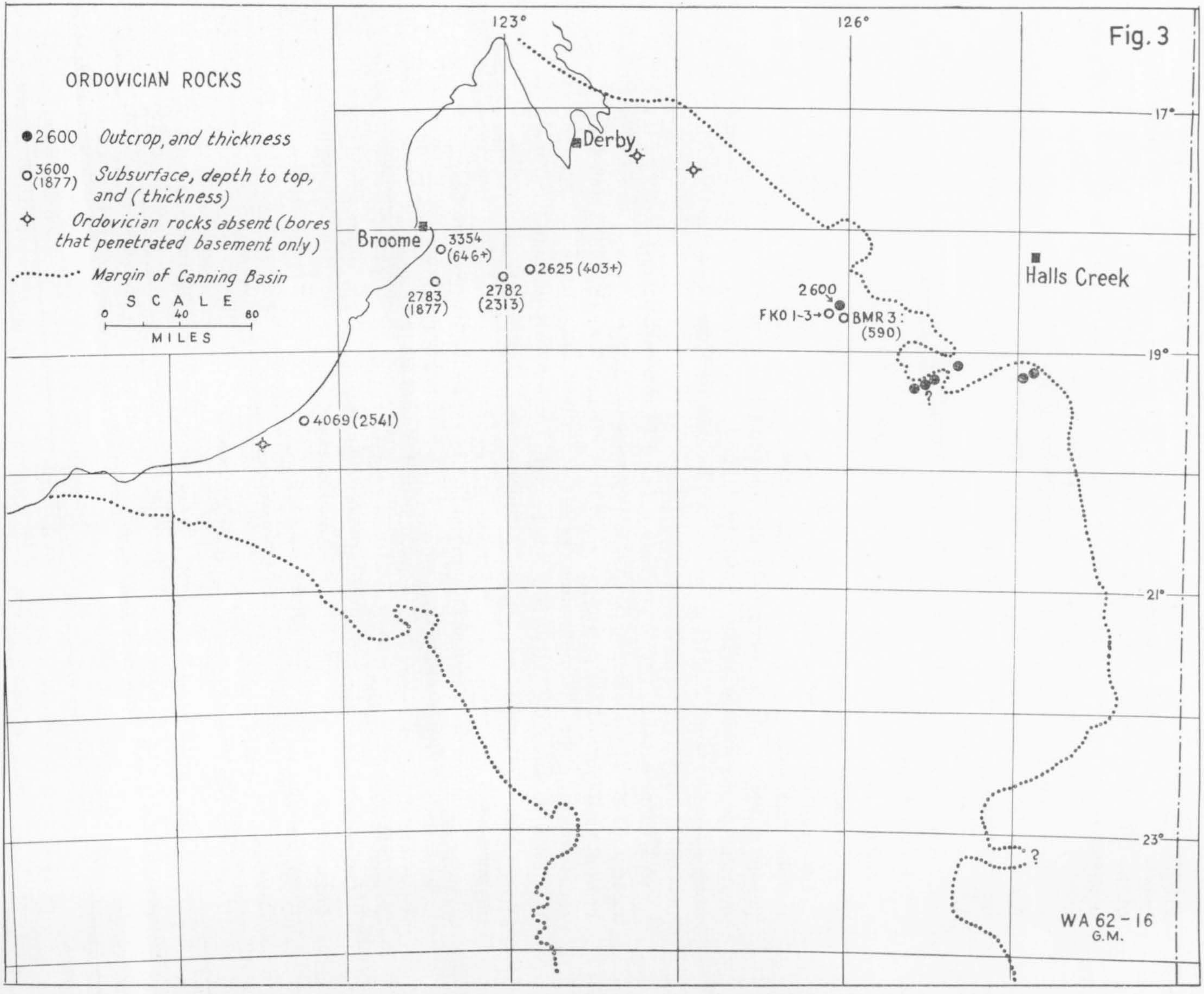


Fig. 3
ORDOVICIAN ROCKS
2600 Outcrop, and thickness
3600 (1877) Subsurface, depth to top, and (thickness)
Ordovician rocks absent (bores that penetrated basement only)
Margin of Canning Basin
SCALE
0 40 80
MILES
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
3354 (646+)
2625 (403+)
2783 (1877)
2782 (2313)
2600
FKO 1-3
BMR 3 (590)
4069 (2541)
?
?
WA 62-16
G.M.

Fig. 3.

TABLE 2

PRECAMBRIAN ROCKS MARGINAL TO THE CANNING BASIN

SUNDAY ISLAND (Brunnschweiler, 1957)	KIMBERLEY PLATEAU (Guppy et al.)	NORTH-EAST CANNING BASIN (Casey & Wells)	SOUTH-WEST CANNING BASIN (Traves et al.)	SOUTH-WESTERN AND SOUTH-EASTERN MARGINS (Appendix 1)
SEDIMENTARY, VOLCANIC, AND INTRUSIVE IGNEOUS ROCKS				
....	*Hart Basalt*: basalt and dolerite flows. *Mt. House Beds*: siltstone, shale, sandstone, quartzite, with bands of limestone and dolomite; sills of dolerite. *Walsh Tillite*: unsorted sediment with boulders up to 7 feet across. *Warton Beds*: medium to fine conglomeratic quartzite, red micaceous sandstone, shale. *Mornington Volcanics*: andesite, dolerite, with interbedded shale and quartzite, dykes of basalt and quartz. *King Leopold Beds*: quartzite, shale, basal conglomerate and sheared conglomerate quartzite.	*Phillipson Beds*: friable coarse and fine sandstone with thin conglomerate beds and micaceous shale; thin basal polymictic conglomerate. *Gardiner Beds*: strongly jointed silicified flaggy sandstone, micaceous shale, and interbedded sandy dolomite. Basal polymictic conglomerate. *Kearney Beds*: steeply dipping silicified, flaggy sandstone with thin beds of conglomerate.	Extrusions of andesitic volcanics. Intrusions of quartz feldspar porphyry and sills of hornblende porphyry in arkosic sandstone. Dolomite and limestone with cap of breccia. Arkosic sandstone.	Silicified massive quartz sandstone with micaceous sandy shale and quartz greywacke.
METAMORPHIC ROCKS AND GRANITE				
Coarse mica-tourmaline quartzite, granite orthogneiss, quartz-mica schist, and quartzite.	*Lamboo Complex*: granitic rocks, acid porphyry, diorite, dolerite, aplite, basic and acid lavas, schist, gneiss, quartzite, quartz reefs.	*Halls Creek Metamorphics*: quartzite, quartz greywacke, slate, siltstone, sandstone. Intrusions of biotite granite with quartz and pegmatite reefs (includes *Lewis Granite*).	Serpentine, talc-chlorite-carbonate schist, dolomitic marble, quartzite, slate, banded hematite, jasper, altered pillow lava, sheared basic volcanics. Intrusions of biotite granite, hornblende granite, with dolerite dykes, quartz reefs, pegmatite veins.	Quartz-feldspar schist, quartzite, amphibolite gneiss. Intrusions of granite with quartz dykes.

Parts of the Ordovician succession are abundantly fossiliferous. From the Prices Creek Group, Öpik (*in* Guppy & Öpik, 1950) records brachiopods, ostracods, conodonts, trilobites, gastropods, nautiloids, and graptolites. Teichert & Glenister (1952, 1954) described the nautiloids; and McTavish (1960, unpubl.) the conodonts. The only fossil recorded from the Ordovician conglomerate and sandstone west of the Wolf Creek Meteorite Crater is the pygidium of the trilobite *Dikelokephalina* (Tomlinson, *in* Casey & Wells). Ordovician rocks in bores have yielded trilobites, graptolites, conodonts, and brachiopods.

A. A. Öpik and J. G. Tomlinson use a time-scale with four subdivisions for the Ordovician succession. In ascending order, the subdivisions, which refer to the stages of the British succession, are Tremadocian, Arenigian, Llanvirnian-Llandeilian, and Caradocian. The British scale is being used until a local scale, based on the shelly fossils of northern Australia, is worked out. Teichert & Glenister (1954) and Glenister & Glenister (1958) refer to àn American time-scale whose subdivisions are not equivalent to those of the scale used by Öpik and Tomlinson.

The oldest known fossiliferous Phanerozoic rocks in the basin are those from Core 9 (5852-62) and Core 10 (6185-87) in Samphire Marsh No. 1 Bore. According to Tomlinson (*in* Johnstone, 1960) these rocks lie 'within the limits of late Upper Cambrian and early Tremadocian (lowermost Ordovician)'. Fossils were not found between 6187 feet and the base of the sedimentary succession at 6610 feet.

The youngest known fossiliferous Ordovician rocks in the basin are those in the upper part of the Gap Creek Formation, which, according to Öpik, lies near the top of the Llanvirnian-Llandeilian. Ordovician rocks in the basin thus span the interval between lowermost Ordovician or possibly uppermost Cambrian to the top of the Llanvirnian-Llandeilian.

Teichert & Glenister (1954) discuss the correlation of the Prices Creek Group as it is indicated by nautiloids. Their conclusions differ only slightly from these of Guppy & Öpik (1950).

Outcropping Ordovician rocks

Prices Creek Group (Guppy & Öpik, 1950; Guppy et al.; McWhae et al.)

The Prices Creek Group is the name given to the Ordovician succession of the Prices Creek area. The succession is about 3100 feet thick, and consists of two conformable sequences, the Emanuel Formation and the Gap Creek Formation (Fig. 4). The *Emanuel Formation* is 2450 feet thick, and consists of interbedded grey limestone and calcareous siltstone, except for the basal 500 feet, which consists of sandy dolomite and arkose (Condon & Henderson, 1960(b), MS.). Glauconite occurs in the arkose, in the sandy dolomite, and in the lower part of the limestone. The Emanuel Formation overlies sheared volcanic rocks, which in turn overlie schist. The schist is Precambrian, and, according to Condon & Henderson, the volcanics are possibly Cambrian. The fossiliferous part of the Emanuel Formation probably ranges from Tremadocian to the top of the Arenigian. The obscured part of the Emanuel Formation—that part penetrated by BMR Prices Creek Bore—possibly ranges down into the lowermost Tremadocian.

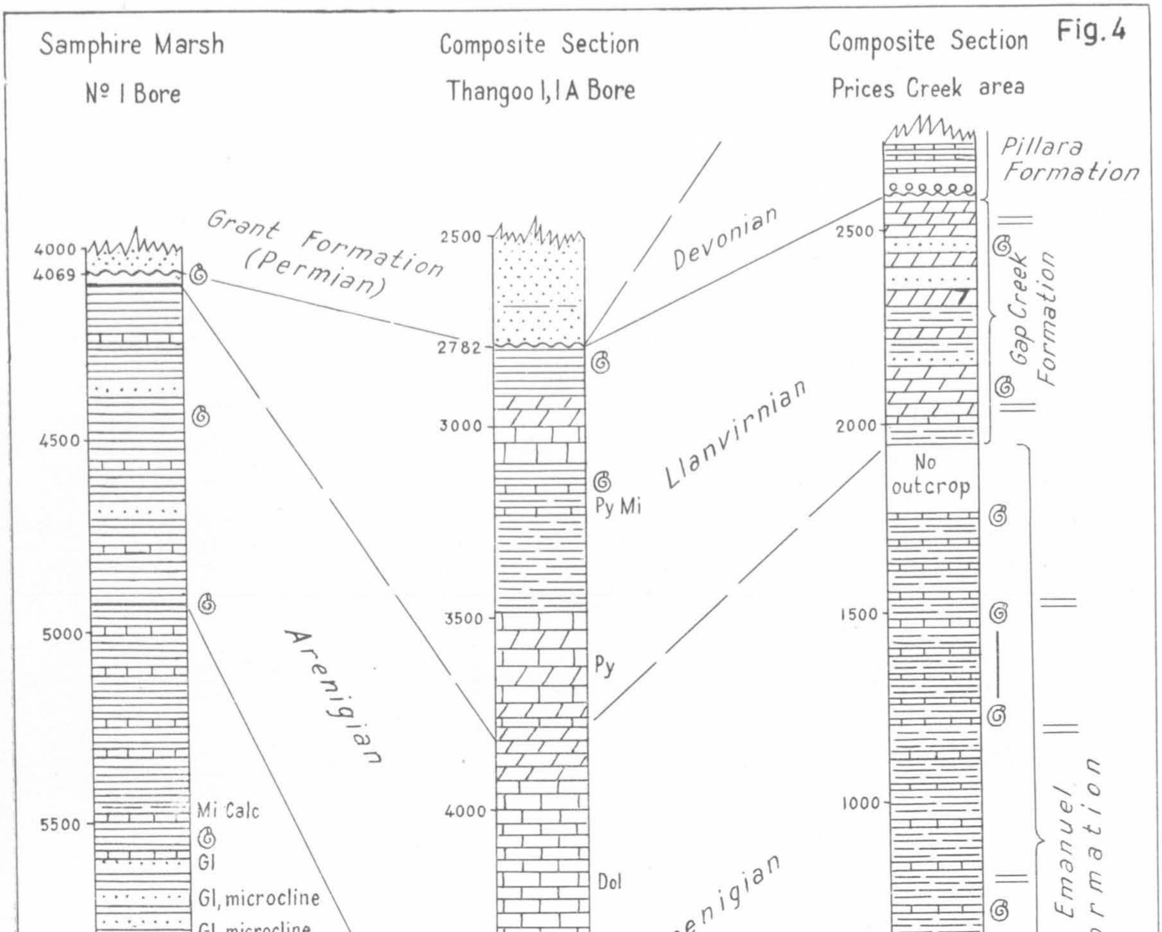


Fig. 4.—Columnar sections of Ordovician rocks.

The *Gap Creek Formation* is at least 630 feet thick, and consists of dolomite and limestone interbedded with siltstone and sandstone; it conformably overlies the Emanuel Formation, and is unconformably overlain by the Devonian Pillara Formation. According to Öpik, its age is Llanvirnian-Llandeilian.

Outcrop 10 miles west of Wolf Creek Meteorite Crater

A low outcrop (Casey & Wells) of 250 feet of gently folded interbedded medium-grained conglomerate and medium-grained quartz sandstone at B3, in the north-western part of the Billiluna 4-mile Sheet area, yielded a trilobite pygidium, which Tomlinson (*in* Casey & Wells) identifies as the late Tremadocian *Dikelokephalina*. The only other fossils are indeterminate worm tracks. The top of this succession is eroded, and its base is not exposed. The conglomerate contains boulders up to one foot across.

Outcrops 10 miles west-south-westward have the same trend and air-photograph pattern as that at B3, and are tentatively regarded as Ordovician. Thirty miles westward, in the Cummins Range, outcrops of gently folded, unfossiliferous, cross-bedded greywacke (MB 58, Appendix 2), with a light, even tone in the air photographs, lie between ridges of contorted Precambrian quartzite. The greywacke is also tentatively regarded as Ordovician. Outcrops in the area with a similar air-photograph pattern have been tentatively mapped as Ordovician.

Subsurface Ordovician rocks

Broome/Dampier Downs area

McWhae et al. and Glenister & Glenister (1958) have published accounts of subsurface Ordovician rocks in the Broome/Dampier Downs area. McWhae et al. (pp. 29, 30) introduced two new names for some of these rocks.

The *Roebuck Dolomite* is the dolomite sequence encountered between 3660 feet and 4000 feet (total depth) in Roebuck Bay No. 1 Bore, and between 2625 feet and 3028 feet (total depth) in Dampier Downs No. 1 Bore. It is overlain by the Grant Formation in the Dampier Downs Bore, and by the Thangoo Calcarenite in the Roebuck Bay Bore. Conodonts (Glenister & Glenister) and a tritoechiine brachiopod, probably *Pomatotrema*, in the Dampier Downs Bore indicate either Arenigian (Canadian), or, because tritoechiines are known in the Gap Creek Formation, Llanvirnian-Llandeilian.

The *Thangoo Calcarenite* was cut between 3354 feet and 3660 feet in Roebuck Bay No. 1 Bore, and consists of calcarenite, which is in part dolomitic, with minor thicknesses of dolomite and calcilutite. It is overlain by the Grant Formation. The Thangoo Calcarenite has not yielded identifiable fossils. According to McWhae et al. (p. 30): 'It is probably of Ordovician age, but may be the same age as the lithologically similar Devonian calcarenites along the north-eastern margin of the Fitzroy Basin.'

The Ordovician succession in Thangoo No. 1A is at least 2313 feet thick. The lithology is shown in Figure 4. Glauconite occurs near the base, and pyrite throughout most of the section. According to Tomlinson, graptolites at 4600 feet indicate Arenigian, and those near the top of the sequence Llanvirnian. The subhorizontal Ordovician rocks overlie steep-dipping phyllite at 5095 feet, which is either Cambrian or Precambrian. Of the marginal sedimentary rocks mapped as Precambrian, the phyllite resembles the Mount House Beds of the Kimberley Plateau, which, as Guppy et al. and Traves (1957, p. 87) indicate, may be Lower Cambrian. The nearest known Precambrian rock is the granite at the bottom of Goldwyer No. 1 Bore. Except in metamorphism, the phyllite is like the siltstone and shale of the overlying Ordovician succession, and is possibly an outlier of rocks that were folded, metamorphosed, and eroded in a postulated diastrophism that intervened between Cambrian and Ordovician deposition.

Samphire Marsh area

The Ordovician succession in Samphire Marsh No. 1 Bore is shown in Figure 4. The fossils, which have been studied by Tomlinson (*in* Johnstone, 1960), indicate lowermost Ordovician or uppermost Cambrian to Arenigian. Tomlinson distinguishes about 30 species of shelly fossils, including brachiopods, ribeirioids, trilobites, ostracods, gastropods, pelecypods, and a machaeridian; graptolites, conodonts, and worm tracks are associated with the shelly fossils.

Discussion

The recorded Ordovician rocks of the Canning Basin lie within an area stretching from Long. 121° E to 127½° E, and Lat. 18° S to 19½° S. Correlation between these widely spaced localities is established by abundant fossils. Too little is known of the rocks themselves, however, to indicate anything but the broad outlines of the geological history.

The oldest known Phanerozoic fossils in the Canning Basin are those from Cores 9 and 10 of the Samphire Marsh No. 1 Bore, which, according to Tomlinson, 'indicate an age within the limits of late Upper Cambrian and early Tremadocian'. Even if these rocks are early Tremadocian, the underlying 400 feet of rock almost certainly ranges down into the Cambrian. Doubtful Cambrian rocks are the volcanic rocks that lie between the Precambrian and Tremadocian rocks in BMR 3 Prices Creek Bore, and the phyllite that underlies the Ordovician rocks in Thangoo No. 1A Bore. Öpik (1957, p. 252) observed that during the lower Middle Cambrian 'in Western Australia shield conditions prevailed. The Flexible Belt [the western part of which is thought to cross the Canning Basin] may have been inundated, but the region is unexplored and no evidence is available as yet'; this still holds true.

The discovery in 1958 of probable late Upper Cambrian sandstone and thin dolomite beds in the Samphire Marsh No. 1 Bore fulfilled Öpik's (1957, pp. 257-258, fig. 7) prediction that 'in Upper Cambrian time, the Flexible Belt was completely submerged and was surrounded by three lands: the Kimberley Platform, Carpentaria, and the united Western Australian Shield and South Australian land'. Upper Cambrian rocks are unknown elsewhere in the basin; the nearest are 200 miles north-east in the Cambridge Gulf area (*Clark Sandstone*, Traves, 1955, p. 53). BMR 4A Wallal Bore, 30 miles south-westward of the Samphire Marsh Bore, passed through Permian sediments into Precambrian granite; Goldwyer No. 1 Bore, 110 miles north-eastward, passed through Ordovician rocks into Precambrian granite. Most of the oil exploration bores were situated on structural culminations over which the older rocks may have been removed.

In the Tremadocian, glauconitic sandstone and shale, and calcarenite and shale, were deposited in the Samphire Marsh area, glauconitic arkose, sandy dolomite, limestone, and shale in the Prices Creek Area, and conglomerate, quartz sandstone, and greywacke in the area west of the Wolf Creek Meteorite Crater. The extent of the Tremadocian sea is unknown. The boulders one foot across in the conglomerate near the Meteorite Crater were derived either from quartzite exposed nearby in a postulated shore or island, or from 'ready-made' boulders in underlying rock. In the Samphire Marsh area, deposition of calcarenite and shale continued into the Arenigian; in the Thangoo area deposition started in the Arenigian, and sandstone, dolomite, shale, and siltstone were succeeded by dolomite and dolomitic limestone. The Arenigian interbedded siltstone and limestone in the Prices Creek area indicate that uniform conditions were maintained by slow subsidence.

The Llanvirnian rocks in the Thangoo Bore changed little from the preceding Arenigian deposits. In the Prices Creek area, interbedded siltstone and limestone gave way to dolomite and thin beds of sandstone and siltstone. No Ordovician sediments younger than Llanvirnian-Llandeilian are known in the Canning Basin. The erosion of the Gap Creek Dolomite, which the Devonian Pillara Formation overlaps to rest directly on Emanuel Formation, indicates that younger Ordovician rocks were probably deposited in the Prices Creek area, and later stripped off.

All the known Ordovician rocks of the Canning Basin were probably deposited in shallow sea-water. Benthonic organisms, such as brachiopods and trilobites, indicate that the sea bottom was well aerated; the remains of these organisms, and those of planktonic organisms, including graptolites, were buried in the sediment, which in most areas is now in a reduced condition.

Whether the Ordovician sea in the Canning Basin was continuous with that in central Australia will be discussed under 'Structure'.

DEVONIAN*

All recorded Devonian rocks in the Canning Basin lie north of the line joining Roebuck Bay and Balgo Mission (Fig. 5). Four separate areas of Devonian or probable Devonian outcrop are known:

(1) The main outcrop, which fringes the northern margin of the basin, and extends 170 miles from the north-west of the Van Emmerick Range to the Sparke Range (see the 8-mile map in Guppy et al.).

(2) An area near Bohemia Downs, 20 miles south-east of the main outcrop.

(3) The Knobby Hills area, which lies 50 miles east-south-east of the Bohemia Downs outcrop.

(4) A small area which lies 10 miles east of Balgo Mission.

The rocks of (3) and (4) are dated by plants (*Leptophloeum*) which indicate Upper Devonian or Carboniferous, but because *Leptophloeum* elsewhere in north-western Australia is known only from Upper Devonian rocks, the rocks in these areas are tentatively assigned to the Upper Devonian.

* By J. H. Rattigan, University College, Newcastle, New South Wales, and J. J. Veevers.

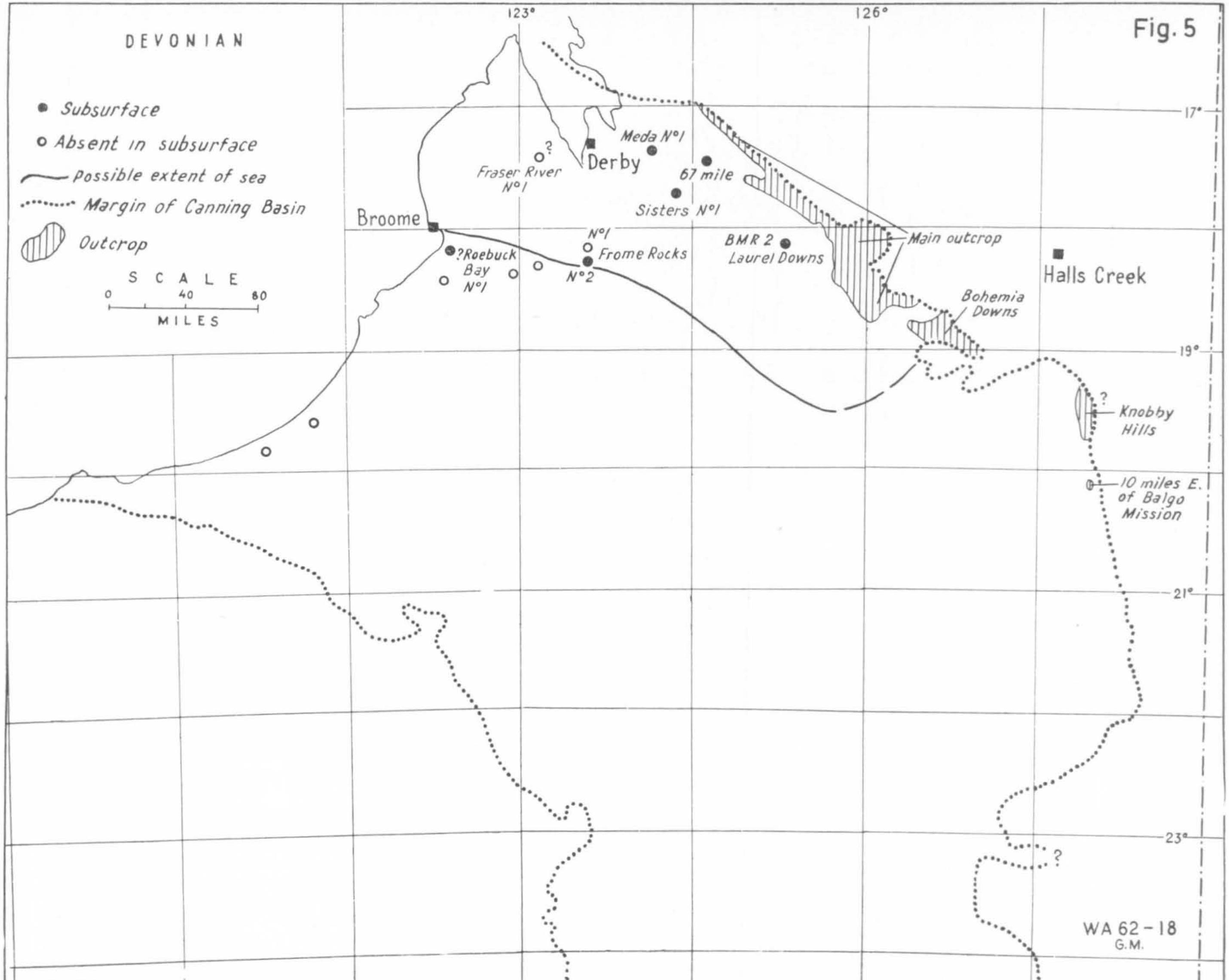


Fig. 5
DEVONIAN
Subsurface
Absent in subsurface
Possible extent of sea
Margin of Canning Basin
Outcrop
SCALE
0
40
80
MILES
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
Meda No1
67 mile
Sisters No1
Fraser River No1
No1
Frome Rocks
No2
?Roebuck Bay No1
BMR 2 Laurel Downs
Main outcrop
Bohemia Downs
Knobby Hills
10 miles E. of Balgo Mission
WA 62-18
G.M.

Fig. 5.

Subsurface extensions of the Devonian rocks are known from the records of five, or possibly six, deep bores in the north-western part of the basin.

All the known Devonian rocks have been regionally mapped, but the published stratigraphical nomenclature deals with broad units only, and most of it is considered preliminary. Eighteen formations have been distinguished in the main outcrop (Guppy et al., McWhae et al.). Only a few formations are clearly recognizable units of uniform lithology; the others are less uniform, and have arbitrary boundaries where they pass upwards into younger units or laterally into different rocks of the same age. More detailed surface and subsurface work will undoubtedly lead to the recognition of additional stratigraphical units.

The main outcrop is one of the finest outcrops of Devonian rocks in the world: it is well exposed, richly fossiliferous, and relatively little disturbed by folding and faulting. This outcrop is therefore ideal for detailed studies on sedimentation, stratigraphical relationships, and faunal distribution. The abundance of ammonoids led Teichert (1949) to claim 'that the correlation of the *Manticoceras* Beds of the Kimberley District is firmly established, probably more so than that of any other unit of the stratigraphic scale of the Australian continent', and his claim has been supported by later workers. Virtually all groups of Devonian fossils have been collected, and each group is represented by numerous species and individuals.

The main outcrop also contains an abundance of organic reefs of various types and sizes, none of which has hitherto been adequately described.

The significance of rich organic sediments as potential source rocks of oil, and of reef structures as potential traps, need not be stressed. Moreover, some of the marginal Devonian rocks contain thin bands of chemically precipitated calcite and gypsum, which were possibly deposited under conditions similar to those responsible for the deposition of the salt discovered by boring in Frome Rocks No. 1 Bore. So far, the Devonian rocks have not produced oil, but each of the four, or possibly five, deep bores drilled since 1957 that has cut Devonian rocks has provided valuable information for the continuing search for oil.

Palaeontological work on outcropping Devonian rocks has made it possible to correlate the subsurface sections cut by these bores. The most detailed attempt at correlation has been made by Veevers (1959, fig. 3). This correlation refers to a time-scale in which the Middle Devonian (Givetian) is represented by two zones, and the Upper Devonian by ten zones. More detailed work may refine this zonal scheme, but for the moment it is the chief means of detecting faunal and depositional breaks in the succession. Jones (Appendix 3) recognizes ostracods in Devonian-Carboniferous rocks younger than known outcrops of Veevers' highest zone.

In the following pages, a synthesis of the geological history of the Devonian is presented, so far as present knowledge allows, and attention is drawn to aspects of this subject which merit further study.

Since Guppy et al. and McWhae et al. went to press in 1957, new information on the Devonian has been provided by:

(1) Records of exploratory bores (Meda Nos. 1 and 2, Frome Rocks No. 2, The Sisters No. 1, BMR 2 Laurel Downs, and possibly Roebuck Bay No. 1).

(2) The discovery of probable Upper Devonian plant fossils at Knobby Hills and near Balgo Mission.

(3) Palaeontological studies, including descriptions of goniatites (Glenister, 1958) and brachiopods (Veevers, 1959); the discovery of abundant conodonts, arenaceous foraminifera, and radiolaria (Glenister & Crespin, 1959); and the studies of Mary White (Appendix 6) on plants, and of P. J. Jones on ostracods (Jones, 1960, and Appendix 3), and the unpublished work by B. E. Balme on spores, and G. A. Thomas on brachiopods.

Rattigan's unpublished M.Sc. thesis (Adelaide University, 1954) contains information not elsewhere available, and many of his concepts concerning sedimentation during the Devonian are used here. Furthermore, as one of the authors of this chapter, Rattigan has contributed hitherto unrecorded information derived from his field experience with the Bureau Kimberley Party during 1949 to 1952.

CORRELATION

All the formations recognized by Guppy et al. in the main outcrop are entered in the correlation chart (Fig. 6). The time-scale of the chart is based on the ranges of assemblages of brachiopods, ammonoids, and stromatoporoids. Twelve zones are recognized; the sequence of stromatoporoid, brachiopod, and ammonoid zones is based on superposition; that of isolated ammonoid zones is determined by reference to the standard sequence of ammonoids. The zones are based on imperfect and incomplete data, and are capable of refinement. Few zones directly succeed one another, and further work should aim at finding the exact overlap of zones, and at extending the zonal scheme to rocks in which fossils have not yet been found.

Formations have been entered in the chart by reference to fossil content and to field relations, in particular superposition and interdigitation. Most of this information was compiled by Veevers (1959, fig. 3). Omissions in that paper, and new information, require the following amendments to his figure 3:

(1) The lower part of the Virgin Hills Formation lies within the Upper *Manticoceras* zone (Glenister, 1958).

(2) Fossils indicating either the *apena* or the lower *Manticoceras* zone have not yet been found in the Pillara Formation in the Emanuel Range.

(3) Part of the Copley Formation contains Frasnian goniatites, probably those indicating the widespread upper *Manticoceras* zone (McWhae et al., p. 39); and Rattigan's field work shows that the Copley Formation interfingers with the Pillara Formation.

(4) The Geikie Formation is continuous on the west side with the Brooking Formation, and on the east with the Copley Formation (Guppy et al., pp. 36-37).

(5) The Oscar Formation is continuous with the Brooking Formation (Guppy et al., p. 36).

(6) Probable Lower Carboniferous rocks are exposed in the Napier area, where formerly only Devonian rocks were known (Jones & Thomas, 1959, unpubl.).

Figure 6, which includes these amendments, supersedes figure 3 of Veevers (1959).

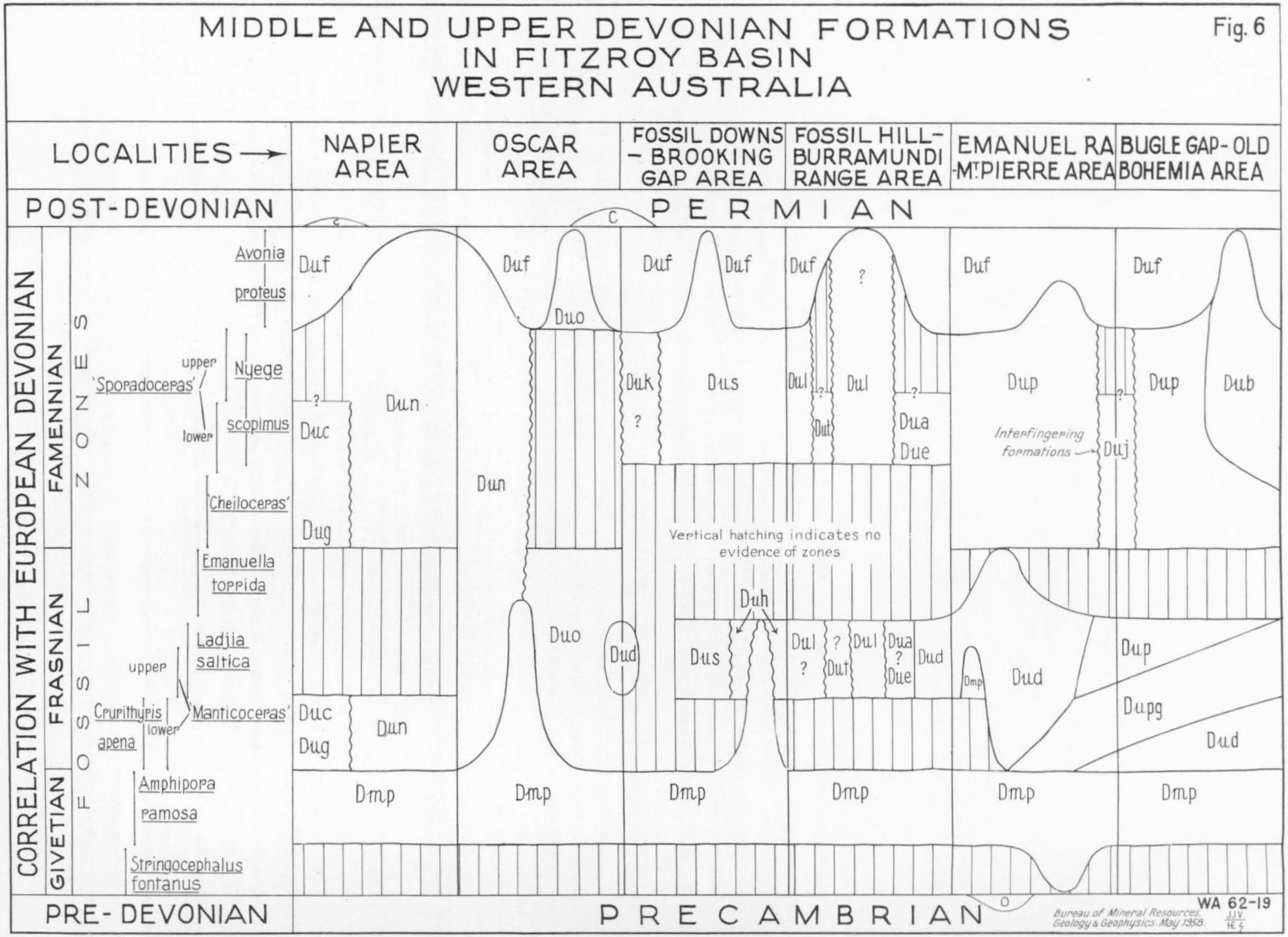


Fig. 6.—Devonian correlation chart. Dmp—Pillara Formation; Dua—Burramundi Conglomerate; Dub—Bugle Gap Limestone; Duc—Behn Conglomerate; Dud—Sadler Formation; Due—Mount Elma Conglomerate; Duf—Fairfield Beds; Dug—Van Emmerick Conglomerate; Duh—Copley Formation; Duj—Sparke Conglomerate; Duk—Brooking Formation; Dul—Fossil Downs Formation; Dun—Napier Formation; Duo—Oscar Formation; Dup—Virgin Hills Formation; Dupg—Gogo Formation; Dus—Geikie Formation; Dut—Stony Creek Conglomerate.

The joint Wapet-BMR party (1953) collected fossils from a few areas only, and no serious search was made for fossils in reef barriers and in associated deposits of the fore and back reef. The fossils so far collected indicate contemporaneity between far-spaced rocks only. Our claim, based on field observations, that the rocks associated in reefs are contemporaneous therefore has yet to be tested by palaeontology. Sampling was also too general for palaeoecology. We hope that what follows will stimulate detailed sampling directed at the solution of problems of correlation and palaeoecology.

The Main Outcrop

The main outcrop corresponds broadly with Devonian barrier reefs. Only a small, but very significant, part of the outcrop consists of organic rocks: detrital limestone (off-reef deposits), chemically precipitated rocks, and terrigenous detritus are each as abundant as organic limestone. Within the main outcrop, six types of reef or their associations are distinguished. These are:

Bioherm: Small lens of massive diagenized limestone, with a framework mainly of algae and stromatoporoids (rarely of corals) that grew upwards faster than the contemporaneous deposition of detritus (Figs. 24, 27).

Biohermal reef: Wall of massive diagenized limestone, with a framework of algae and stromatoporoids (Fig. 28).

Biohermal reef barrier: Biohermal reef that bounds biostromes and other sediments of the back reef (Fig. 20).

Biostrome: Tabular limestone with an organic framework (stromatoporoids, algae, corals) that grows upwards faster than the contemporaneous deposition of detritus, and at roughly the same rate as bioherms (Figs. 15, 30, 31).

Reef complex: Undifferentiated complex of bioherms, biostromes and off-reef clastics (Figs. 26, 34).

Reef mass: Comprehensive term for continuous body of rock deposited as a result of the upward growth of algae and stromatoporoids. In many places, consists of biostromes bounded by biohermal reef barrier.

Guppy et al.'s description of the main outcrop requires critical examination. Guppy et al. describe most of their formations from single sections only, and provide few details of lateral variation. Many Upper Devonian formations simply include all the rocks of a certain area that were deposited during the Upper Devonian: for example, the Napier Formation includes all the Upper Devonian rocks, except conglomerates and the upper part of the Pillara Formation, of the Napier Range area. Consequently the boundaries, both vertical and lateral, of many formations are arbitrary, and most formations are too broadly or too narrowly defined to faithfully reflect the geological history. We do not formally reclassify the rocks of the main outcrop; our intention is to add to the understanding of the rocks by supplying whatever additional information we can, and by describing the geological history.

The stratigraphy of the main outcrop is complicated by the effects of a diastrophism which took place during the Upper Devonian, and by the abundance of organic reefs, features not adequately described by Guppy et. al. Our ideas are expressed mainly by a diagrammatic section along the regional strike of the main outcrop (Fig. 7), by a time chart (Fig. 6), and by a map showing the variation in lithology (Fig. 8).

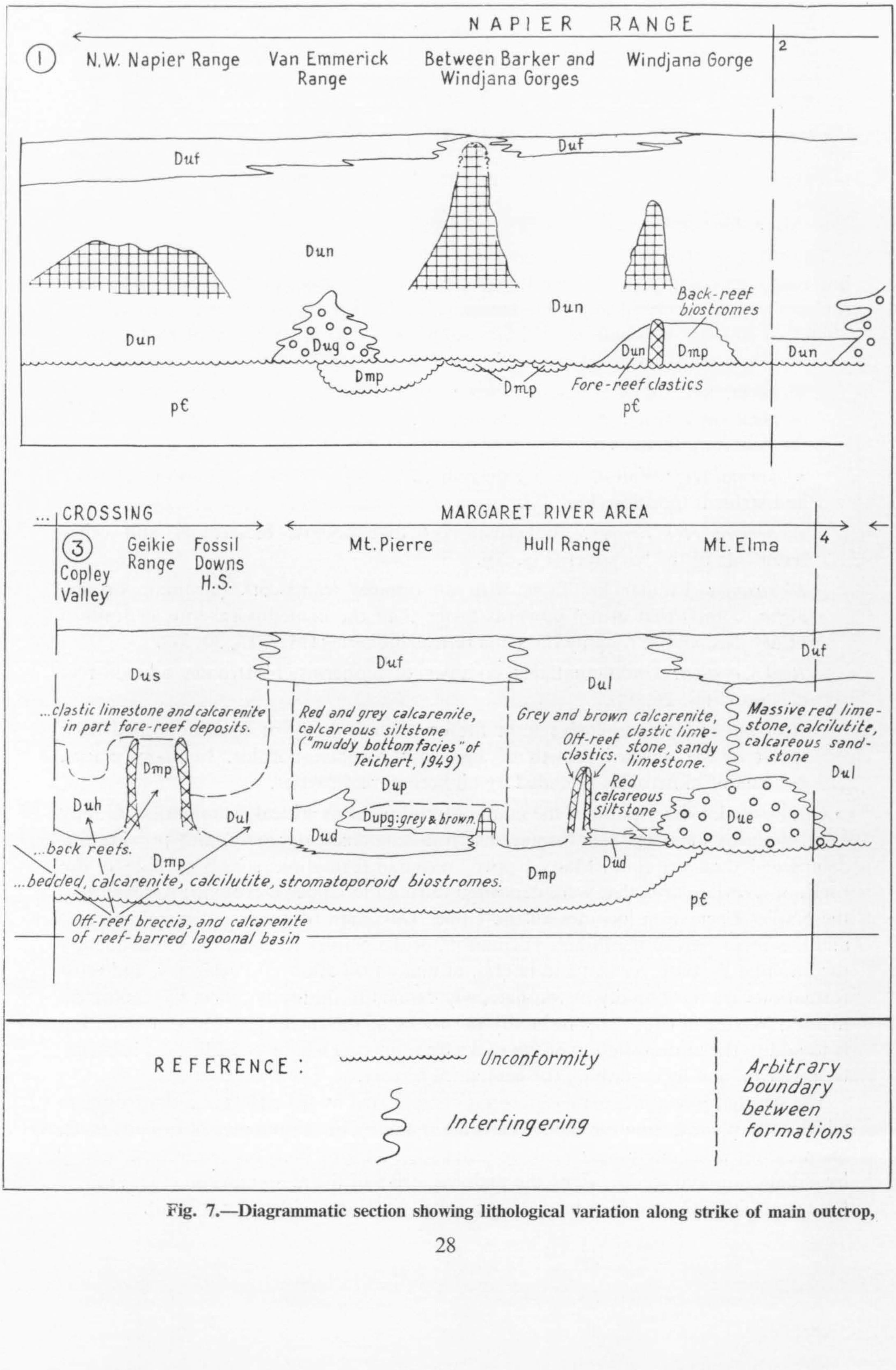
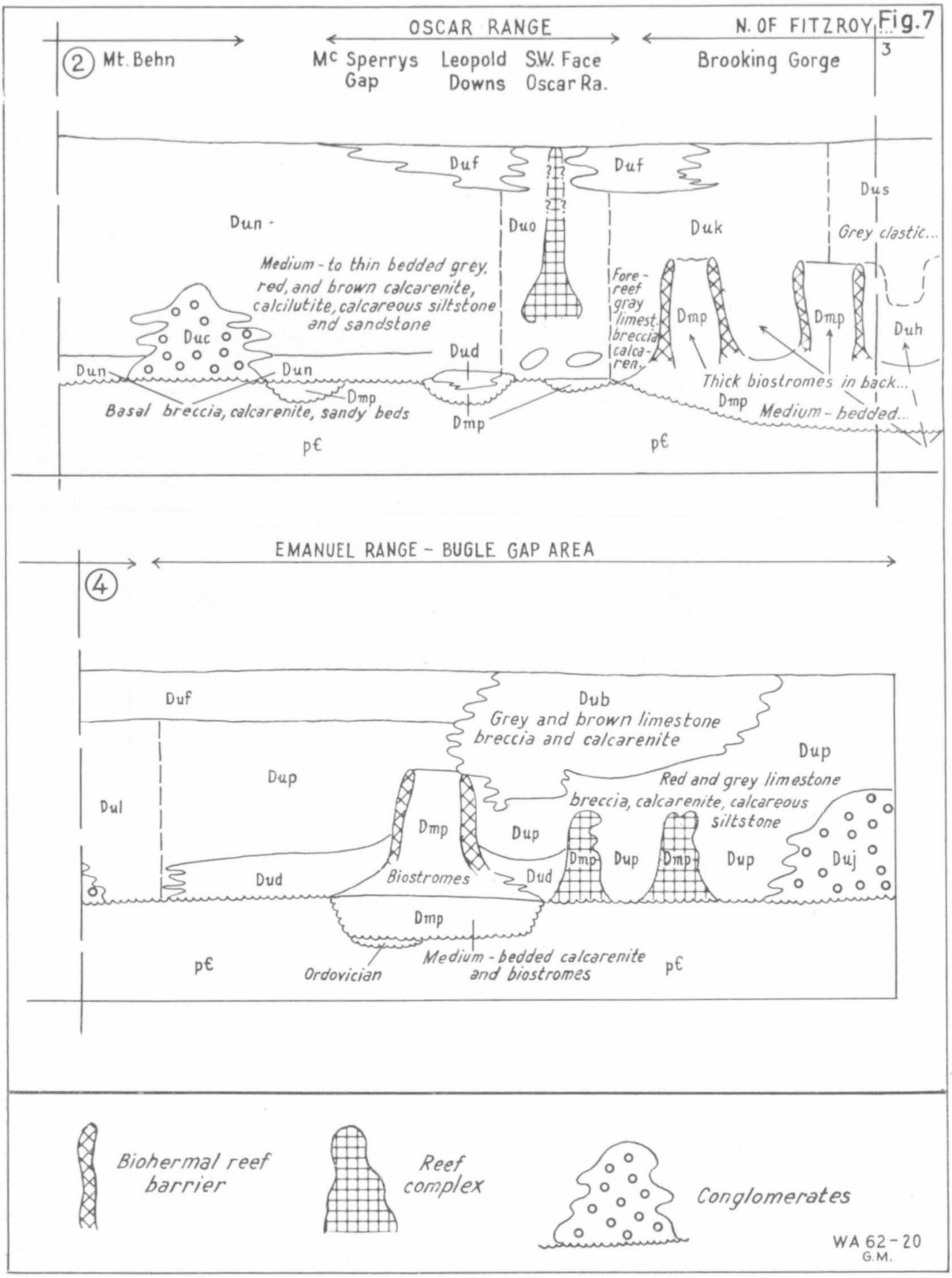


Fig. 7.—Diagrammatic section showing lithological variation along strike of main outcrop,



and formation names defined by Guppy et al. See Figure 6 for key to letter symbols.

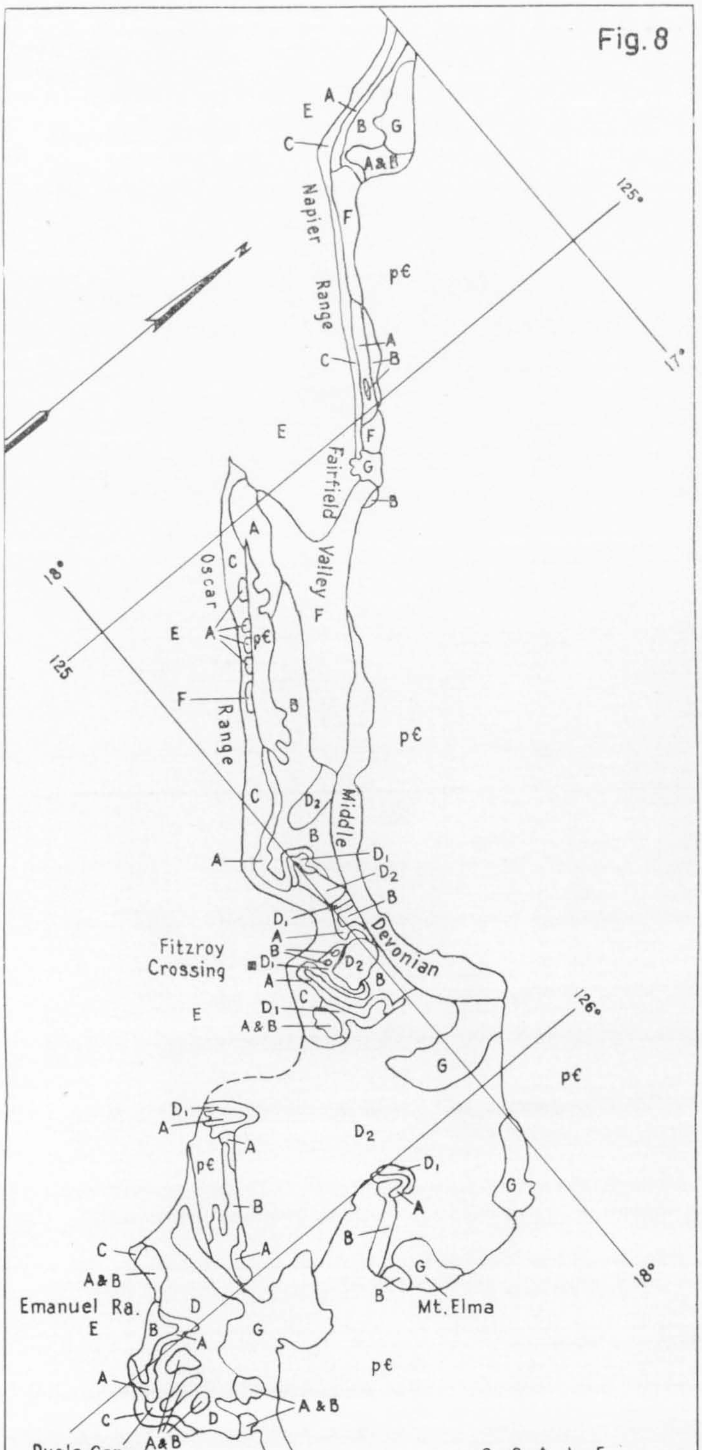


Fig. 8.—Lithology and depositional environments of Upper Devonian rocks of main outcrop. A—reef barrier; B—back reef; C—fore reef of open basin; D—shelf basin or lagoon partly enclosed by reefs; E—open basins on seaward side of reef; F—basin edge lateral to reef; G—near-shore torrential fans.

Pillara Formation

The Pillara Formation is defined by Guppy et al. as the lowermost unit in the succession. Palaeontology and field work indicate that the Pillara Formation ranges from the Givetian, to which Guppy et al. restricted it, to the Frasnian. The base consists of medium-bedded calcilutite, calcarenite, stromatoporoid biostromes, and sandy limestone (Figs. 13, 14) that overlie Precambrian and Ordovician rocks along the edge of the basin or around inliers. Terrigenous material locally forms a large part of the rock; elsewhere, the base consists of pure carbonate rock, including coquinite. Dunbar & Rodgers' (1957, p. 142) description of an overstepping limestone is worth quoting because it also describes the overstep of the Pillara Formation:

'If subsidence very greatly exceeds supply, ordinarily because of very limited supply rather than very rapid subsidence, the deposits of the spreading sea will be little affected by the land-derived material. What material is supplied will be spread discontinuously at the base of the marine deposit, probably as local patches of basal sandstone or conglomerate, and these basal layers will be followed directly by open sea deposits (commonly limestone) virtually free of terrigenous matter. The relation of the deposit to the underlying rocks will be that of *overstep*, and lateral facies changes (at least as conditioned by the overstep) will be negligible. An example is the overstep of Ordovician limestone over Precambrian rocks on the south margin of the Canadian Shield from the north shore of the St. Lawrence River to Lake Timiskaming and the Hudson Bay Lowland. Locally there is a basal sandstone or conglomerate, but elsewhere clean limestone rests directly on the Precambrian basement, and corals are found where they grew in clefts or attached to the surface of the crystalline rocks.'

The medium-bedded basal rocks are succeeded by thicker-bedded biostromes (Fig. 15). The upper part of the Pillara Formation is lithologically distinct from the underlying part, and its stratigraphical relationships with adjoining formations are complex. In some areas, biostromal growth was partly restricted by biohermal barriers behind which biostromes accumulated as back-reef deposits. Clastic rocks were deposited contemporaneously in between reef masses. These clastics are assigned to other formations. Many difficulties in understanding the relationships between the Pillara Formation and other formations could be solved by detailed mapping of distinct rock units now grouped in the Pillara Formation. Some of these relationships are described below.

Diastrophism during the Upper Devonian, and its effect on the morphology of the shelf

Upper Devonian formations contiguous with portions of the Pillara Formation vary widely in their structural relationships with that formation. An angular unconformity between the Pillara Formation and succeeding formations indicates an uplift and an erosional interval before post-Pillara deposition (Fig. 16). This unconformity is not to be confused with the steep depositional dips of clastic rocks off subhorizontal reef masses. Elsewhere, the succession is conformable from the base of the Pillara Formation through to the youngest Devonian rocks, and the known fauna indicates no break in deposition.

These complex relationships can be explained in terms of a diastrophism which took place during the Frasnian. Evidence for tectonic activity during the Devonian, as determined from field studies, falls under three heads:

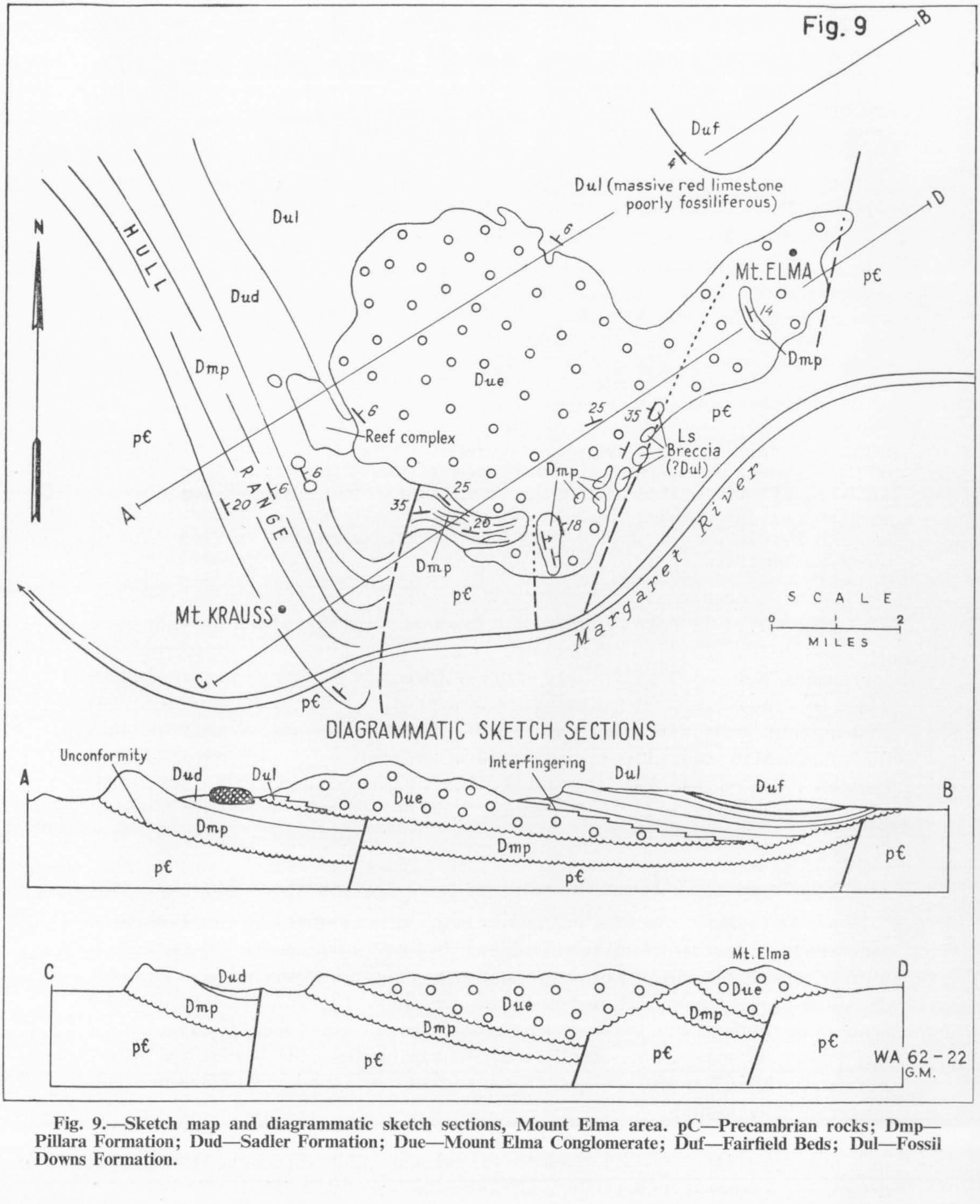


Fig. 9.—Sketch map and diagrammatic sketch sections, Mount Elma area. pC—Precambrian rocks; Dmp—Pillara Formation; Dud—Sadler Formation; Due—Mount Elma Conglomerate; Duf—Fairfield Beds; Dul—Fossil Downs Formation.

1. Deformation and erosion, expressed by angular unconformity between rocks mapped as the Pillara Formation and overlying Upper Devonian sediments, is clearly shown at many localities along the northern face of the Napier Range (Fig. 16), the southern face of the Oscar Range, and in the Mount Elma area.

2. Faults active during the Devonian were recorded by J. H. Rattigan, whose mapping was later confirmed by McWhae et al. The field relationships of the Mount Elma area (Fig. 9) indicate that the Pillara Formation and the Precambrian basement were broken into tilted blocks by north-trending faults during the Frasnian; the Mount Elma Conglomerate later filled in depressions, partly concealing the faults, and unconformably overlies the eroded Pillara Formation in the faulted blocks. In less disturbed areas to the south and west (Emanuel Range/Bugle Gap area), deposition was essentially continuous from Givetian to Famennian.

Further evidence is available from the structure of the Pillara Formation and of the Upper Devonian rock units in the series of parallel ranges, Emanuel, Pillara, and Hull, and many smaller outcrops in the Margaret River area. In these *en echelon* blocks, the Pillara Formation has been tilted in a direction opposite to the regional basinward dip. North-west strike faults outline these blocks, and were considered by J. H. Rattigan to be early Upper Devonian. McWhae et al. (p. 137) agree with this view, and consider that the main movement along one of the Virgin Hills Faults ceased before the close of the Upper Devonian.

Along the southern face of the Oscar Range small remnants of Pillara Formation dip northward toward the Precambrian basement and are unconformably overlain by the Oscar Formation, which dips steeply southward. A concealed west-north-west fault of Frasnian age possibly underlies this area.

3. The internal evidence of the sedimentary record: the Upper Devonian succession is characterized by an almost bewildering variety of lithological divisions, which first appear in the Frasnian, in contrast to the relative uniformity of the lower, Givetian, part of the Pillara Formation. Three features directly indicate tectonic events; the first is the sudden appearance of conglomerates and coarse basal breccias in areas previously marked by organic deposits (biostromes) laid down in clear quiet water; the second is the shallowing of depositional basins in some areas, as in the Oscar Plateau, indicated by the appearance of mudcracked laminated calcilutites, in contrast to the underlying thick biostromal deposition indicative of long-continued subsidence; the third is the growth of biohermal reefs.

The intensity of the diastrophism, expressed chiefly by block faulting, varied from place to place in the marginal shelf area. The shore-line must have changed position markedly, and the environment of sedimentation changed as a result of the movements. In many areas, such as the Mount Elma area, the unconformity is proof that blocks of Middle Devonian rocks emerged above sea level and were eroded before Upper Devonian rocks were laid down on them. Over the downfaulted areas, on parts of the shelf which did not emerge above sea level, deposition was continuous, but the new conditions caused changes in the lithology of the sediments.

Relationships between rock units deposited during the Upper Devonian

The relationships between rocks deposited during the Upper Devonian, except the conglomerates, cannot be adequately described in terms of the formations named by

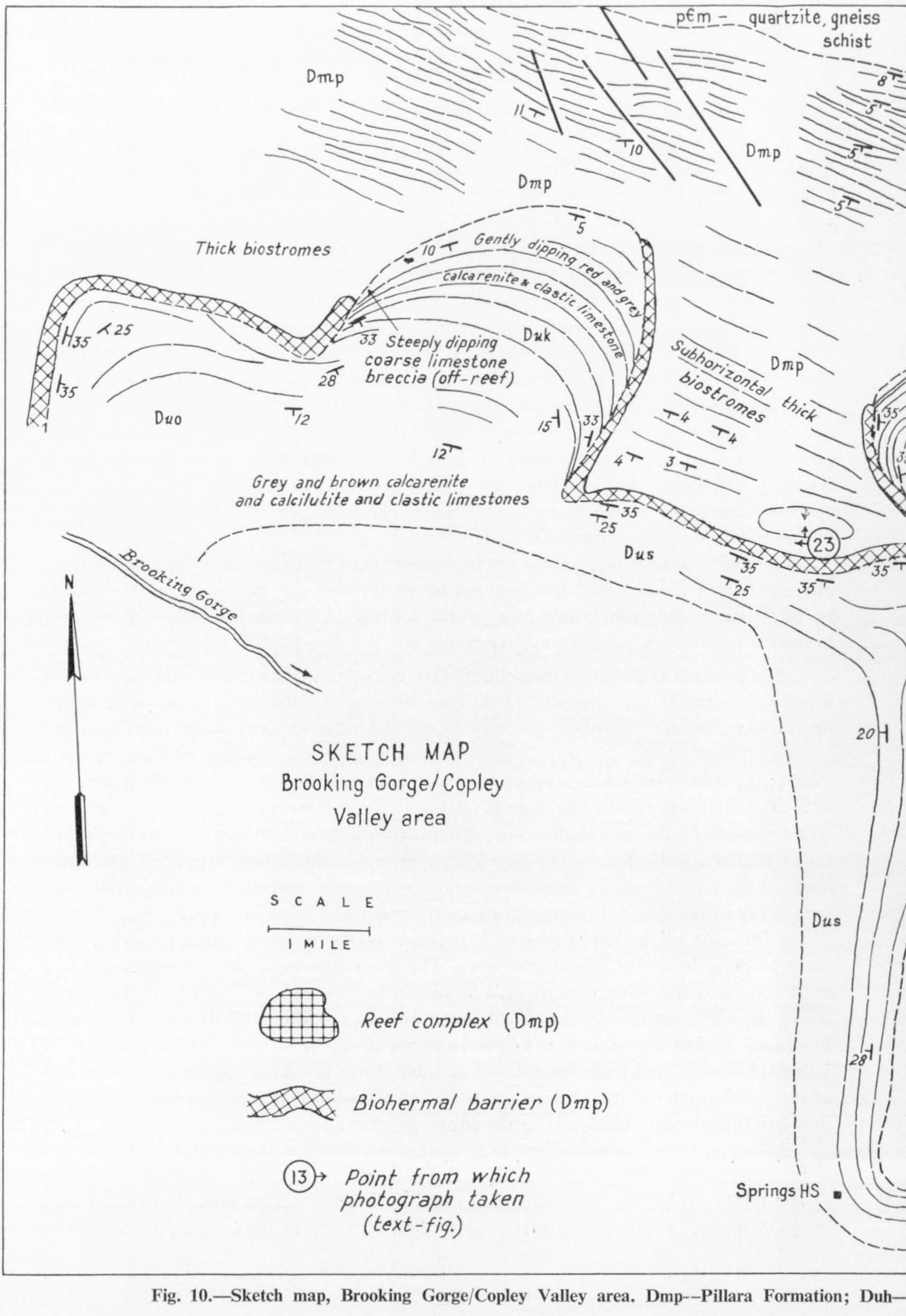
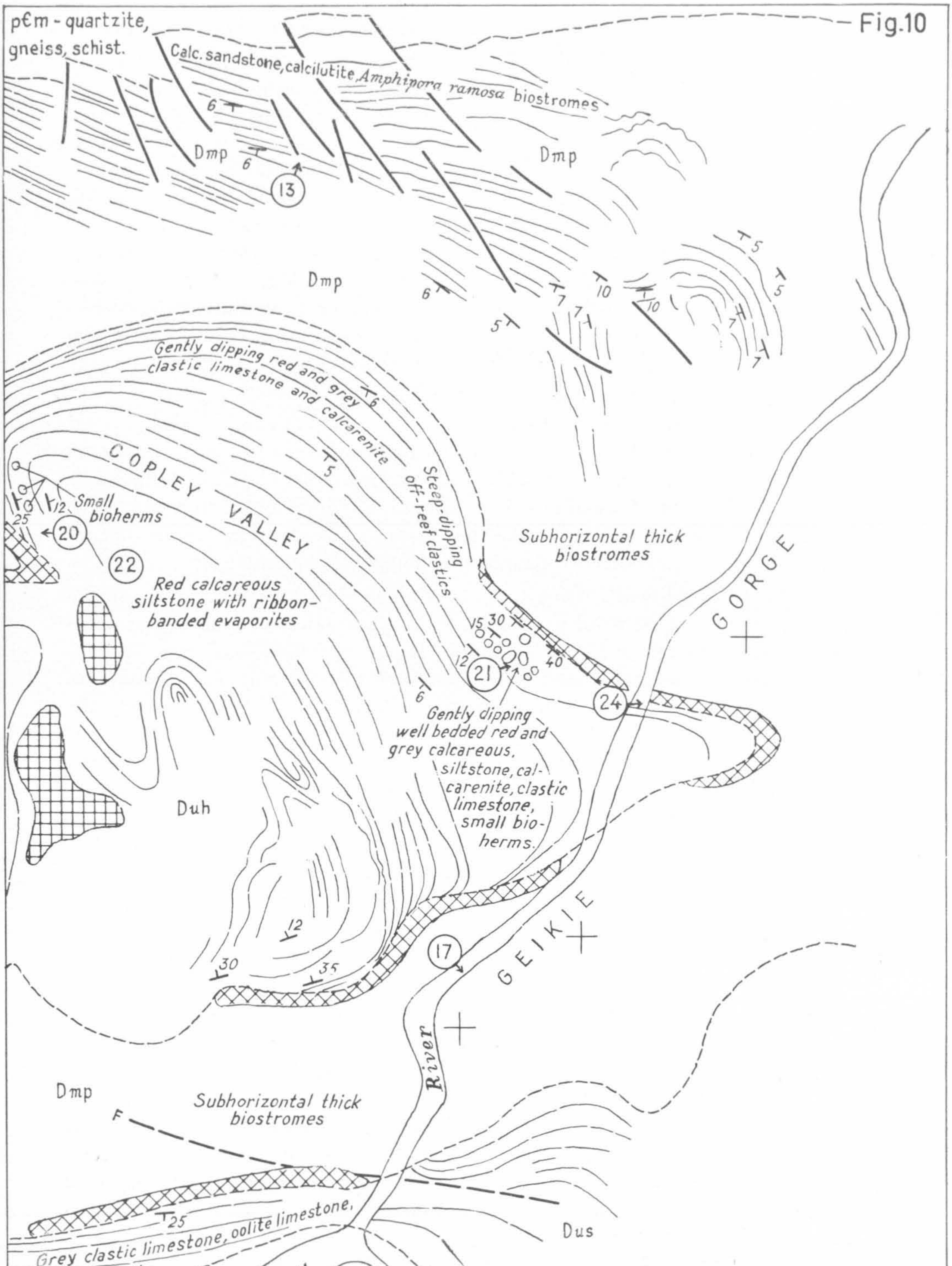


Fig. 10.—Sketch map, Brooking Gorge/Copley Valley area. Dmp--Pillara Formation; Duh—



Copley Formation; Duk—Brooking Formation; Duo—Oscar Formation; Dus—Geikie Formation.

Guppy et al. The relationships as interpreted from present knowledge are expressed in a diagram (Fig. 7) and in the time chart (Fig. 6).

The *Upper Devonian conglomerates* (Figs. 18, 19) probably first appeared in the upper part of the Frasnian, as indicated by the appearance of pebbles and boulders in rocks mapped as the uppermost part of the Sadler Formation in the Castle Rocks area (Fig. 9), and by conglomerate and sandstone that soon after became dominant in the section. The conglomerates are isolated lenses that tongue outward from the basin margins, and from their lithology and shape can be presumed to be fans formed by torrential streams. In part they may be terrestrial, but marine fossils are found in some beds, and the rocks also interfinger with the marine Virgin Hills Formation, Fossil Downs Formation, and Napier Formation. The field relationships at Mount Elma (Fig. 9) indicate that deposition of conglomerate in this area ceased before the beginning of the *Sporadoceras* zone, because conglomerate is overlain by rocks, included in the Fossil Downs Formation, containing *Sporadoceras*.

The relationships between the Pillara Formation and adjoining formations are complex. In many areas there is evidence of unconformity between rocks mapped as Pillara Formation and others mapped as Napier, Oscar, Sadler, Geikie, Brooking, Gogo, and Fossil Downs Formations. This unconformity is related to the early Upper Devonian diastrophism. In some areas the Pillara and adjoining formations are conformable and in others reef structures have complicated relationships.

Figure 10 shows the field relationships in the Geikie/Brooking Gorge area. In this area, the medium-bedded basal part of the Pillara Formation extends continuously along the outcrop margin and dips basinwards. Higher in the sequence, the continuity of the medium-bedded rocks is interrupted, and biostromes are bounded by biohermal barriers that appear as promontories on the geological map. All these rocks are mapped as Pillara Formation. Between the reefs, in the Copley Valley and north of Brooking Gorge, the medium-bedded Pillara Formation is succeeded by limestone breccia and calcarenite, which have been included in other formations. At the head of Copley Valley, the Copley Formation conformably succeeds the gently dipping medium-bedded Pillara Formation; from the head of Copley Valley, the beds swing round in an arc with increasing dip to abut against the biohermal reef barriers that lie normal to the regional strike (Fig. 20). In plan, these reef barriers lie at a tangent to the trends of the Copley Formation. Where reef barriers are parallel to the regional strike (Fig. 21), the Copley Formation trends parallel to the barriers and dips steeply. Similar rocks north of Brooking Gorge are called he Brooking Formation.

The reef-bounded biostromes of the Pillara Formation east and west of the Copley Valley are younger than the medium-bedded part of the Pillara Formation of the basin margin, and are probably back-reef deposits laid down behind biohermal masses that started growth early in the Frasnian. The field evidence indicates that the Copley Formation is equivalent to the biohermal masses. Where adjacent to the reef barriers, the Copley Formation consists of steeply dipping coarse fore-reef breccia (Fig. 22); elsewhere, the Copley Formation consists of gently dipping finer limestone breccia, calcarenite, calcareous sandstone and calcareous siltstone. Some thin bands of evaporites in the upper part of the Copley Formation support the interpretation that this formation was deposited in a lagoon barred by reef masses.

The contemporaneous deposition of the Copley Formation, which contains Frasnian goniatites (probably *Manticoceras*), with the reef mass mapped as part of the Pillara Formation indicates that the Pillara Formation ranges into the Frasnian, as Veevers (1959) found in other areas.

Deposition like that in the Copley/Brooking area also took place in the Emanuel Range, Fossil Downs, northern Hull Range, and Windjana Gorge areas. A reinterpretation of the relations between the rocks mapped as Pillara and Sadler Formations, Mount Pierre Group, and Bugle Gap Limestone in the Emanuel Range/Bugle Gap area is necessary from the results of the study of the Copley/Brooking area. The field relations are shown in Figure 11. The medium-bedded, probably Givetian, part of the Pillara Formation rests unconformably on Ordovician rocks, and dips north-eastward. Higher in the section, thick biostromes are bounded by biohermal reef barriers with irregular or, in some parts, linear outlines. A biohermal barrier lies along a lineament continuous with the Cadjebut Fault, and indicates that biohermal reef and back-reef biostromal growth was limited by early Upper Devonian faulting. Other lineaments on the map possibly indicate other Upper Devonian faults. In the northern part of the Emanuel Range, the clastic Sadler Formation of the type section strikes concordantly with the underlying biostromes of the Pillara Formation; eastward along Sadler Ridge, the strike of the Sadler Formation swings in an arc to abut against the biohermal reefs that trend obliquely to the regional north-west strike. Field relations and the sections through the Sadler Formation and the reef mass in this locality (Fig. 12) indicate that these rocks are contemporaneous. The structure and the change in lithology along the strike are comparable with those of the Copley Formation (Fig. 10). Adjoining the biohermal reef, the Sadler Formation consists of steeply dipping fore-reef limestone breccia and calcarenite which pass along the strike into calcarenite, finer clastic limestone, and probably also into siltstone and shale, which are not exposed. The Gogo Formation, which interfingers with and succeeds the Sadler Formation, is in part also equivalent to the reef mass. In Bugle Gap, the Mount Pierre Group lies between biohermal reefs, mapped as Pillara Formation, and abuts against the reefs with an arcuate strike where they are normal to the regional strike, and lies parallel to the reefs that parallel the regional strike. The interfingering between the Mount Pierre Group and the biohermal reef of the Pillara Formation is well exposed near Cave Spring.

The *Bugle Gap Limestone* is recorded from a small area in the Bugle Gap/Old Bohemia area, and, as pointed out by Guppy et al., in lithology and fauna resembles the Geikie and Oscar Formations. We carry the parallel further, and attempt to show that the conditions under which the Bugle Gap Limestone was deposited and its field relations with the reef masses of the Pillara Formation and with the red and grey clastic limestone and calcarenite of the Mount Pierre Group are generally the same as those of the rocks of the Copley/Brooking area.

With Guppy et al. and McWhae et al. we interpret the steep dips (Fig. 25) of the Bugle Gap Limestone, like those of the Geikie and Brooking Formations, as depositional. These rocks dip steeply off higher platforms on which reefs were growing. The clastics of the Sadler Formation and Mount Pierre Group accumulated between reefs in lagoonal areas, and the Bugle Gap limestone has a steep depositional dip off these sediments.

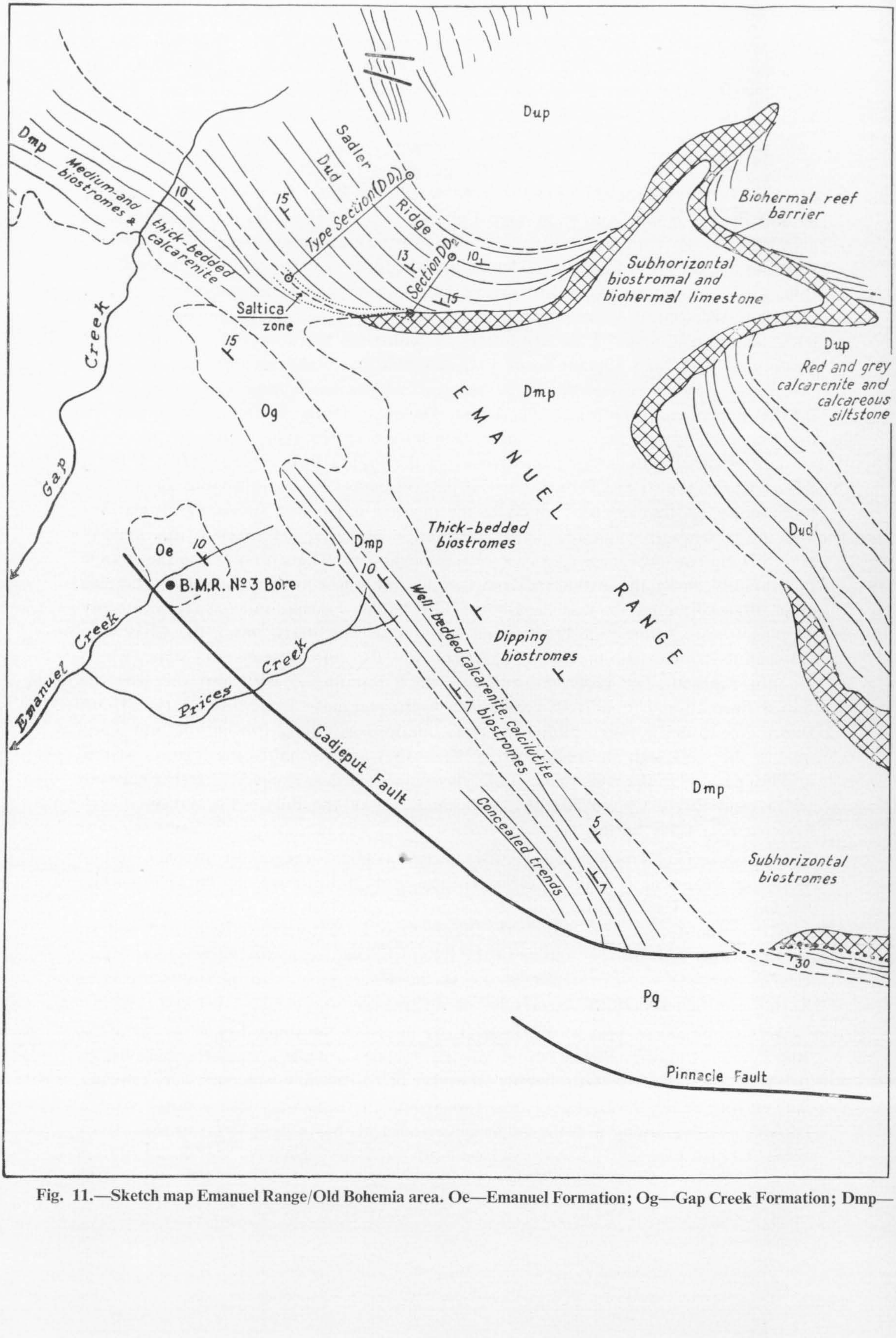
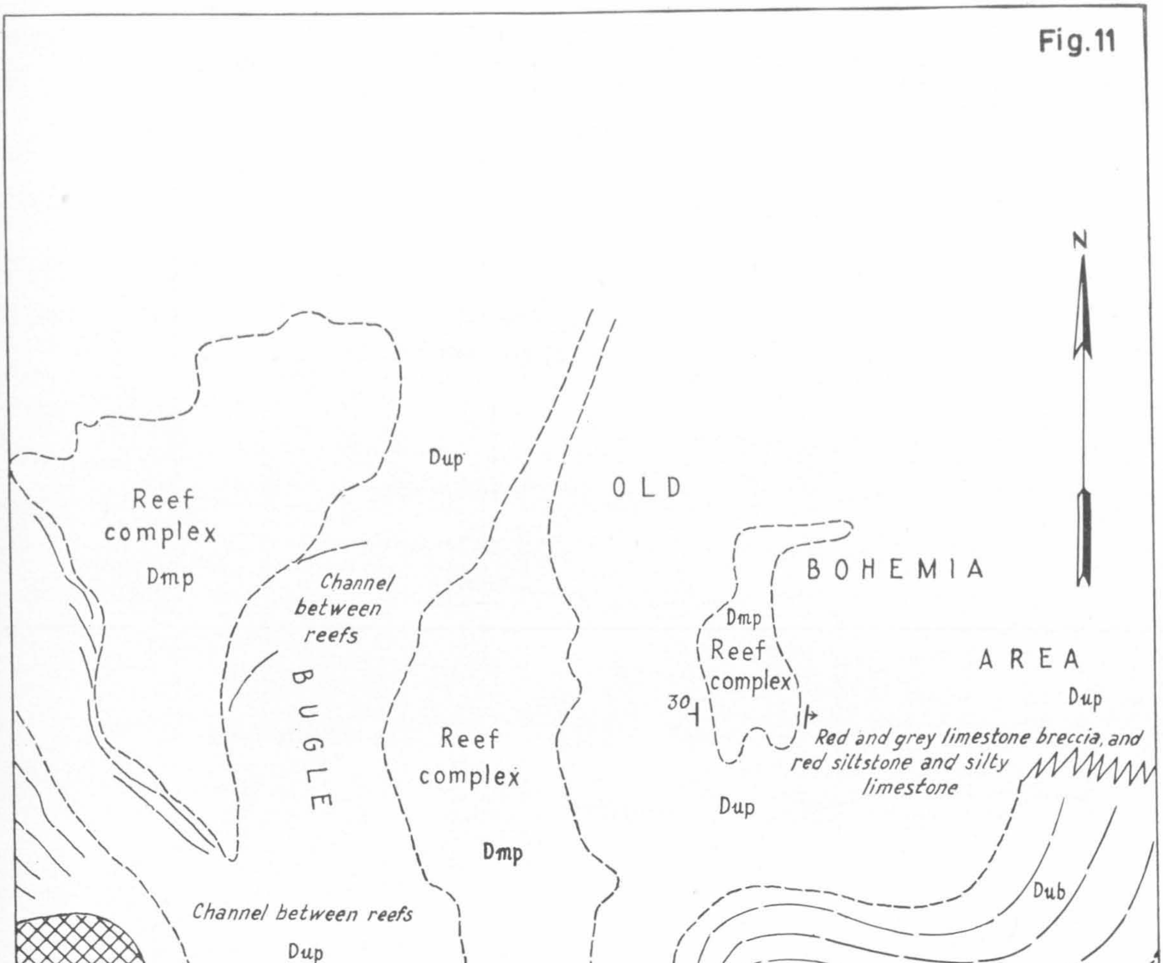


Fig. 11.—Sketch map Emanuel Range/Old Bohemia area. Oe—Emanuel Formation; Og—Gap Creek Formation; Dmp—



Pillara Formation; Dud—Sadler Formation; Dub—Bugle Gap Limestone; Dup—Mount Pierre Group; Pg—Grant Formation.

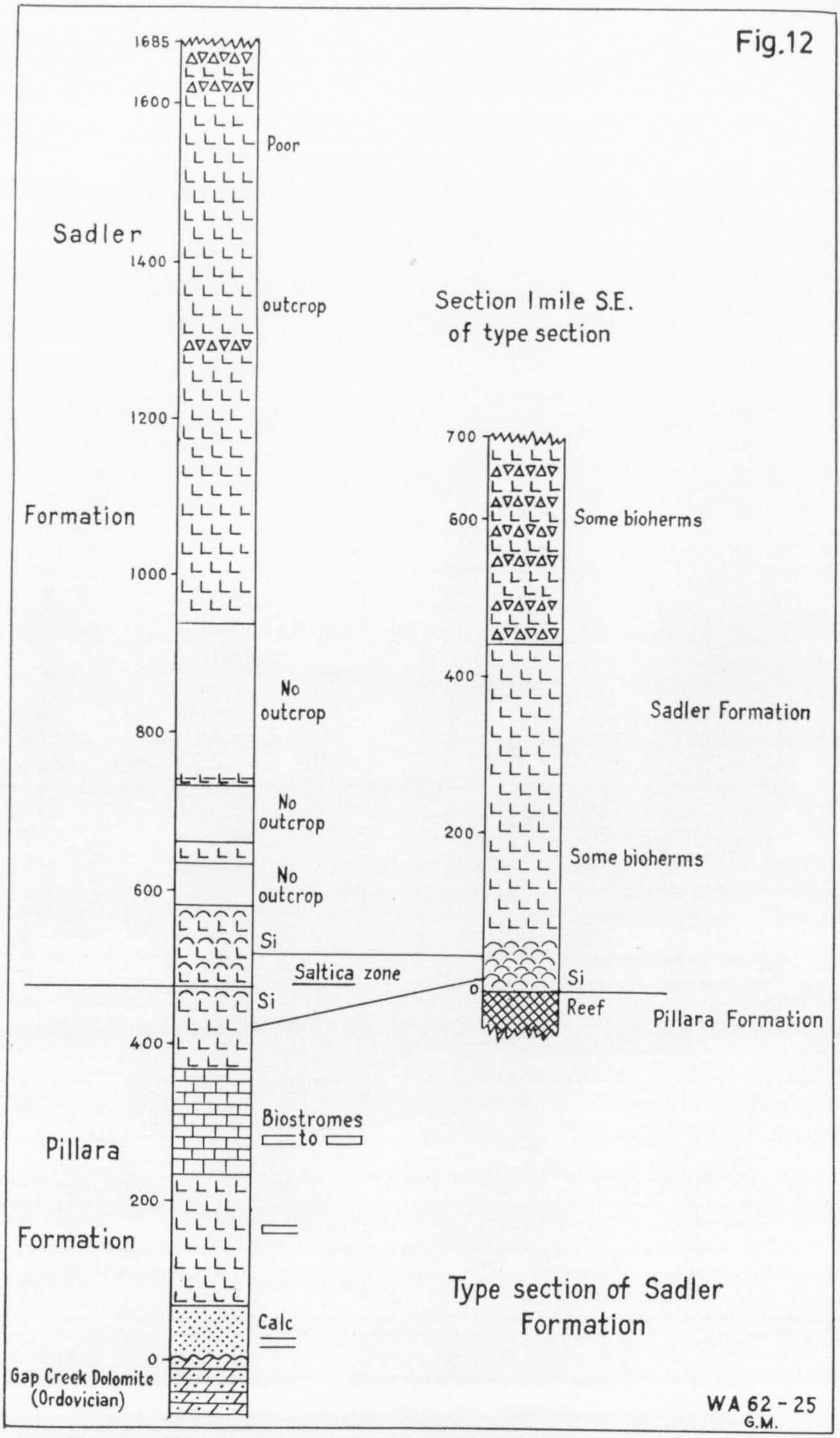


Fig. 12.—Type section of Sadler Formation (DD_1) and measured section 1 mile south-east of type section (DD_2). For locality, see Figure 11.

Our interpretation of the field relations in the Emanuel Range/Bugle Gap and Copley/Brooking area may be extended to the other parts of the main outcrop such as the Hull Range.

The *Sadler Formation* is recorded from many isolated localities besides the type area; these are not erosional remnants of a formerly continuous formation, but are lenses of similar lithology and fauna that were deposited at approximately the same time and in a similar environment. The Sadler Formation is contemporaneous with the bioherms and biostromes of the upper Frasnian part of the Pillara Formation and with the lower part of the Mount Pierre Group. Guppy et al. (p. 28) believed that an unconformity separated the Pillara Formation from the Sadler Formation in the Emanuel Range, and inferred that this unconformity extends throughout the main outcrop. Local unconformity possibly resulted from the Frasnian diastrophism, but in most areas, as in the Emanuel Range, the discordance at the contact of the clastic Sadler Formation and the organic reef sediments of the Pillara Formation is not structural but depositional.

The *Mount Pierre Group*, which consists of the Gogo and Virgin Hills Formations, is best known in the type, Margaret River, area. The boundaries mapped are arbitrary. The group consists of steep-dipping off-reef clastic limestones near reefs, and gently dipping finer-grained limestone breccias, grey and red calcareous siltstones, silty limestone, and sandy limestone, in channels and basins between reefs. The group was deposited in semi-enclosed basins, channels, and lagoons between biohermal reefs and around islands uplifted by faults. The goniatite zones of the Upper Devonian are based on sections of the group. The Sadler, Copley, Brooking, Geikie, Napier, and Oscar Formations are contemporaneous with part of the Mount Pierre Group. In lithology, structure, and age the Fossil Downs Formation is indistinguishable from the Mount Pierre Group.

The *Napier Formation* in many places rests unconformably on Precambrian rocks or on the Pillara Formation. In other areas, such as Windjana Gorge (Figs. 26-31), the Napier Formation consists of fore-reef sediments deposited against the bioherms and back-reef biostromes of the Pillara Formation. The Napier Formation also includes reef complexes (Fig. 34). Between the reef masses, the Napier Formation contains abundant terrigenous rock and mineral fragments (chiefly quartz). Basal breccia with a steep depositional dip rests on Precambrian basement and is succeeded by red and grey calcarenite, calcareous siltstone, calcareous sandstone, sandy and silty limestone, and calcilutite (Figs. 32, 33). The terrigenous components of these rocks, and the contemporaneous and interfingering conglomerates, probably reduced the area on which reef growth could be maintained. The rocks included in the Napier Formation range through all the zones of the Upper Devonian.

The *Oscar Formation* (Fig. 35) is lithologically similar to the Napier Formation except that it lacks terrigenous material, probably because it was deposited off an island ringed by reef barriers which supplied little terrigenous matter, whereas the Napier Formation was deposited along the basin margin. The Oscar Formation includes limestone breccia and calcarenite interpreted as fore-reef deposits derived from bioherms of the Frasnian part of the Pillara Formation, and biohermal reefs with steep fore-reef clastics. Between the reef masses clastic limestone with steep depositional dip rests directly on Precambrian rocks or on eroded remnants of Pillara Formation. The linear outline and steep depositional dip of the between-reef rocks of the Oscar and Napier Formations compared with the low dips in the Givetian part of the Pillara Formation of the basin margin probably indicate that the margin of the basin in which the Upper Devonian rocks were deposited was determined by faulting.

Rocks called the *Fairfield Beds* crop out poorly in widely separated localities throughout the main outcrop. They consist of well-bedded grey and brown calcarenite, sandy limestone, sandstone, siltstone, and shale. The Fairfield Beds are overlain, probably unconformably, by the Lower Carboniferous Laurel Formation and by the Permian Grant Formation. The base of the beds is arbitrary in many areas, and no completely exposed section is known. Guppy et al. regarded the Fairfield Beds as a synonym of Teichert's biostratigraphical unit the *Productella* Limestone; accordingly they regarded the Fairfield Beds as a uniform formation that succeeds all the other Upper Devonian formations, and attributed its characteristic lithology to different conditions of deposition in the late Upper Devonian.

The youngest parts of the Fossil Downs, Napier, Geikie, and Oscar Formations and of the Bugle Gap Limestone range up into the *proteus* (Teichert's *Productella*) zone, to which the Fairfield Beds are restricted. At its junction with the youngest parts of these formations, the Fairfield Beds are the same age as the fore-reef and reef limestones, and are interpreted as the basinward equivalent of these formations. The characteristic lithology of the Fairfield Beds accordingly results from its deposition on the seaward edge of the shelf. The inshore equivalent of the Fairfield Beds is the uppermost part of the Virgin Hills Formation.

A characteristic feature of rocks of reef complexes is their grey or brown colour, which contrasts with the red, grey, and green colour of the sediments of the reef-bounded basins. The lithologies and environments of deposition of the Upper Devonian rocks are summarized in Table 3, and their distribution shown in Figure 8.

Devonian Rocks in Areas Beyond the Main Outcrop

The complex stratigraphical relationships within the main outcrop, the fact that most formations are defined without regard for lateral variation in lithology, and the recurrence of similar lithologies in many formations, rule out the reliable identification of rock units beyond the main outcrop. Biostratigraphical units, as initially used by Teichert (1949) in the main outcrop, will probably indicate stratigraphical relationships best until detailed lithological mapping, both surface and subsurface, is done. Certain parts of Teichert's (1949) work have been superseded, but hitherto Teichert's was the only attempt at understanding the geological history. Not a small part of his success is attributable to the use of biostratigraphical units.

Conglomerate and thin-bedded horizontal calcarenite in the *Bohemia Downs* area resemble Upper Devonian rocks of the main outcrop, and are dated as undifferentiated Upper Devonian. The conglomerate rests on Precambrian rocks; its top is eroded or is probably overlain by the calcarenite. The calcarenite is unconformably overlain by the Grant Formation, which is draped over the dissected, locally exhumed, surface of the calcarenite (Fig. 36). Further information on these rocks is given by Casey & Wells.

TABLE 3

LITHOLOGY AND ENVIRONMENTS OF DEPOSITION OF UPPER DEVONIAN ROCKS OF MAIN OUTCROP

Environment	*Lithology*	*Bedding*	*Depositional Structure*	*Represented in Named Units*
A. Reef barrier.	Grey and white diagenized carbonate rock. Organic framework for clastic debris.	Massive.	Linear-outlined masses and lenses parallel or oblique to regional strike.	Pillara (upper part), Oscar, Napier Formations.
B. Back reef.	Grey and white stromatoporoid and algal biostromes, calcarenite and calcilutite.	Thick to very thick.	Subhorizontal.	Pillara, Oscar, Napier Formations.
C. Fore reef of open basin.	Grey and white limestone breccia and calcarenite with small bioherms.	Medium to thick.	Steep dips (up to 55°) off reef barriers, shallow dips in semi-enclosed lagoons.	Bugle Gap Limestone, Geikie, Oscar, Brooking, Fossil Downs, Napier Formations.
D. Shelf basin or lagoon partly enclosed by reefs.	1. Off-reef deposits adjacent to reefs: red and grey limestone breccia with small bioherms.	Medium to thick.	Steep adjacent to reefs. Beds strike parallel to reefs that parallel regional strike; curve towards and abut against those oblique to strike.	Mount Pierre Group. Fossil Downs, Brooking, Copley, and Sadler Formations.
	2. In central areas of basins distant from reefs: finer limestone breccia, calcarenite, siltstone, sandy limestone. Red, brown, and grey-green.	Thin to medium.	Low dips.	
E. Open basins on seaward side of reef.	Fine clastic limestone, calcarenite, sandy limestone, shale, sandstone, grey-brown and reddish.	Medium to thin.	Shallow dips.	Mount Pierre Group, Fossil Downs and Fairfield Formations.
F. Basin margin lateral to reef.	Red, grey, brown limestone breccia, calcarenite, sandy limestone, sandstone.	Medium to thin.	Moderate dips.	Napier, Fossil Downs, Oscar Formations.
G. Near-shore torrential fans.	Conglomerate and sandstone matrix red and brown unsorted, arenaceous, phenoclasts well rounded.	Medium to thick.	Low to moderate dips.	Behn, Van Emmerick, Stony Creek, Burramundi, Mount Elma and Sparke Conglomerates.

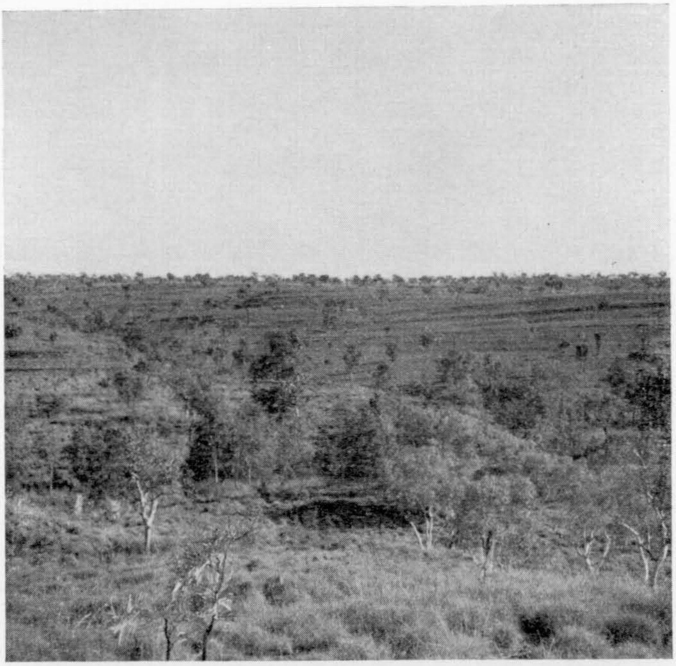


Fig. 13.—Looking north to medium-bedded calcilutite, calcarenite, sandy limestone, and biostromes of the Pillara Formation near the basin margin, north of Copley Valley (Figure 10).

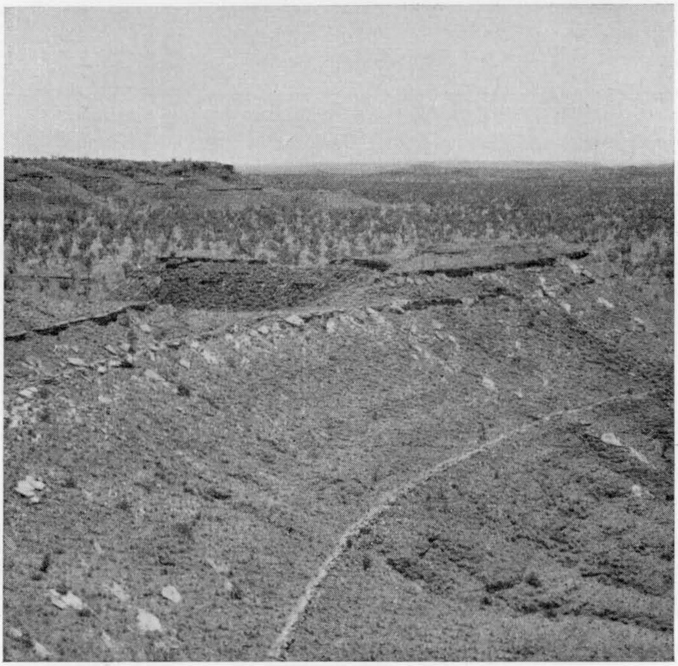


Fig. 14.—Medium-bedded to thin-bedded subhorizontal Pillara Formation overlying Precambrian rocks, north-west part of Napier Range.

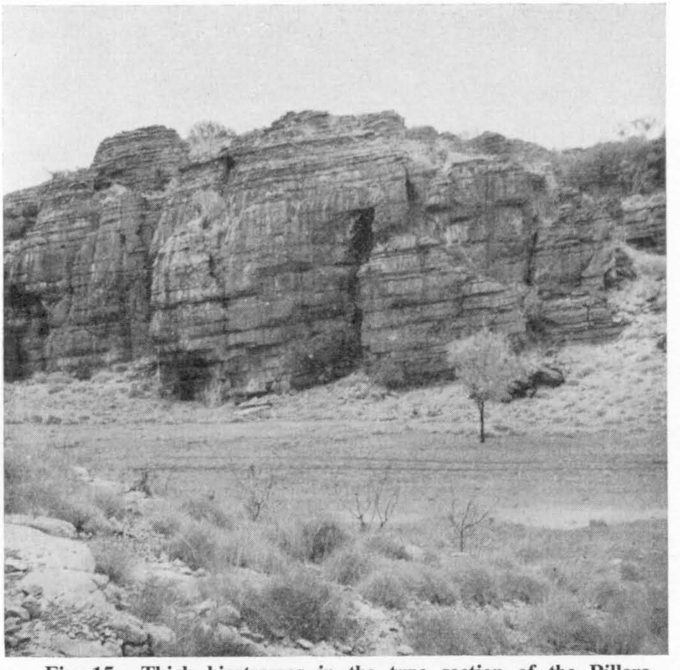


Fig. 15.—Thick biostromes in the type section of the Pillara Formation, Menyous Gap, Pillara Range.

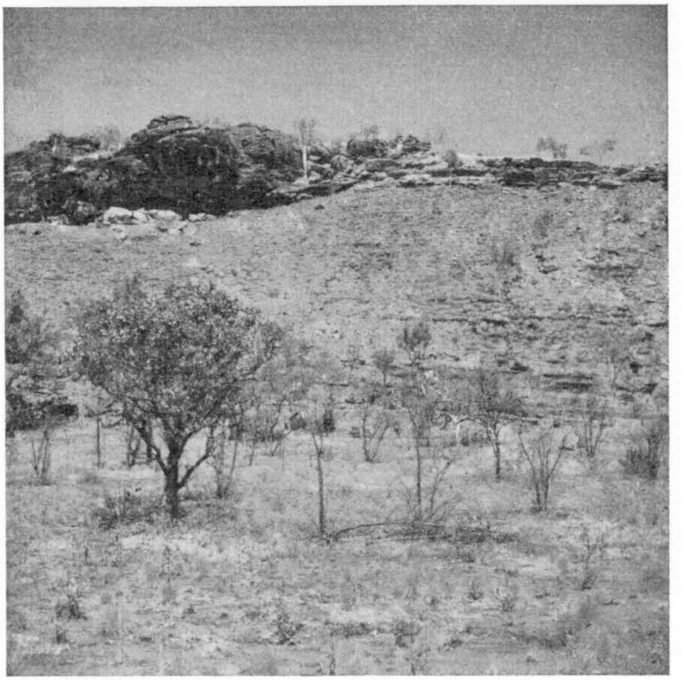


Fig. 16.—Limestone breccia of the Napier Formation unconformably overlying medium-bedded rocks of the Pillara Formation, Napier Range.

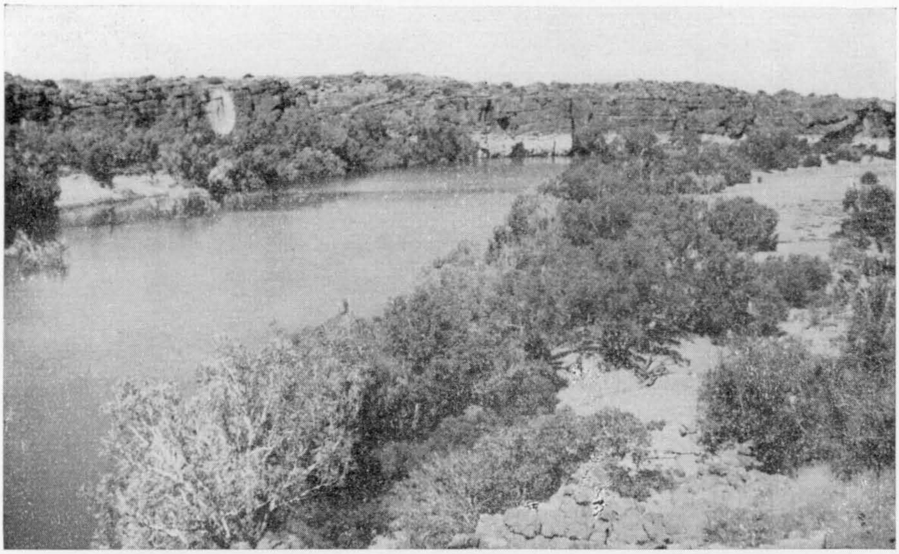


Fig. 17.—Subhorizontal biostromes of the reef mass of the Pillara Formation, Geikie Gorge (Fig. 10).

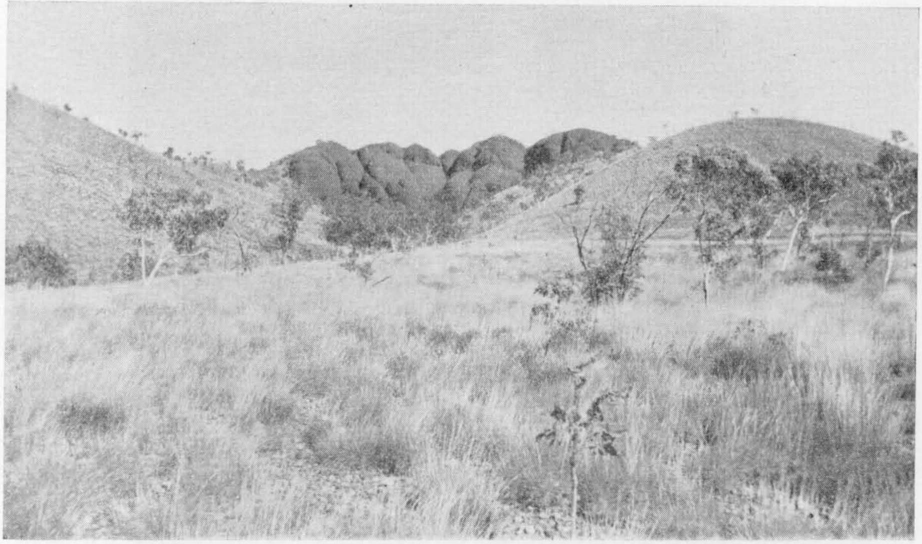


Fig. 18.—Burramundi Conglomerate, BY52 Trig. View west from Precambrian granite and schist.

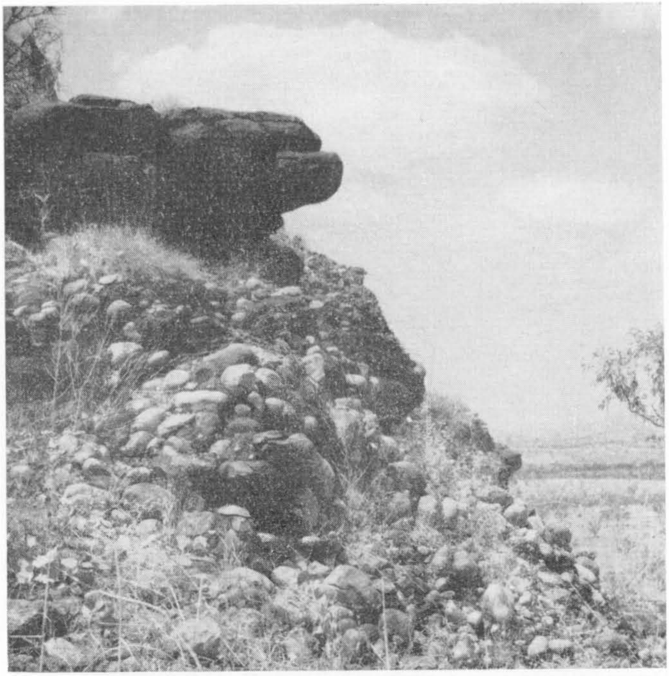


Fig. 19.—Behn Conglomerate, north face of Napier Range.

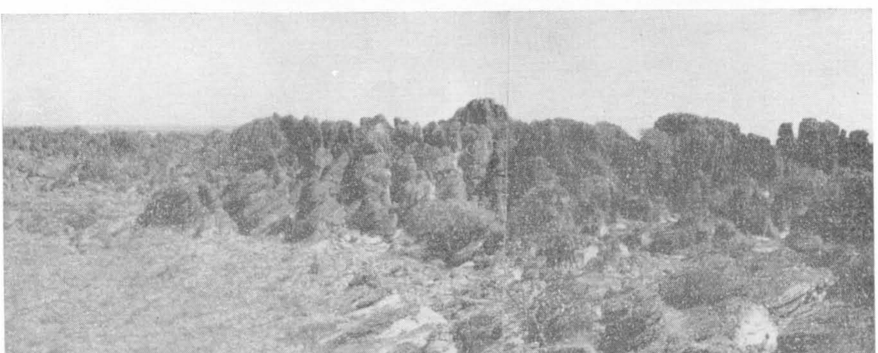


Fig. 20.—Medium-bedded off-reef limestone breccia of the Copley Formation striking toward and abutting against a biohermal reef barrier (Pillara Formation) in the western part of Copley Valley (Fig. 10).

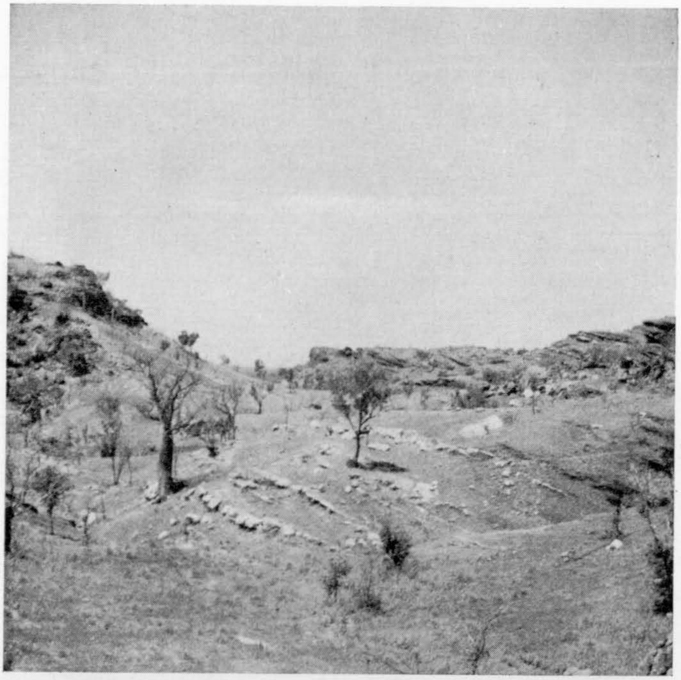


Fig. 21.—Off-reef limestone breccia and calcarenite adjoining a reef mass, Copley Valley (Fig. 10).

Fig. 22.—Limestone breccia of the Copley Formation adjacent to a reef mass, Copley Valley (Fig. 10).

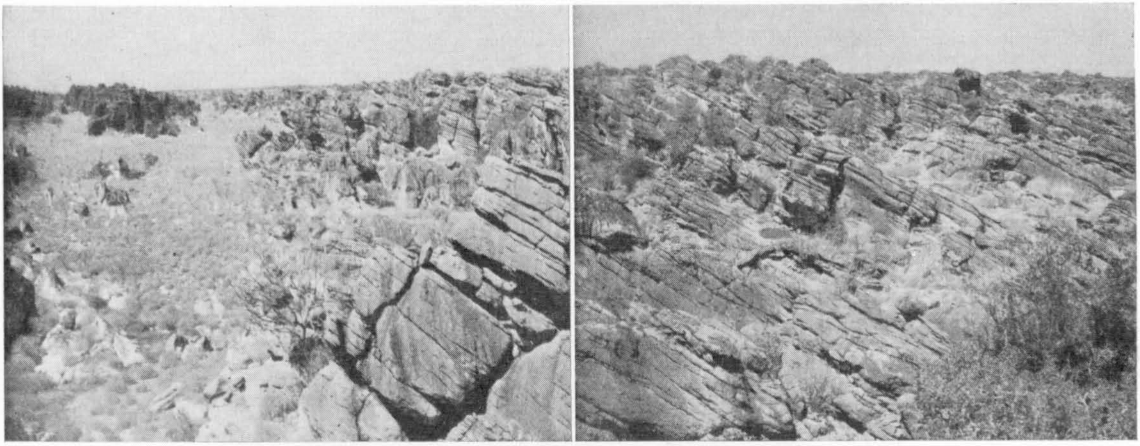


Fig. 23.—Fore-reef limestone breccia and calcarenite of the Geikie Formation dipping steeply southward off a biohermal reef barrier, Brooking Gorge area. Note linear trend of reef barrier.

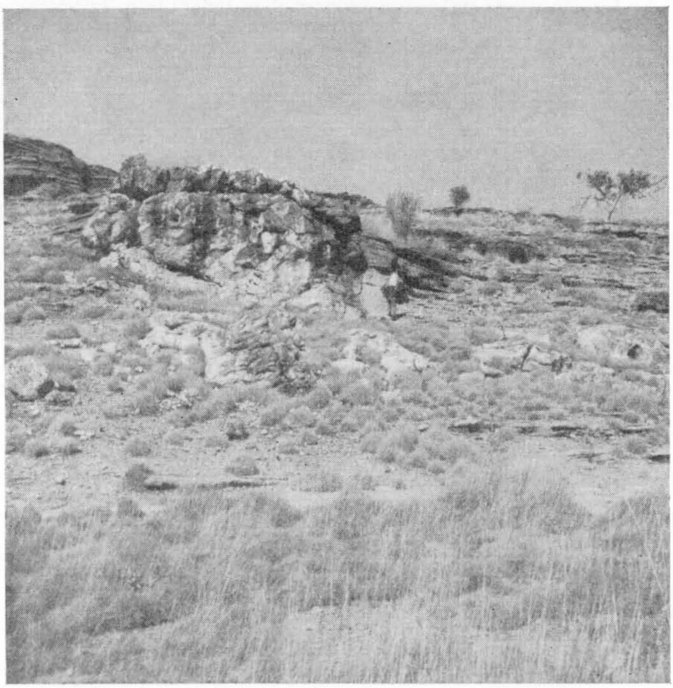


Fig. 24.—Limestone breccia, calcarenite, silty limestone, calcareous siltstone, and a small bioherm of the Copley Formation, Copley Valley. Scale indicated by figure to right of bioherm.

Fig. 25.—Fore-reef calcarenite of the Bugle Gap Limestone dipping south-eastward. Outlier of Permian Grant Formation on the sky-line. Two miles south-east of Cave Spring (Fig. 11).

Fig. 26.—Section through biohermal reef: subhorizontal back reef biostromes (Pillara Formation) on right, medium-bedded fore-reef sediments (Napier Formation) on left. Windjana Gorge.

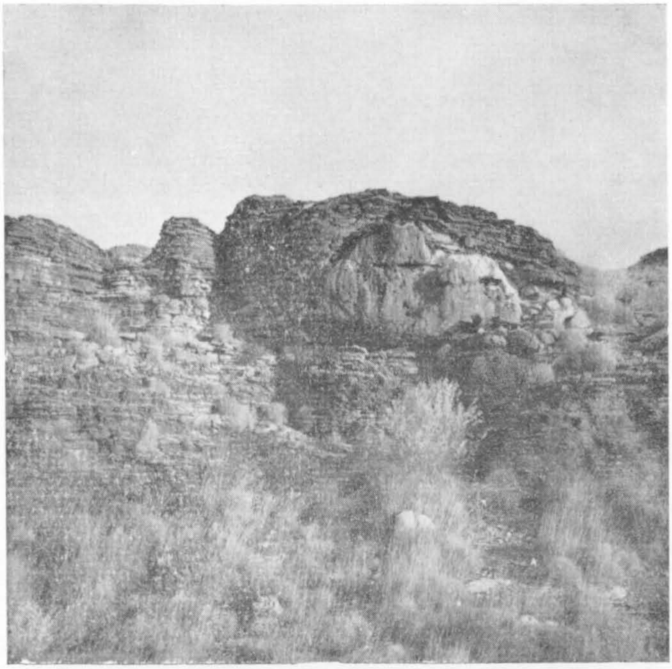


Fig. 27.—Fore-reef beds of Windjana Gorge reef complex. Medium-bedded and thin-bedded limestone breccia and calcarenite, calcareous siltstone and silty limestone, and a small bioherm.

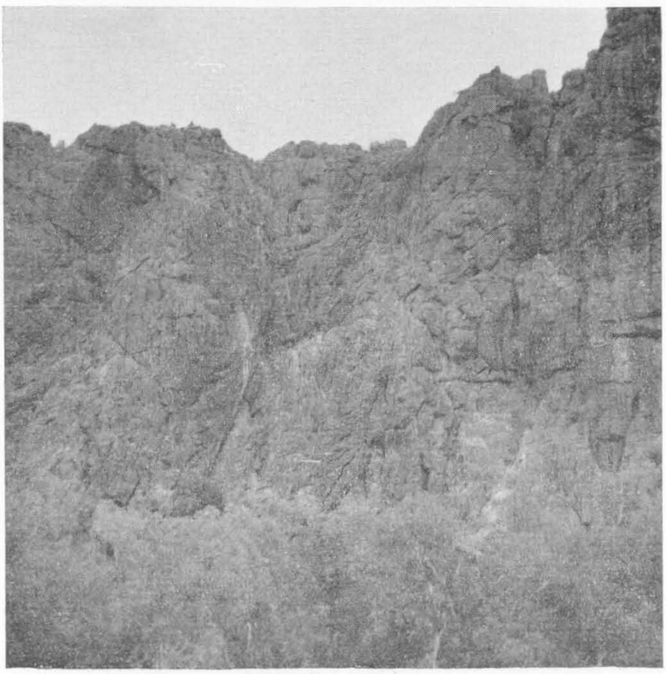


Fig. 28.—Massive diagenized carbonate rock of biohermal reef, Windjana Gorge (detail of Figure 26).

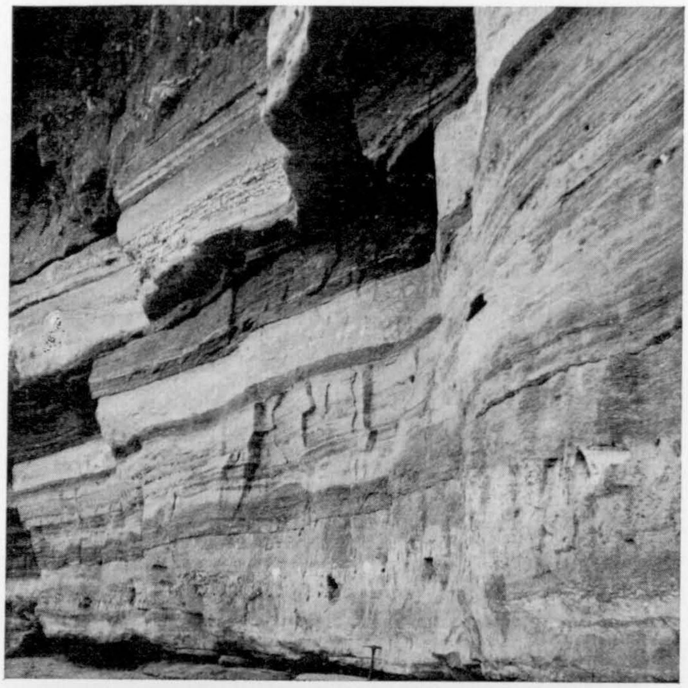


Fig. 29.—Interbedded biostrome, calcarenite, and calcilutite, of back reef, Pillara Formation, Windjana Gorge (detail of Figure 26, right-hand side). Scale indicated by hammer at bottom centre.

Fig. 30.—*Amphipora ramosa* biostrome, bedding surface. Detail of Figure 29.

Fig. 31.—Stromatoporoid biostrome. Detail of Figure 29. Surface wet.

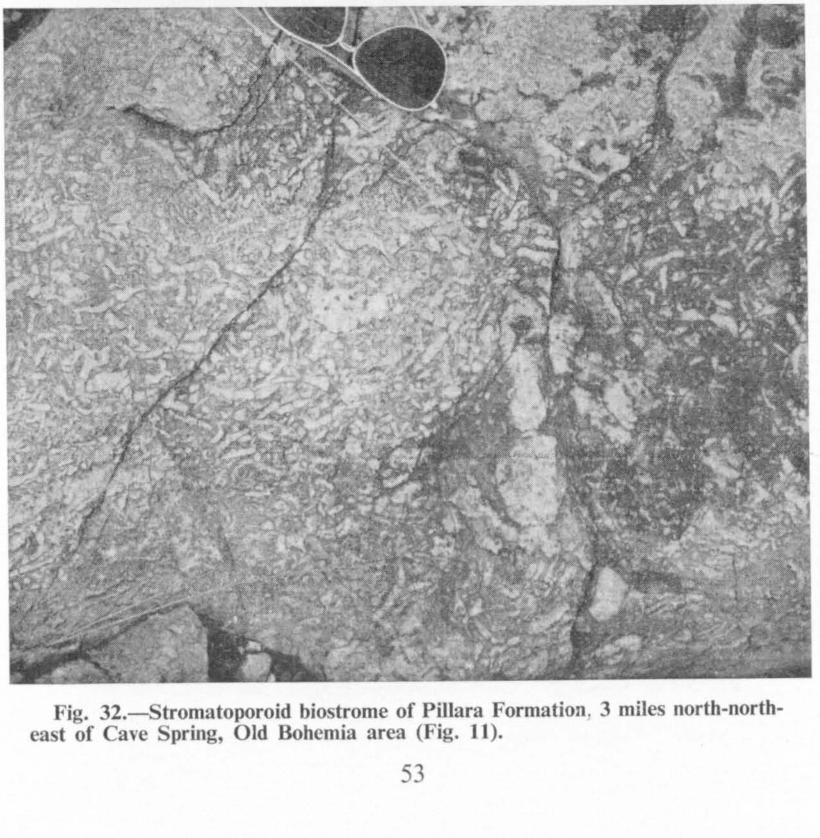


Fig. 32.—Stromatoporoid biostrome of Pillara Formation, 3 miles north-northeast of Cave Spring, Old Bohemia area (Fig. 11).

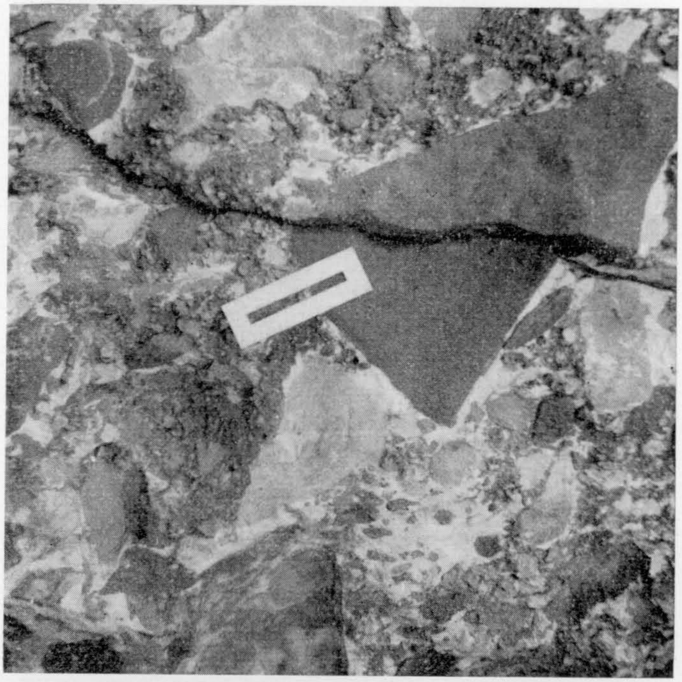


Fig. 33.—Basal limestone breccia, Napier Formation, near McSperrys Gap, Napier Range. The ruler is 6 inches long.

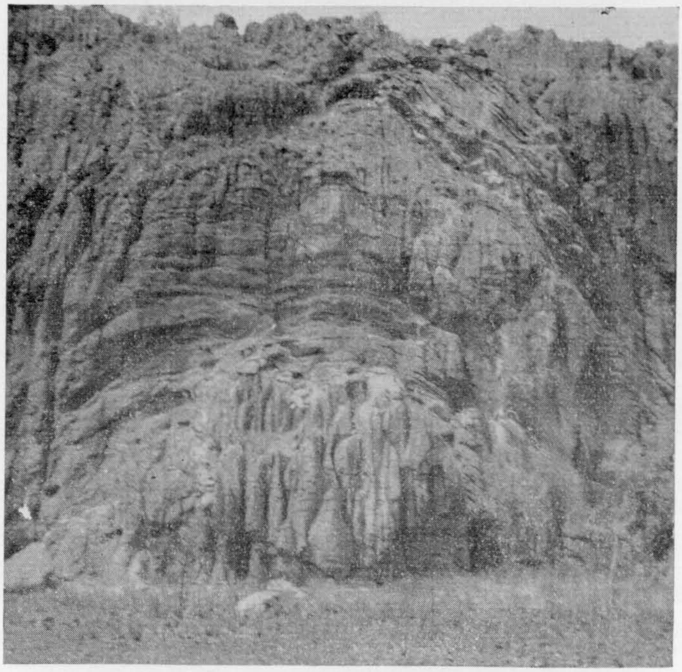


Fig. 34.—Looking north at southern face of Napier Range, northwest of Windjana Gorge: a reef complex in the Napier Formation.

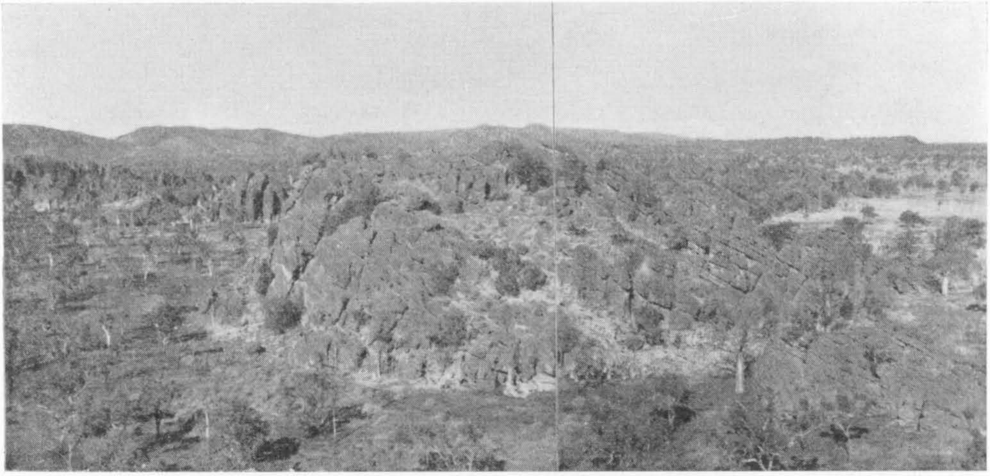


Fig. 35.—Looking westward along the southern face of the Oscar Range. Small reefs and fore-reef calcarenite of the Oscar Formation dipping southward off the Precambrian core of the Oscar Range.

Fig. 36.—Probable Upper Devonian limestone unconformably overlain by the Permian Grant Formation south of Christmas Creek on Bohemia Downs Station. Note depositional dip (about 30°) of Grant Formation on right side of photograph.

In the *Knobby Hills* area (Casey & Wells) probable Upper Devonian plant-bearing cross-bedded medium to coarse sandstone about 200 feet thick rests unconformably on steep-dipping Precambrian quartzite. The sandstone contains pebbles up to 4 inches across. The Knobby Hills rocks are gently folded (dips up to 20°), and the top is eroded.

White (Appendix 6) tentatively determined *Leptophloeum australe* (McCoy) from these rocks. This plant ranges from Upper Devonian to Carboniferous; it is most commonly found in Upper Devonian and Lower Carboniferous rocks, and, within the Fitzroy and Bonaparte Basins, occurs in well-dated Upper Devonian rocks. The Knobby Hills rocks are therefore tentatively dated as Upper Devonian.

Brunnschweiler & Dickins (1954, unpubl.) determined *Leptophloeum* in rocks collected by Reeves (1949, unpubl.) from an area about *10 miles east of Balgo Mission*. In this area, a 20-feet-thick medium cross-bedded clayey sandstone with quartzite pebbles rests in a fault trough in Precambrian quartzite (Casey & Wells).

These rocks and those at Knobby Hills were probably deposited in lakes contemporaneous with those in which the Dulcie Sandstone (Hills, 1959) was deposited 600 miles to the east-south-east.

DEVONIAN ROCKS PENETRATED BY DEEP BORES (Fig. 37)

67-mile Bore (Teichert, *in* Reeves, 1949, unpubl., 28-29)

Devonian rocks were penetrated between depths of 1094 and 2527 feet in the 67-mile Bore. These rocks consist of dense coarse-grained limestone and dolomite; many beds contain vugs. A conglomerate with pebbles of granite up to 2 cm. across between 1170 feet and 1185 feet, and a sandy shale at 2164 feet, are the only rocks other than carbonates in the sequence. Within the Devonian interval of the bore, Teichert (1950, pp. 1789-1790) determined *Cyrtospirifer* from 1094 to 1129 feet, and *Barrandeophyllum rubrum* from 2482 feet. According to Teichert (1950) the *Cyrtospirifer* indicates the '*Productella* limestone' (or *proteus* zone of Veevers) and *B. rubrum* the *Sporadoceras* zone. G. A. Thomas (pers. comm.) has found *Cyrtospirifer* s.l. in rocks below the *proteus* zone, but the form determined in the bore is presumably the same form that is abundant and widespread in the *proteus* zone. Teichert's (1950) observation that *B. rubrum* 'has not been found below the Upper Devonian and is mainly characteristic of the *Sporadoceras* zone' is not true. The type specimens of *B. rubrum* were collected from the 'south-eastern entrance of Mountain Home Spring Valley. Upper Givetian or Lower Frasnian' (Hill, 1939, p. 142) and Hill's age determination has been confirmed by the discovery of the Givetian *Stringocephalus fontanus* at the base of the Pillara Formation in this area. Teichert (1949) identified *B. rubrum* in the *Sporadoceras* zone. The known range of *B. rubrum* in the Fitzroy Basin therefore is the *fontanus* or *ramosa* zone to *Sporadoceras* zone, and its occurrence in the 67-mile Bore indicates undifferentiated Givetian to Famennian. The range of *B. rubrum* is discussed in some detail, because, on the mistaken inference that it indicates Famennian, Teichert suggested that the Middle Devonian and also the basal part of the Upper Devonian are altogether missing in the 67-mile Bore. This of course may be so, but firmer evidence is required to prove it.

In the 67-mile Bore, Devonian rocks overlie Precambrian schist; according to Teichert's log, the boundary is sharp; that is, the Devonian carbonate rocks contain no detritus from the underlying schist.

Meda No. 1 Bore (Pudovskis, 1960)

About 3000 feet of Devonian rocks were penetrated by the Meda No. 1 Bore. These rocks rest at a depth of 8663 feet on Precambrian schist, and are overlain by Lower Carboniferous rocks. The boundary between Lower Carboniferous and Devonian rocks is not precisely known. The lowest definite Lower Carboniferous in the bore is Core 9 (5239-5245 feet), and the highest definite Devonian is Core 13 (6686-6696 feet). Core 11 (6175-6185 feet) contains conodonts and fish plates which Glenister (*in* Pudovskis, 1960) tentatively regards as Upper Devonian. The Carboniferous-Devonian boundary therefore probably lies in the interval 5245 to 6686 feet. On the assumption that the Carboniferous-Devonian boundary corresponds with a formation boundary Playford (*in* Pudovskis, 1960) places the boundary at 5483 feet or at 6150 feet. Meda No. 1 Bore is 30 miles from the nearest known exposed Devonian and probable Carboniferous rocks at Station Creek, and the lithology probably changes considerably over this distance. Accordingly, palaeontology is probably the only criterion to indicate the Carboniferous-Devonian boundary in this area. In the interval 6686 to 7101 feet, conodonts, ostracods, and brachiopods indicate the Upper *Manticoceras* zone.

Sisters No. 1 Bore (Hill, 1957, unpubl.)

The Sisters No. 1 Bore bottomed in Devonian rocks at 9828 feet. P. J. Jones identified the highest Devonian fossils, ostracods, in cuttings from 7140 feet; Dr Dorothy Hill identified a Lower Carboniferous coral from Core 8 (6083-6093 feet); so the Devonian-Carboniferous boundary lies within the interval 6093-7140 feet. Playford (*in* Pudovskis, 1960) tentatively places the boundary between the Devonian and Carboniferous at 6107 feet on the criterion of a lithological change. Presumably on the same criterion, Hill (1957, unpubl.) places the boundary at 6190 feet. Deposition probably continued uninterruptedly from the Devonian to the Carboniferous.

Jones (Appendix 3) found ostracods of assemblage A in cuttings from 7140 to 7779 feet; from Core 10, Miss J. G. Tomlinson identified *Leptophloeum* sp. (Upper Devonian—Lower Carboniferous), and B. E. Balme identified microspores indicating Upper Devonian; and from Core 14 (9721-9728 feet), Tomlinson identified *Leptophloeum* sp., and J. M. Dickins identified *Buchiola* sp. *Buchiola* ranges throughout the Upper Devonian of Germany, but is known in the Fitzroy Basin only in the *Manticoceras* zone (Teichert, 1949).

Frome Rocks No. 2 (Willmott, 1960)

Devonian rocks were penetrated in Frome Rocks No. 2 Bore between depths of 3557 and 7504 feet (total depth). The stratigraphical thickness of penetrated Devonian rocks is less than the bore thickness of 3947 feet, because the bore crossed a normal fault. Fossils indicate that all but the basal 500 feet of the Devonian section is Famennian, and the continuity of the unfossiliferous basal part with the rest of the

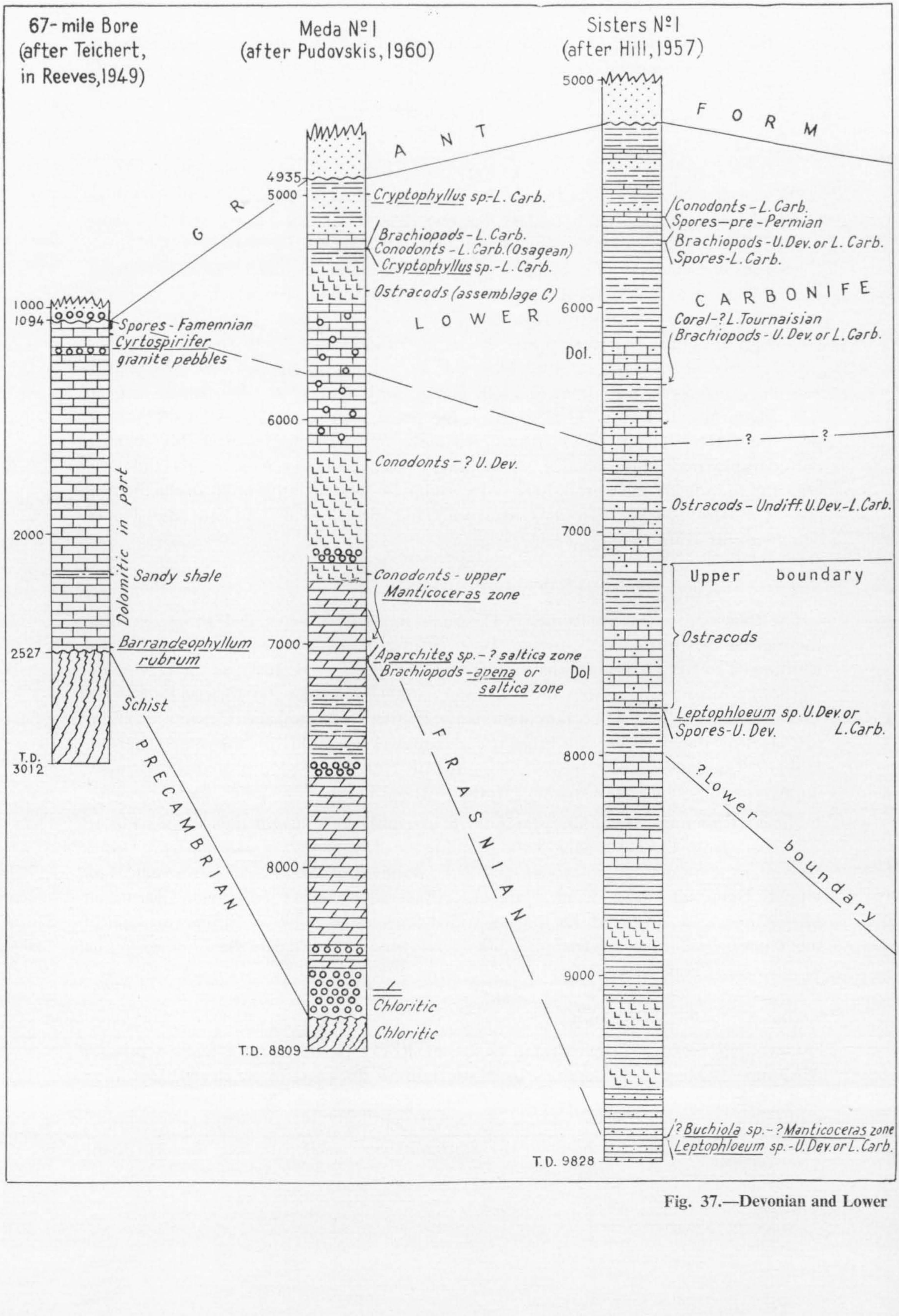
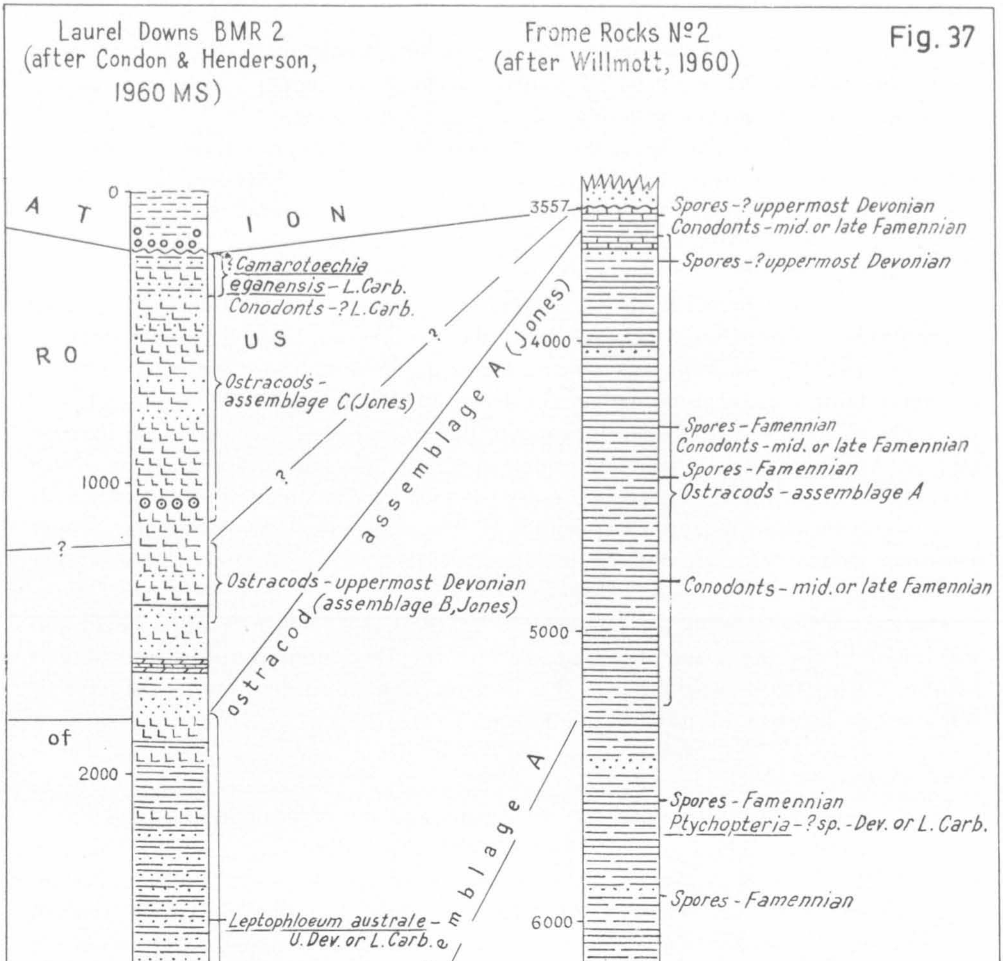


Fig. 37.—Devonian and Lower



Carboniferous rocks in bores.

section indicates that the whole section is probably Famennian. The *Sporadoceras* zone is probably represented by *Platyclymenia* and in the upper part of the section, ostracods of assemblage A probably indicate the *proteus* zone.

Willmott (1960) divides the section into two parts: an upper part of interbedded siltstone, shale, limestone, and fine sandstone from 3557 to 6264 feet, and a lower part of siltstone that grades in places into a fine-grained sandstone.

BMR 2 Laurel Downs (Condon & Henderson, 1960(a), MS.)

Upper Devonian fossils have been found in the interval 1210 to 4000 feet (T.D.) in the BMR 2 Laurel Downs Bore. Ostracods of Jones' assemblage B (*see* Appendix 3) in the interval 1210 to 1515 feet indicate Devonian-Carboniferous, younger than the known outcrops of the *proteus* zone; ostracods in the interval 1775 to 3170 feet, and probably to 4000 feet (total depth) indicate the *proteus* zone. *Leptophloeum australe* (White, Appendix 6) and an indeterminate species of *Cyrtospirifer* also occur in this interval. Evidence indicating the boundary between the Devonian and Carboniferous is discussed in detail by Jones (Appendix 3). The first indication of probable Upper Devonian is at 1210 feet, and we tentatively regard this as the top of the Upper Devonian.

The nearest outcropping Devonian rocks are the Fairfield Beds, 8 miles north and north-east of the bore, and the upper part of the Devonian section in the bore is identified with the Fairfield Beds. The identification of formations in the bore is discussed in detail by Condon & Henderson (1960(a), MS.).

Roebuck Bay No. 1

McWhae et al. (p. 30) named the calcarenite and minor dolomite and calcilutite encountered between 3354 and 3660 feet in the Roebuck Bay No. 1 Bore the Thangoo Calcarenite. These rocks overlie the Ordovician Roebuck Dolomite, and are overlain by the Grant Formation. They have not yielded fossils. 'It is probably of Ordovician age, but may be the same age as the lithologically similar Devonian calcarenites along the north-eastern margin of the Fitzroy Basin.'

Summary of Geological History

During the Givetian, the base of the Pillara Formation overstepped a fairly flat terrain. The high content of large and small limestone fragments in the basal part of the Upper Devonian Napier Formation not associated with reefs and in some marginal conglomerates indicates that the base of the Pillara Formation was deposited farther north. Except for lenses of terrigenous clastics, the basal part of the Pillara Formation consists of medium-bedded biostromes and calcarenite, which indicate deposition on a shallow slowly subsiding shelf. Thicker biostromes were deposited higher in the Givetian, and these mark the end of uniform deposition.

In the early Frasnian, differential uplift of the shelf floor, chiefly by block faulting, and the uplift of part of the shelf margin caused

(a) a short regression of the sea, probably to the present outcrop margin of the Upper Devonian rocks, directly indicated by mud-cracked and ripple-marked calcilutites that overlie the biostromes of the Pillara Formation near Leopold Downs Station;

(b) the local emergence of tilted blocks of the lower part of the Pillara Formation, which were then eroded;

(c) the start of local biohermal reef growth, and the resulting deposition of back- and fore-reef sediments; biostromes form much of the back reef, limestone breccia the fore reef;

(d) along the margin, the local deposition of limestone breccia not related to reefs, and of conglomerates, some of which contain large angular blocks of limestone.

Thence to the end of Devonian deposition, large and small reef masses continued growth; red and grey beds, locally with thin bands of evaporites, were deposited in lagoons between reefs; and finer red and grey calcareous rocks were deposited on the seaward side of the reef masses and their associated fore-reef clastics.

Rocks cut by bores 50 miles east of Derby indicate that the Upper Devonian, and probably the Middle Devonian, sea covered this area, over which various rocks, including reef complexes and associated off-reef deposits, conglomerate, siltstone, and shale, were deposited. In the Frome Rocks area, 100 miles south-west of the main outcrop, thick deposits of siltstone, shale, and sandy siltstone were deposited in the *Sporadoceras* and *proteus* zones, and perhaps earlier too. In the coastal part of the Canning Basin, south of the Frome Rocks area, bores pass direct from Permian to either Ordovician or Precambrian rocks, indicating that the Devonian sea probably did not cross the Fenton-Dampier Hinge.

In the Bohemia Downs area, conglomerate, calcarenite, and silty limestone were probably deposited in the easternmost part of the Upper Devonian sea. South-eastward, at Knobby Hills and near Balgo Mission, plant-bearing sandstone was deposited in lakes, probably in the Upper Devonian.

CARBONIFEROUS

As recently as 25 years ago, most of the outcropping limestone of the Fitzroy Basin was dated as Carboniferous. Studies of goniatities by Delépine (1935) and corals by Hill (1936) were the first to indicate that most of the limestone is Devonian. Outcropping Lower Carboniferous rocks (Laurel Formation) were later described from the Fitzroy Basin by Thomas (1957, 1960), and Upper Carboniferous rocks (Anderson Formation) by McWhae et al.

Laurel Formation (Thomas, 1957, 1960)

The Laurel Formation crops out in the Laurel Downs area immediately south of the main Devonian outcrop, and consists of 1500 feet of calcarenite and calcareous siltstone, with ammonoids, brachiopods, corals, conodonts, nautiloids, ostracods, pelecypods, and sharks' teeth. According to Thomas, the outcropping formation is late Tournaisian, and probably unconformably overlies the Upper Devonian rocks (Fairfield Beds) of the area. The postulated unconformity is not exposed and the lower age limit is uncertain because the lower part of the formation contains few fossils. The Laurel Formation is unconformably overlain by the Grant Formation.

A search for other outcrops of Lower Carboniferous rocks in the Fitzroy Basin has failed, except in the Station Creek area, near Old Napier Homestead. Mr J. Rade, of Westralian Oil Limited, recently mapped the area between Hawkestone Peak and

Mount Percy, and sent fossils from this area to the Bureau. Among them, Jones & Thomas (1959, unpubl.) determined fossils which indicate that outcrops near Station Creek, 4 to 6 miles west of Old Napier Homestead, are probably Lower Carboniferous. In apparent disagreement is Veevers' (1959, p. 165) determination of Upper Devonian (*proteus* zone) brachiopods collected by Dr C. Teichert in Station Creek 5 miles from Old Napier Homestead. This is clearly an area for further attention.

Lower Carboniferous rocks in bores (Fig. 37)

Lower Carboniferous rocks have been identified in BMR 2 Laurel Downs (Jones, 1960, Condon & Henderson, 1960(a), MS.), The Sisters No. 1, and Meda Nos. 1 and 2. Details of these rocks, and their relationships to the underlying Upper Devonian rocks, are described in the Devonian chapter.

Unambiguous evidence of the postulated unconformity between the Laurel Formation and the Fairfield Beds and of the postulated hiatus between these formations must be found before a geological history of the Lower Carboniferous can be attempted.

Anderson Formation (McWhae et al., p. 50)

The Anderson Formation underlies the Grant Formation in the Grant Range No. 1 and Fraser River No. 1 Bores. More than 5000 feet of the Anderson Formation were penetrated in these bores but its base was not reached. The type section of the Anderson Formation, in the Grant Range Bore, consists of alternating sandstone, siltstone, and shale, with thin beds of limestone, dolomite, and anhydrite. In the Fraser River Bore, the upper part of the section is mainly sandstone, and the lower part carbonaceous siltstone. We identify the interbedded sandstone and shale in the interval 8010-9072 feet in A.F.O. Nerrima No. 1 Bore (Hill, 1955, unpubl.) as the Anderson Formation.

Plants (White, Appendix 6), conchostraca, ostracods, *Lingula*, non-marine pelecypods, fish remains, and microspores have been found in the Anderson Formation, and indicate estuarine deposition. According to Öpik (in McWhae et al., p. 50), the conchostraca, which are common over the entire section of the Anderson Formation in Grant Range No. 1, indicate Westphalian to Lower Stephanian. From the lower part of the section, Dickins (op. cit.) determined a pelecypod which suggests Westphalian, and Balme (op. cit.) recognized spores, both in the Grant Range and Fraser River bores, with Upper Carboniferous affinities ('*Lycospora*' assemblage). No fossils were found in the Anderson Formation of AFO Nerrima No. 1.

The oldest part of the Grant Formation is probably Upper Carboniferous and succeeds the Anderson Formation without hiatus. The geological history of the Anderson Formation is therefore described with that of the Permian rocks.

PERMIAN

The Permian rocks of the Canning Basin form a rock body 100 to at least 14,500 feet thick that extends over almost the entire basin. Together with the Upper Carboniferous and Lower Triassic rocks of the basin, these rocks represent three and a half rhythmic alternations of freshwater or estuarine and shallow marine deposition. The correlation of these alternations with those observed in Permian rocks elsewhere

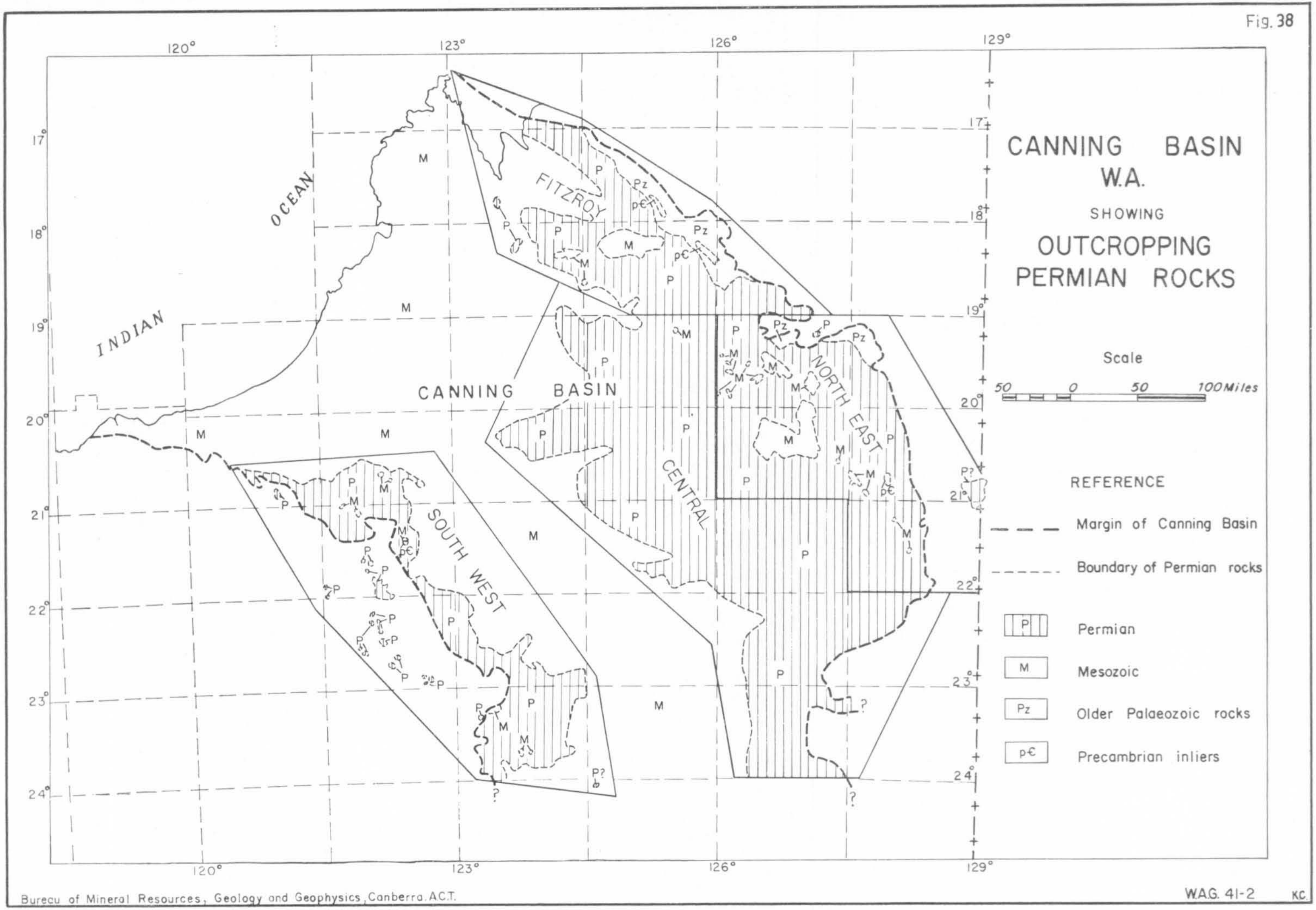


Fig. 38
CANNING BASIN
W.A.
SHOWING
OUTCROPPING
PERMIAN ROCKS
Scale
50 0 50 100 Miles
REFERENCE
Margin of Canning Basin
Boundary of Permian rocks
Permian
Mesozoic
Older Palaeozoic rocks
Precambrian inliers
INDIAN
OCEAN
CANNING BASIN
FITZROY
NORTH EAST
CENTRAL
SOUTH WEST
120°
123°
126°
129°
17°
18°
19°
20°
21°
22°
23°
24°
Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.
W.A.G. 41-2
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Fig. 38.

in Australia indicates that eustatic change in sea level was probably a cause of rhythmic deposition. From a regional viewpoint, the area of deposition remained essentially the same during the Lower Permian, and possibly was reduced in the Upper Permian; in detail, the limits shifted to and fro near the basin margin. The rocks deposited during the Permian are thus essentially conformable, and only at the basin margin are some disconformable. This condition contrasts with that of the Jurassic and Cretaceous rocks of the basin, which were deposited as a transgressive-regressive marine wedge. Each Permian formation is probably the same age throughout, and hence lithology can be used tentatively as a guide to correlation.

For convenience in discussing the various areas of Permian rocks, we divide the Canning Basin into four areas (Fig. 38), viz., Fitzroy Basin, north-east Canning Basin, central Canning Basin, and south-west Canning Basin.

Permian rocks crop out at the edge of the basin except (a) where they are overlapped by Mesozoic rocks in Dampier Peninsula and in the Yarrie and Port Hedland Sheet areas, and (b) where the Permian rocks lie on the basin side of Devonian rocks in the Lennard River, Noonkanbah, and Mount Ramsay Sheet areas, and near Knobby Hills and Balgo Mission, and of Ordovician rocks west of Wolf Creek Meteorite Crater. Notable outliers of Permian rocks occur in the Paterson Range and Rudall Sheet areas, and possible Permian rocks in the Lucas Sheet area. Small outliers overlie outcropping Devonian rocks in the northern part of the basin. An inlier of possible Permian rocks occurs in the core of the dome at Woolnough Hills.

Bores indicate that Permian rocks underlie outcropping Mesozoic rocks in the coastal area of the Canning Basin. Farther inland, Permian rocks presumably extend under outcropping Mesozoic rocks.

The Permian rocks of the Canning Basin, as shown in Plate 1, were mapped by the following:

4-mile Sheet areas	*Authors*
Derby, Lennard River, Mount Anderson, Mount Ramsay, Noonkanbah	Guppy et al.
Crossland (northern half)	R. M. Elliott and D. Roberts (Wapet, unpublished)
Mount Bannerman, Billiluna, Cornish, Lucas, Stansmore	Casey & Wells
Anketell, Callawa, Paterson Range, Rudall, Tabletop	Traves et al.

The remaining Permian rocks were mapped by the present authors.

Work on Permian macrofossils from the Canning Basin is currently being carried out by J. M. Dickins and G. A. Thomas. Their time-scale is indicated by Dickins (1961, footnote):

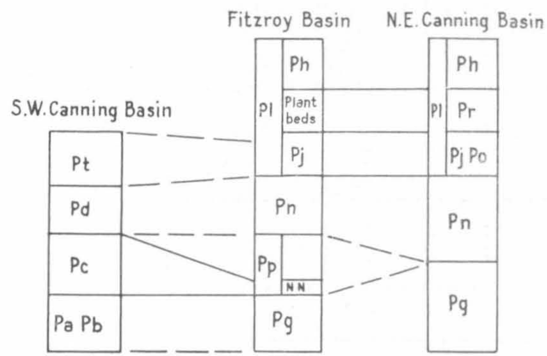
'General although not unanimous Soviet opinion is followed with regard to the subdivision of the Permian System. The System is regarded as containing two subdivisions, Lower and Upper, the Lower comprising the Sakmarian, Artinskian and Kungurian Stages, and the Upper, Kazanian and Tartarian . . . The Australian deposits are correlated with the standard subdivisions and the names are used to indicate the age.'

METHODS OF DATING UPPER CARBONIFEROUS AND PERMIAN ROCKS

Table 4

AGE		1. By fossils regionally compared	2. By fossils locally compared	3. By superposition	4. By paleogeographical considerations
Upper Permian	TARTARIAN	* Ph			
	KAZANIAN			Plant-bearing sandstone in Pl (Fitzroy Basin) Pr	
Lower Permian	KUNGURIAN	* Pj	Po		
	ARTINSKIAN upper	Pn (outcrop in Fitzroy B.)	* Pt Pn (bores) Pd		
	ARTINSKIAN lower			Rest of Pp	
	ARTINSKIAN basal	NN (outcrop in Fitzroy B.)	NN (bores) Pc		
	SAKMARIAN	Upper part Pg (bores)		Upper part Pg Grant Ra. Pa (?conformably underlies Pc)	Pa Pb Pg elsewhere
Upper Carboniferous	STEPHANIAN			Lower part Pg (Grant Ra and Fraser R.)	
	WESTPHALIAN	Anderson Formation			

NN - Nura Nura Member.



WA 62-13
G.M.

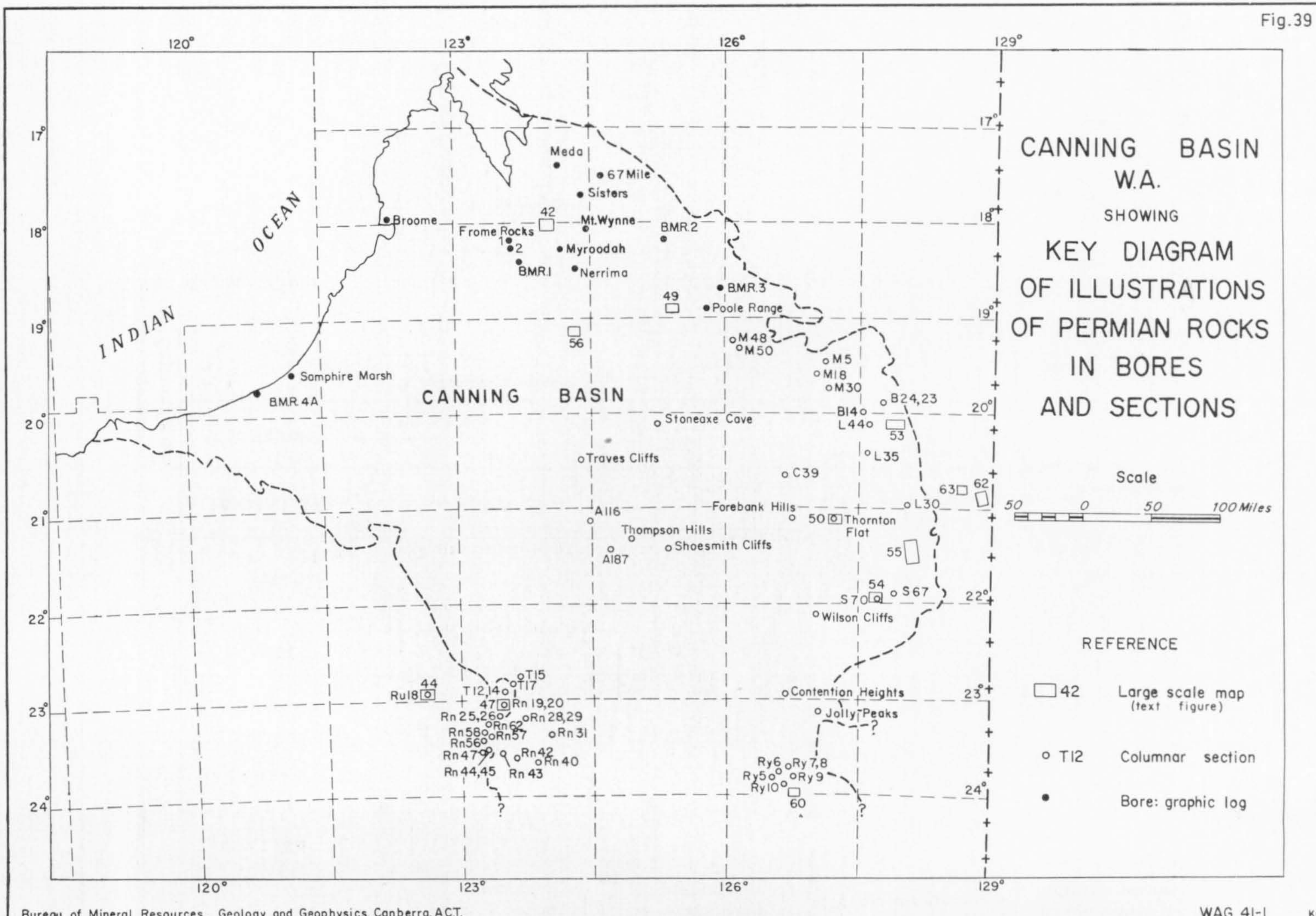


Fig.39
CANNING BASIN
W.A.
SHOWING
KEY DIAGRAM
OF ILLUSTRATIONS
OF PERMIAN ROCKS
IN BORES
AND SECTIONS
Scale
50 0 50 100 Miles
REFERENCE
42 Large scale map (text figure)
T12 Columnar section
Bore: graphic log
INDIAN OCEAN
CANNING BASIN
120° 123° 126° 129°
17° 18° 19° 20° 21° 22° 23° 24°
Meda
67 Mile
Sisters
Broome
Frome Rocks 1 2
42
Mt.Wynne
BMR.2
Myroodah
BMR.1
Nerrima
BMR.3
49
Poole Range
56
M48
M50
M5
M18
M30
Samphire Marsh
BMR.4A
B24,23
B14
L44
53
Stoneaxe Cave
Traves Cliffs
L35
C39
63
62
L30
A116
Forebank Hills
50 Thornton Flat
Thompson Hills
Shoesmith Cliffs
A187
55
54
S70
S67
Wilson Cliffs
44
Ru18
T12,14
T15
T17
47
Rn 19,20
Rn 25,26
Rn 28,29
Rn 62
Rn 58
Rn 57
Rn 31
Rn 56
Rn 47
Rn 42
Rn 40
Rn 44,45
Rn 43
Contention Heights
Jolly Peaks
Ry6
Ry 7,8
Ry5
Ry 9
Ry10
60
Bureau of Mineral Resources, Geology and Geophysics, Canberra. A.C.T.
WAG 41-1
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Fig. 39.

Morphology

The best-exposed Permian rocks extend from the Grant Range south-eastward to Waterlander Breakaway. Within this belt of faulted and gently folded rocks, which is 400 miles long and, on the average, 80 miles wide, the fold ranges in the Fitzroy Basin—the Grant, St George, and Poole Ranges—form the best outcrops. In these ranges, the air-photograph pattern of faults and formations is readily interpreted (*see* Figs. 42, 49, and Woolnough, 1933, p. 79). Most outcrops in the north-east Canning Basin, as exemplified by those at Balgo Mission (Fig. 53) east of Waterlander Breakaway (Fig. 54), and near the Stansmore Fault (Fig. 55), have distinctive air-photograph patterns. The Permian rocks south of Waterlander Breakaway are horizontal, and crop out poorly. Only Contention Heights (Fig. 57) and Ryan Buttes (Fig. 60) reveal more than 50 feet of rock section. Outcrops of probable Permian rocks in the central Canning Basin are intermittent and low, and are deeply weathered. The Permian rocks on the south-western margin of the Canning Basin extend from near Callawa Homestead at least as far south as 24°S, a distance of 300 miles. These rocks, except the Paterson Formation (Fig. 44), are poorly exposed.

Descriptions of the air-photograph patterns of the formations are given in the text below.

Stratigraphy

Descriptions of Permian rocks in certain parts of the Canning Basin have recently been published by Guppy et al. (Fitzroy Basin), Traves et al. (south-west Canning Basin), Casey & Wells (north-east Canning Basin), and McWhae et al. (Fitzroy Basin, north-east and south-west Canning Basin). Extracts from these papers are given here only where these are necessary to our text. Our chief aim is to synthesize, as far as possible, this information, most of which is descriptive, and to present new information that has accumulated since the above-mentioned papers were written.

Superimposed on the rhythm of coarser-grained freshwater or glacigene rocks and 'normal' marine rocks is a broader, three-fold division, best seen in bore sections (Fig. 40); these gross lithological entities are: an upper, finer-grained part, which consists of quartz greywacke, sandstone, and shale, with minor limestone; a middle, coarser-grained part, which consists of quartz sandstone with shale, minor erratics, conglomerate, and thin pebble beds, and locally contains plant fragments; and a lower part, similar to the middle part, but calcareous. The boundary between the coarser-grained rocks and the finer-grained rocks corresponds to the boundary between the Poole Sandstone and the Noonkanbah Formation in the Fitzroy Basin, and to that between the Cuncudgerie Sandstone and Dora Shale in the south-west Canning Basin. The progressively decreasing grainsize may be explained by either a gradual lowering of source areas or a gradual decrease in rainfall in source areas, or both. Independent evidence of an arid climate in the Upper Permian of Western Australia is lacking.

Grant Formation, Paterson Formation, Braeside Tillite

The Grant Formation, Paterson Formation, and Braeside Tillite of the Canning Basin, the Lyons Group of the Carnarvon Basin, the Nangetty Formation of the Perth

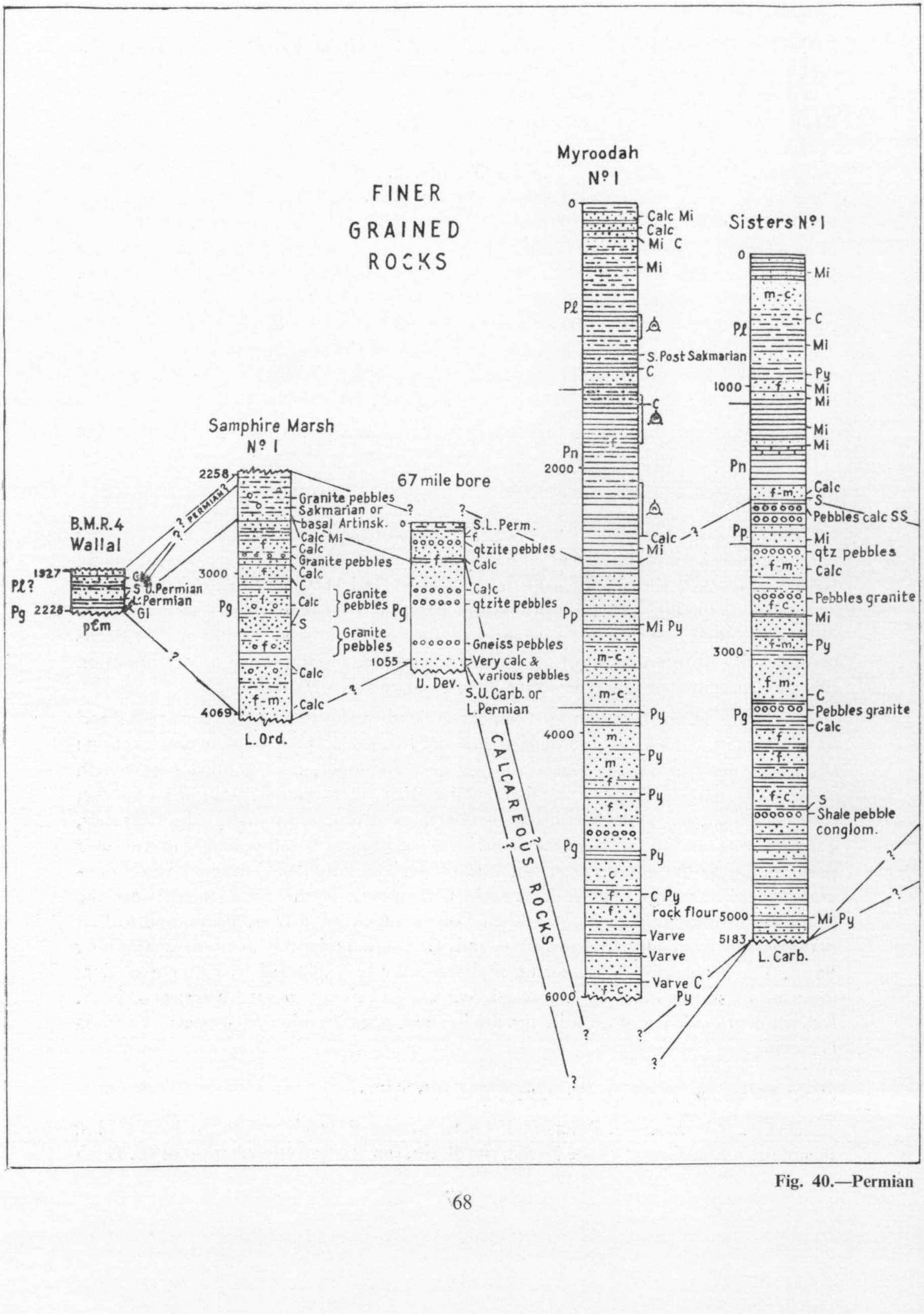
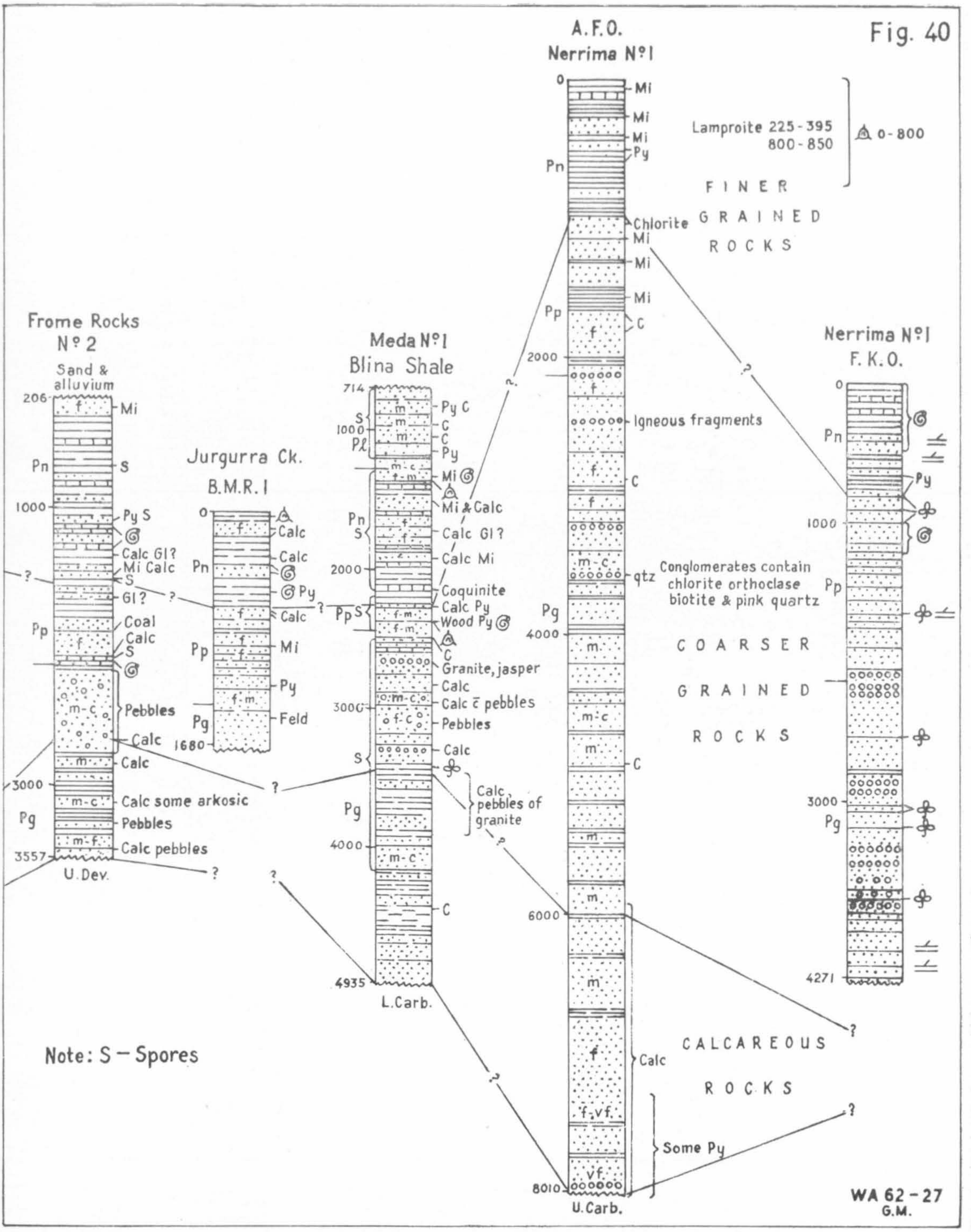


Fig. 40.—Permian



rocks in bores.

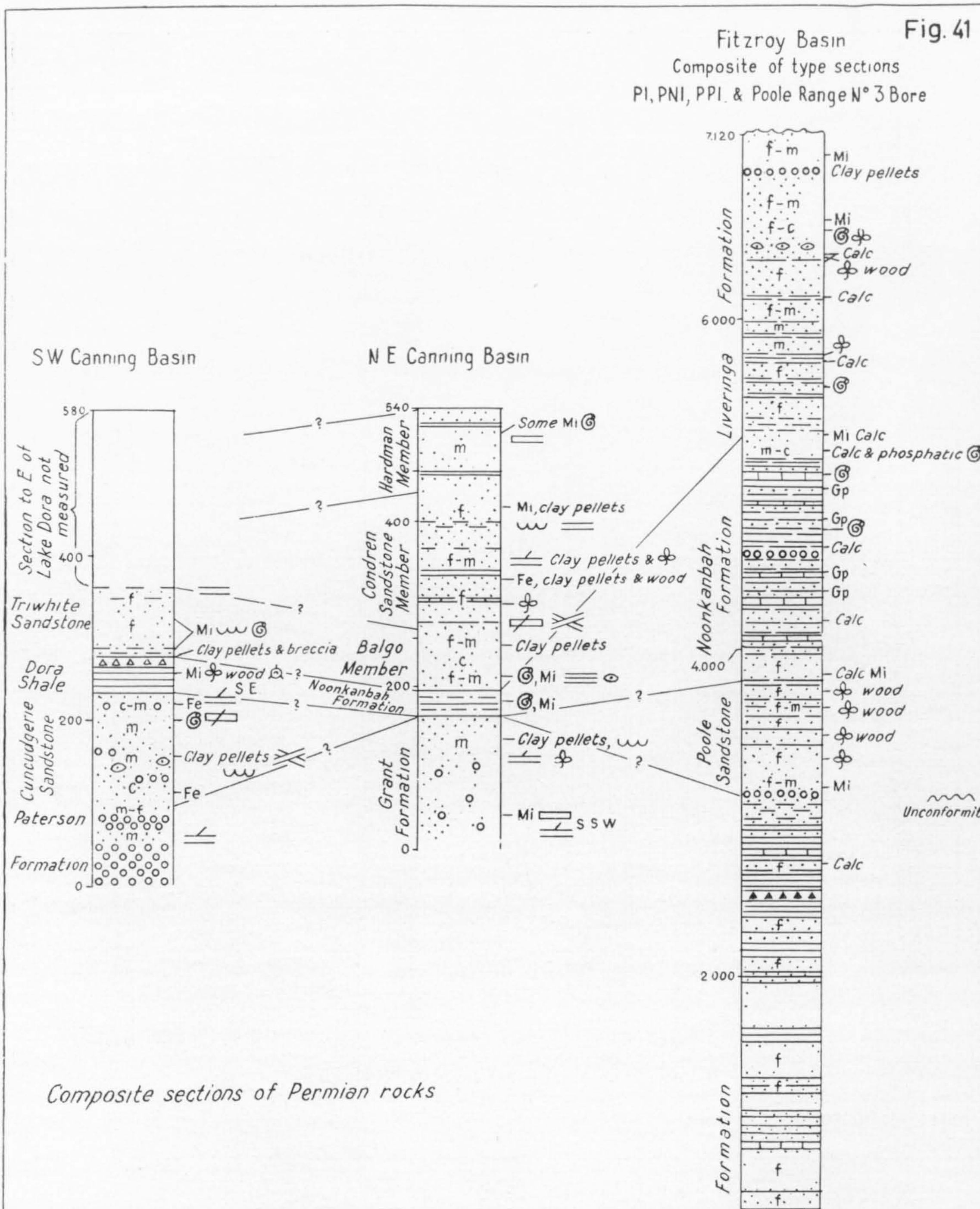


Fig. 41.—Composite sections of Permian rocks.

Basin, and probably also the Wilkinson Range Beds of the Interior Plateau contain glacigene rocks; these formations were probably deposited during the Sakmarian. Of these units, only the Grant Formation and the Lyons Group are known to contain marine fossils.

The *Grant Formation* in the Fitzroy Basin is described by McWhae et al. (pp. 55-56) as follows:

'The formation includes glacial sediments which unconformably overlie Carboniferous and older rocks and are themselves overlain disconformably by the Poole Sandstone. . . . The formation consists of siltstone, shale, greywacke, sandstone, conglomerate, tillite, and varved shale. The dominant rock-type is a massive, white to red-brown, friable to hard, fine- to medium-grained sandstone with grains varying from sub-angular to rounded. Boulders in the tillite beds represent a wide variety of igneous and metamorphic rock types. Many show faceted and striated surfaces. Associated with such beds are fontainebleau sandstones. The thickness of the formation varies considerably . . . and is approximately 9500 feet thick in the Grant Range area. The Grant Formation unconformably overlies Lower Carboniferous, Devonian and Ordovician rocks. In a test bore drilled by WAPET at Grant Range, the formation rests on Upper Carboniferous rocks. It is overlain disconformably by the Poole Sandstone or the Noonkanbah Formation.'

The Grant Formation also unconformably overlies Precambrian rocks in the Mount Ramsay Sheet area. The formation lies between the basal Artinskian Nura Nura Member of the Poole Sandstone and the Lower Stephanian to Westphalian Anderson Formation, and hence by superposition alone, its age lies within the interval Upper Stephanian to Sakmarian. On microfloral evidence, Balme (*in* McWhae et al., p. 56) suggests that the upper part of the formation may be correlated with part of the Sakmarian Holmwood Shale of the Perth Basin.

In the Fitzroy Basin, outcrops of the Grant Formation are readily identified in air photographs (Fig. 42; Woolnough, 1933, p. 79). In the southern part of the Grant Range, the Grant Formation consists of hard well-jointed quartz sandstone, which has been eroded into a rugged terrain that stands 200 to 300 feet above plain level. In most areas, the Grant Formation is massive, but in some places, for example south and south-east of the Grant Range No. 1 Bore (Fig. 42), the formation is well bedded. The Grant Formation contains, probably everywhere, soft well-bedded sandstone interbedded with hard massive sandstone, but the soft beds are visible only in the sides of valleys.

The Grant Formation has been traced from the Fitzroy Basin to the Kearney Range in the north-east Canning Basin. In the south-east corner of the Ryan Sheet area, a small outcrop mapped as undifferentiated Permian is tentatively interpreted from the air photographs as Grant Formation. In the north-east Canning Basin, the Grant Formation overlies Precambrian rocks, and in the Knobby Hills area, where outcrops are poor and no well-defined contacts were seen, probably overlies Upper Devonian or Carboniferous rocks. At Mount Bannerman, the Grant Formation is overlain by what is tentatively identified as the Condren Member of the Liveringa Formation; the contact here was not seen. In other parts of the north-east Canning Basin, the Grant Formation is probably overlain by the Noonkanbah Formation or by the Liveringa Formation.

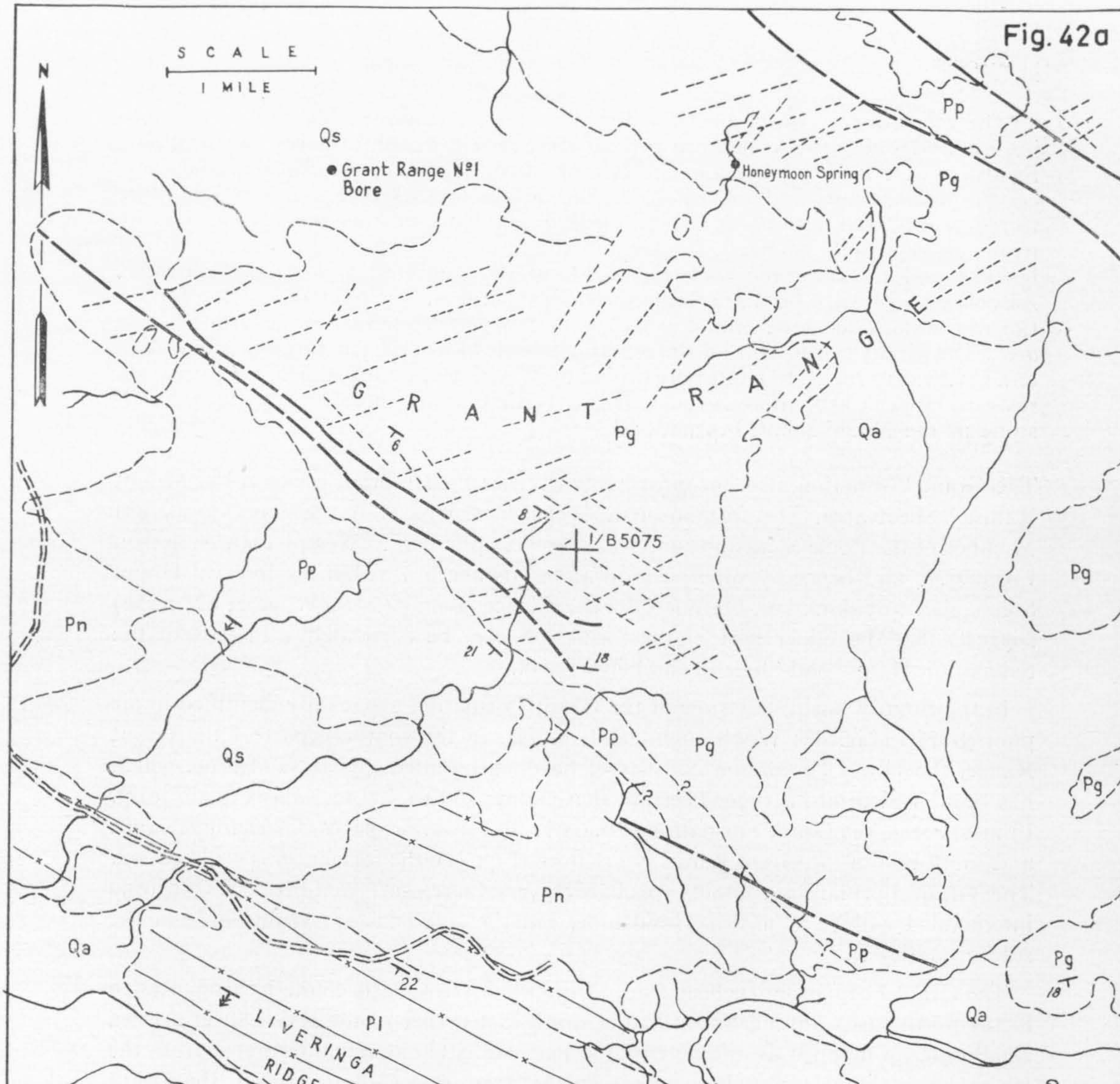


Fig. 42(a) and (b).—Geological sketch map and air photograph of the Grant Range (after Guppy et al.). Pg—Grant Formation; Pp—Poole Sandstone; Pn—Noonkanbah Formation; Pl—Liveringa Formation; Qa—Quaternary alluvium; Qs—Quaternary sand. Air photograph reproduced by permission of the RAAF.

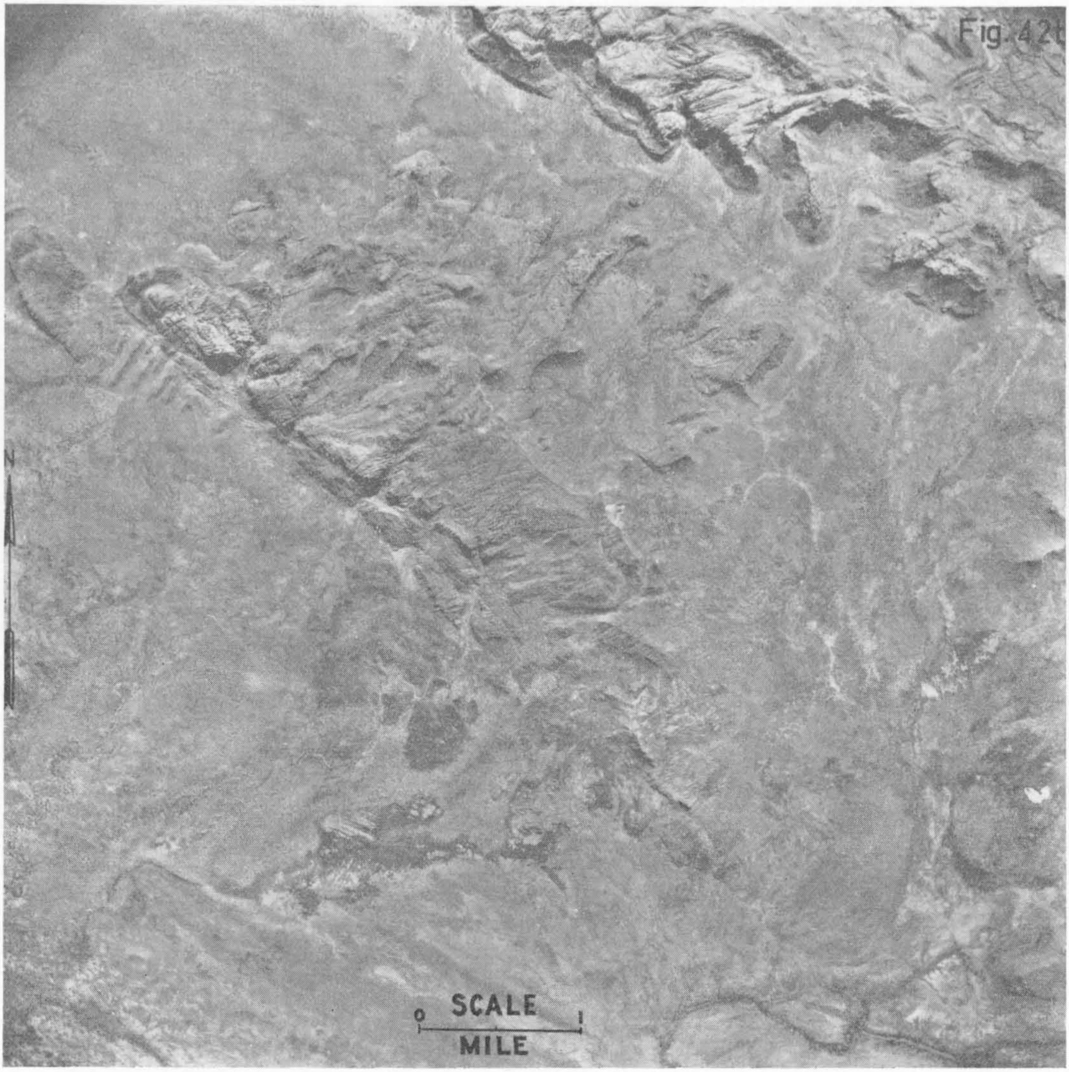


Fig. 42(b).

Fig. 43.—Paterson Formation and Precambrian rocks in the Rudall area. pCm—Precambrian metamorphic rocks; Pa—Paterson Formation; Qs—Quaternary sand. Air photograph reproduced by permission of the RAAF.

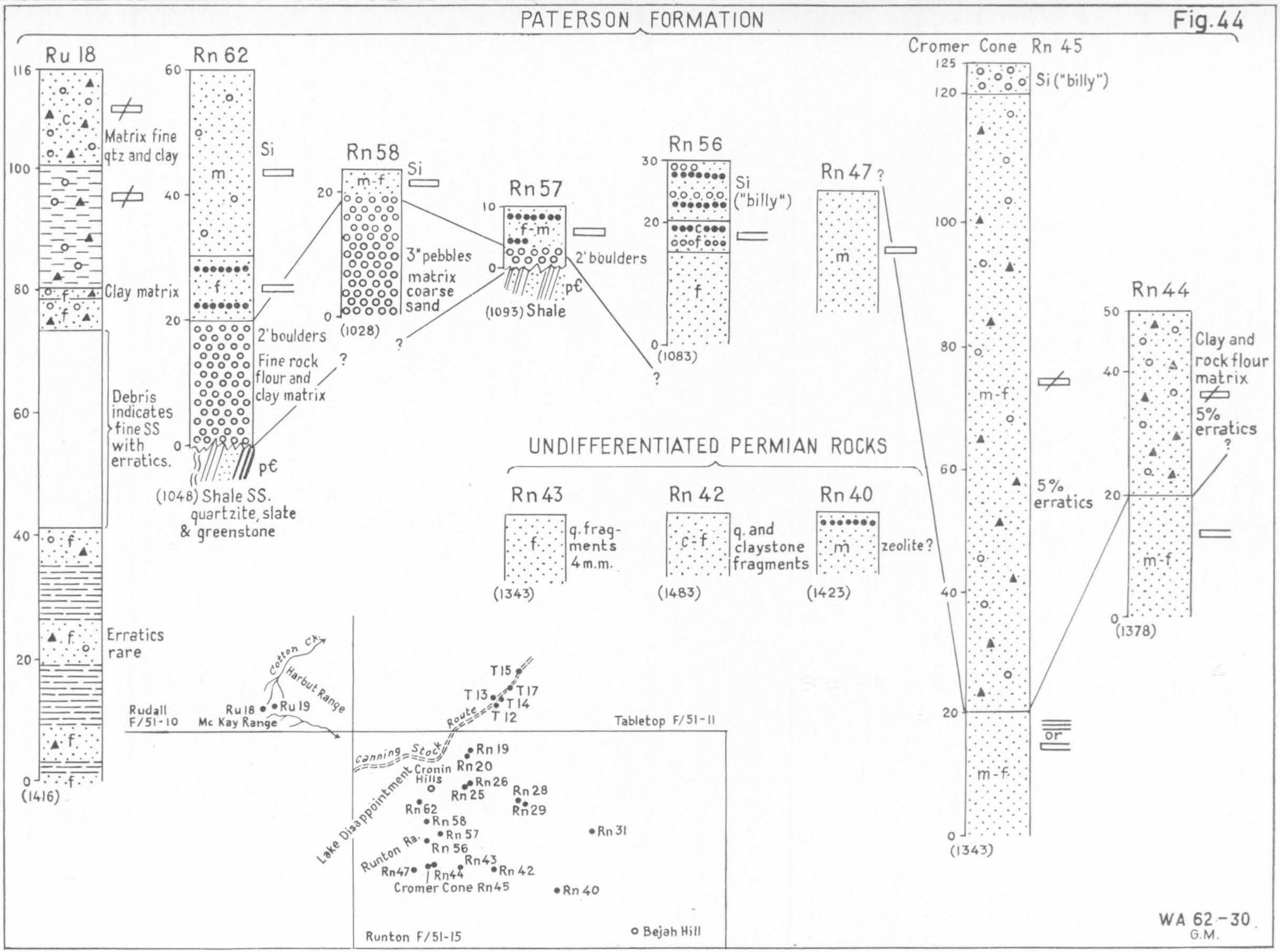


Fig. 44.—Sections of Paterson Formation and undifferentiated Permian rocks, Runton and Tabletop Sheet areas. Figures in brackets—barometric spot heights.

No more than 600 feet of the Grant Formation is exposed at the surface. The thickness of the formation in bores from north to south is as follows (*also see* Fig. 61C):

TABLE 5

BORE	THICKNESS (feet)
Meda Nos. 1 and 2	2510
67-mile Bore	1000 (approx.)
Fraser River No. 1	3080
Sisters No. 1	1967
Grant Range No. 1	7900
Roebuck Bay No. 1	1300
Frome Rocks No. 2	1450
Dampier Downs No. 1	1050
AFO Nerrima No. 1	5860
Goldwyer No. 1	750
Samphire Marsh No. 1	1700
BMR 4A Wallal	110

The thickest-known Grant Formation is in the Grant Range, where, according to McWhae et al. (p. 55), the formation is approximately 9500 feet thick. The basal part of many sections (*see* Fig. 40) is calcareous (*see* Appendix 2, 131C7); the lime occurs in thin beds of limestone or as calcite in fontainebleau sandstone.

The only means of dating the Grant Formation that can be used throughout the basin is by microspores. Balme (pers. comm.) distinguishes in the Carboniferous and Sakmarian of the Canning Basin two assemblages of microspores. The older of these ('*Lycospora*' assemblage) he regards as Carboniferous, and the younger (*Nuskoisporites* assemblage) as Sakmarian.

In what we identify as Grant Formation, the '*Lycospora*' assemblage has been determined in the Grant Range No. 1 Bore at 6106-6115 feet, 1700 feet above the base of the formation, and in Meda No. 1 Bore in the basal half of the Grant Formation at 4045-4065 feet, and 4530-4550 feet; an assemblage transitional between *Nuskoisporites* and '*Lycospora*' was found at 3447-3450 feet near the middle of the Grant Formation in this bore. Where Balme has found microspores in other bore sections of the Grant Formation, they belong to the *Nuskoisporites* assemblage. This includes the top and bottom of the section of the formation in the 67-mile Bore.

The '*Lycospora*' assemblage is also recorded from the Anderson Formation in the Grant Range No. 1 Bore at 7907-7912 feet and 9788-9808 feet, and in the Fraser River No. 1 Bore at 4825 feet to the bottom of the sedimentary section in the hole.

Besides microspores, long-ranging arenaceous and calcareous foraminifera and plants have been found in the Grant Formation. Crespin (1958) records foraminifera in the '?Grant Formation' in Roebuck Bay No. 1 Bore (2543-2605 feet, 2648-2657 feet). White (Appendix 6) determined Permian plant fossils from the Grant Formation of BMR 3 Prices Creek water-well.

The *Paterson Formation* (Traves et al.) extends southward of Lake Waukarlycarly at least to 24° S. The Paterson Formation lies along the basin margin in the Runton Sheet area, and elsewhere forms outliers on Precambrian rocks. In the south-western part of the Paterson Range Sheet area, outliers of Paterson Formation have been mapped up to 70 miles beyond the basin margin.

The Paterson Formation in the Paterson Range area (Traves et al.) consists of at least 100 feet of contorted claystone, sandstone, and conglomerate.

At Cronin Hills, in the Runton Sheet area (Figs. 75, 76), the Paterson Formation underlies the Mesozoic plant-bearing Cronin Sandstone. In several other sections in the Runton Sheet area, the Paterson Formation is conformably overlain by the Cuncudgerie Sandstone. In the Rudall Sheet area, 116 feet of interbedded poorly sorted coarse sandstone and claystone with erratics of quartz, metamorphics, and granite up to 2 feet across are exposed at a butte (Ru18, Figs. 43, 44) in the headwaters of Cotton Creek. In the air photograph (Fig. 43), the top of the butte of Paterson Formation

Fig. 45.—Angular unconformity between Precambrian slates and shales and Paterson Formation at Rn62.

appears smooth and light-grey, and the sides almost white. The white streaks northwest of Ru18 are fireburns in the spinifex-covered sand plain. The Paterson Formation of this area rests on steeply dipping Precambrian rocks. A low rise of metamorphics immediately south of Ru18 is overlain by thin deposits of the glacials, which contain boulders derived from the underlying rock. The top of the section is eroded. At Ru19, about two and a half miles east of Ru18, the ground is covered with debris derived from the Paterson Formation. A large boulder of striated pink quartzite was found here. Other boulders consist of limestone, quartzite, basic lavas, gneiss, granite, and quartz.

Several sections of the Paterson Formation were measured in the Runton Range and at Cromer Cone (Fig. 44). The angular unconformity between the formation and Precambrian rocks is visible at Rn62 and Rn57 (Fig. 45). At Rn62, a 20-foot-thick boulder conglomerate is succeeded by medium and fine-grained sandstone with some erratics. The conglomerate consists of boulders up to 2 feet across in a matrix of fine rock flour. At Cromer Cone (Rn45, Fig. 44) and at Rn44, the Paterson Formation consists of poorly sorted deposits containing boulders up to 3 feet across. The upper 105 feet of the 125-foot-thick section at Cromer Cone consists of massive sandstone, which contains about 5% by volume of erratics of quartz, quartzite, granite, and schist. This rock is underlain by 20 feet of fine to medium-grained sandstone. The base is not exposed. Cromer Cone lies 5 miles from the nearest exposed Precambrian rocks, and the Paterson Formation in this area is possibly much thicker than 125 feet. The rocks at Rn40, Rn42, and Rn43, east of Cromer Cone, are finer grained and better sorted, and were perhaps deposited in sea-water.

At Rn26 (Fig. 46) the Cuncudgerie Sandstone conformably overlies 50 feet of poorly sorted massive fine-grained sandstone and siltstone of the Paterson Formation.

The probable Permian rocks in the core of the dome at Woolnough Hills (Veevers & Wells, 1959, 1960) are perhaps part of the Paterson Formation. The main rock is a medium-grained quartz sandstone, which contains a few pebbles.

The *Braeside Tillite* (Traves et al.) crops out near Braeside Homestead at the base of mesas and buttes, and on valley floors. In the valleys of the Nullagine and Oakover Rivers, it is overlain by the Tertiary Oakover Beds (Fig. 121). Elsewhere, as at Two Sisters Hills, the Tillite forms outliers. The southern extension of the Braeside Tillite in the valleys of the Oakover and Nullagine Rivers is not known, but tillite is known as far south as Woody Woody (Casey & Wells, 1956, unpubl.), and tillite and glaciated pavements at Ripon Hills and Carawine Gorge. The pavements indicate movement of the glaciers northward and north-westward, roughly parallel to the present river valleys. The tillite is about 400 feet thick at Warrawagine.

The Braeside Tillite and Paterson Formation are tentatively correlated with the Grant Formation. No fossils have been found in the Braeside Tillite or the Paterson Formation, and correlation is based on the belief that the Upper Palaeozoic glaciation of Western Australia occurred at the same time in various areas. The correlation of the Paterson and Grant Formations is confirmed by the conformity between the Paterson Formation and the basal Artinskian Cuncudgerie Sandstone. The Braeside Tillite, which is overlain by the Tertiary Oakover Beds and by the Jurassic Callawa Formation, is possibly overlain in the north-eastern corner of the Yarrie Sheet area by the Cuncudgerie Sandstone, and hence, on superpositional grounds, is possibly pre-Artinskian.

Poole Sandstone (including Nura Nura Member) and Cuncudgerie Sandstone

Outcrops of the *Poole Sandstone* (Guppy et al.) lie north of 19° S, in the flanks of the Poole Range, Grant Range, and Mount Wynne, in the Tutu Structure, and near the northern margin of the basin. The Poole Sandstone lies between the Grant Formation below, and the Noonkanbah Formation above, and is probably overlapped by the Noonkanbah Formation south of Fitzroy Crossing. Guppy et al. described the contact between the Grant Formation and the Poole Sandstone as a disconformity, but in some areas they could have been misled by slumping at the top of the Grant Formation. In most areas of outcrop, the Poole Sandstone passes up through transition beds into the Noonkanbah Formation, but in the area between the Grant and Poole Ranges a conglomerate bed that lies at the base of the Noonkanbah Formation suggests a disconformity.

In most areas, the Poole Sandstone consists of white and brown well-bedded ferruginous fine-grained micaceous quartz sandstone with minor shale. Cross-bedding, ripple marks, and worm tracks indicate deposition in shallow water. The Poole Sandstone (Fig. 42) can be identified on the air photographs by its smooth pattern, light tone, and fine bedding. The Sandstone is not jointed, and is less resistant to erosion than the Grant Formation.

The *Nura Nura Member* consists of 50 feet of calcareous sandstone and sandy limestone that lies at the base of the Poole Sandstone in the Grant Range, at Mount Wynne, and at Nura Nura Ridge. The fauna of brachiopods, bryozoa, foraminifera, and ammonoids indicates early Artinskian. The Nura Nura Member is variable in thickness and composition. In the St George Range, the fauna of the member occurs in ferruginous silty sandstone at the base of the Poole Sandstone.

The Poole Sandstone is not exposed in the north-east Canning Basin, probably because it is overlapped by the Noonkanbah Formation.

The abundant foraminifera in the Nura Nura Member distinguish these 'normal' marine calcareous rocks from the glacigene Grant Formation below and the freshwater arenaceous part of the Poole Sandstone above, and thus indicate the boundary between these formations, and its age. The thickness in bores of the freshwater part of the Poole Sandstone is as follows:

TABLE 6

BORE	THICKNESS (feet)
Meda No. 1	148
Sisters No. 1	345
Frome Rocks No. 2	538
Myroodah No. 1	1107
Dampier Downs No. 1	501
BMR 1, Jurgurra Creek	200
AFO Nerrima No. 1	1160
FKO Nerrima No. 1	1305
Goldwyer No. 1	467

In bores particularly, the Poole Sandstone is clearly distinguishable from both the Noonkanbah and the Grant Formations; it is cleaner and its grains are more rounded than either, it is generally coarser than the Noonkanbah, and it does not contain polymict conglomerate like the Grant Formation.

The *Cuncudgerie Sandstone* (Traves et al.) is recorded from two areas in the south-west Canning Basin. The main area lies north of Lake Waukarlycarly, and the second between Cronin Hills and Helen Hill. The Cuncudgerie Sandstone conformably overlies the Paterson Formation, except at Rn19 and Rn20 (Figs. 43, 47), where it overlies Precambrian metamorphics, and in the north-eastern corner of the Yarrie Sheet area, where it possibly overlies the Braeside Tillite. By air-photograph interpretation, the Cuncudgerie Sandstone also lies directly on Precambrian rocks 20 miles north-east of Lake Waukarlycarly, and 10 miles south-west of Helen Hill. The eroded top of the Cuncudgerie Sandstone is overlain by undifferentiated Mesozoic rocks 5 miles south-east of Helen Hill, and 15 miles north of Lake Waukarlycarly. Near P17 (Paterson Range Sheet), undifferentiated Mesozoic conglomerate lies on an erosional surface of Precambrian rocks. The conglomerate, which is not affected by a fault in the Precambrian rocks, lies 15 feet below nearby outcrops of the claystone of the Paterson Formation.

The thickest measured section is 130 feet at Cuncudgerie Hill, and consists of fine to coarse-grained well-bedded to massive quartz sandstone and greywacke, with some siltstone beds and lenses of conglomerate.

New information on the Cuncudgerie Sandstone relates to the area between Helen Hill and Cronin Hills. In this area, exposures of the Cuncudgerie Sandstone, typified by sections in the Helen Hill area (Fig. 46), consist of interbedded claystone, shale, siltstone, and fine-grained sandstone, succeeded by medium to coarse-grained quartz sandstone with clay pellets and worm tracks. The claystone, shale, siltstone, and fine sandstone have rhythmic graded bedding. Brachiopods and pelecypods occur in a ferruginous fine sandstone at T16; an indeterminate blastoid plate (A. A. Öpik, pers. comm.) occurs in coarse sandstone at T14, and indeterminate plants in a fine ferruginous micaceous sandstone at T15 and T17. A rare occurrence of limestone is indicated by rubble at T13. Parts of the dark-green limestone have cone-in-cone structure, others are massive or fine bedded. The limestone rubble lies on the pediment of a breakaway of Cuncudgerie Sandstone, and was probably derived from a thin bed in the Sandstone. The interbedded claystone, siltstone, and fine sandstone of the Cuncudgerie Sandstone in the Helen Hill area (Fig. 48) are not represented in the type locality, 180 miles north-westward. The top of the section in the type locality is eroded away, and the bottom of the Cuncudgerie Sandstone in the Helen Hill area is not exposed, and the observed difference in lithology may indicate the upper and lower parts of the formation.

South of the Helen Hill area, at Rn26 in the Runton Sheet area (Fig. 46), the Cuncudgerie Sandstone consists of thin-bedded medium-grained sandstone with clay lenses and pellets, and thin grit beds. In the same area, at Rn19 and Rn20, a 10-foot-thick boulder conglomerate is succeeded by fine to medium sandstone with thin interbeds of claystone, shale, and grit. The matrix of the boulder conglomerate is poorly sorted coarse sand. In this area, conglomerate is known to occur in the Precambrian succession, and in the Paterson Formation. That of the Paterson Formation has a matrix of rock flour, and the Precambrian conglomerate is silicified. The boulder conglomerate at Rn19 and Rn20 cannot be identified with either the Precambrian conglomerate or the Paterson Formation; it probably represents the base of the Cuncudgerie Sandstone, and the boulders were probably derived from the Paterson Formation and Precambrian conglomerate.

On the basis of the early Artinskian fossils from Helen Hill and from P1, 10 miles south-east of Cuncudgerie Hill, the Cuncudgerie Sandstone is correlated with the Nura Nura Member of the Poole Sandstone.

Noonkanbah Formation and Dora Shale

Outcrops of the *Noonkanbah Formation* (Guppy et al.) extend from King Sound in the north-western part of the basin to Thornton Flat in the Helena Sheet area. Throughout most of this area, the Noonkanbah Formation consists of soft calcareous

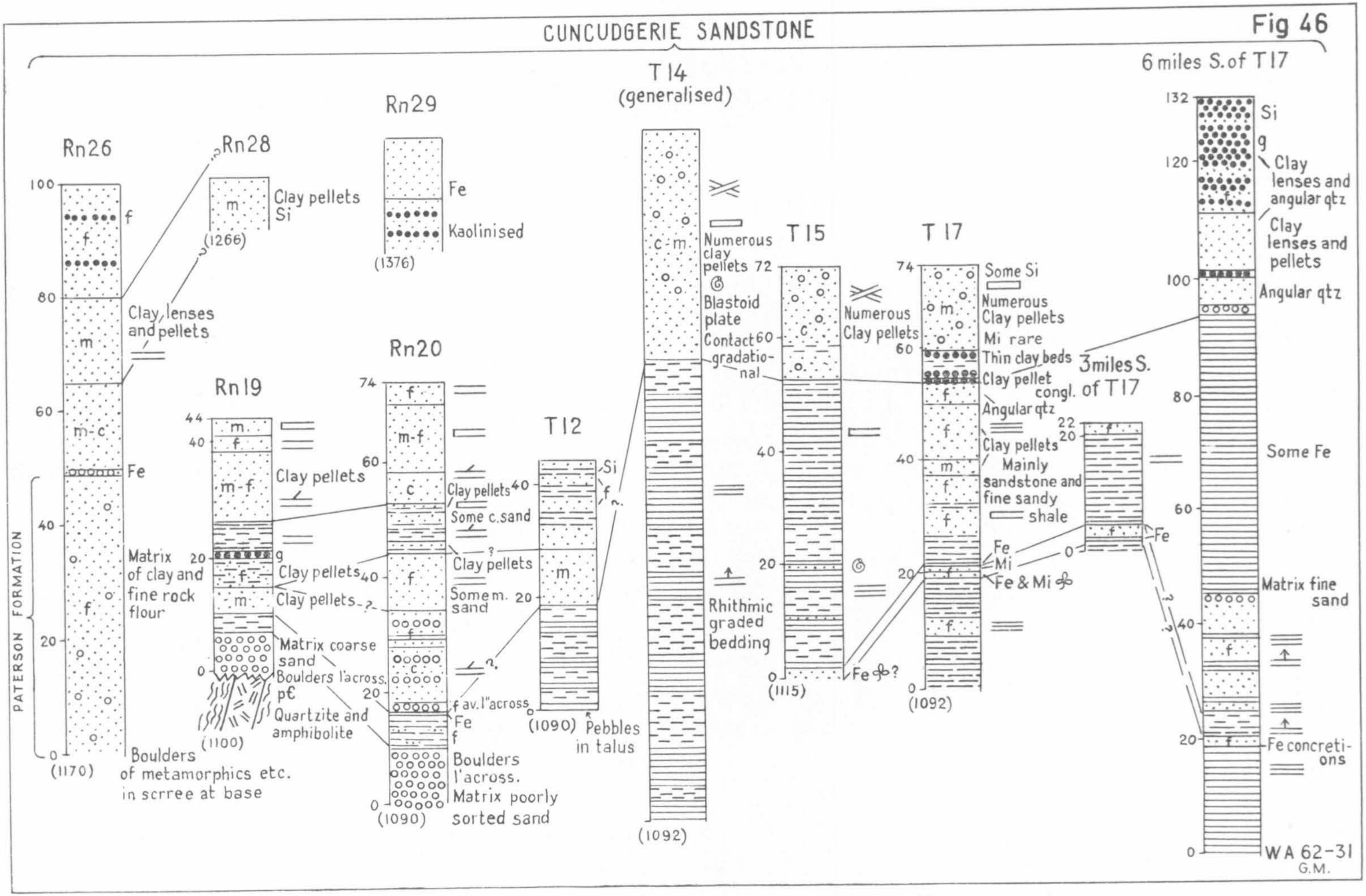


Fig. 46.—Sections of Cuncudgerie Sandstone, Runton and Tabletop Sheet areas.

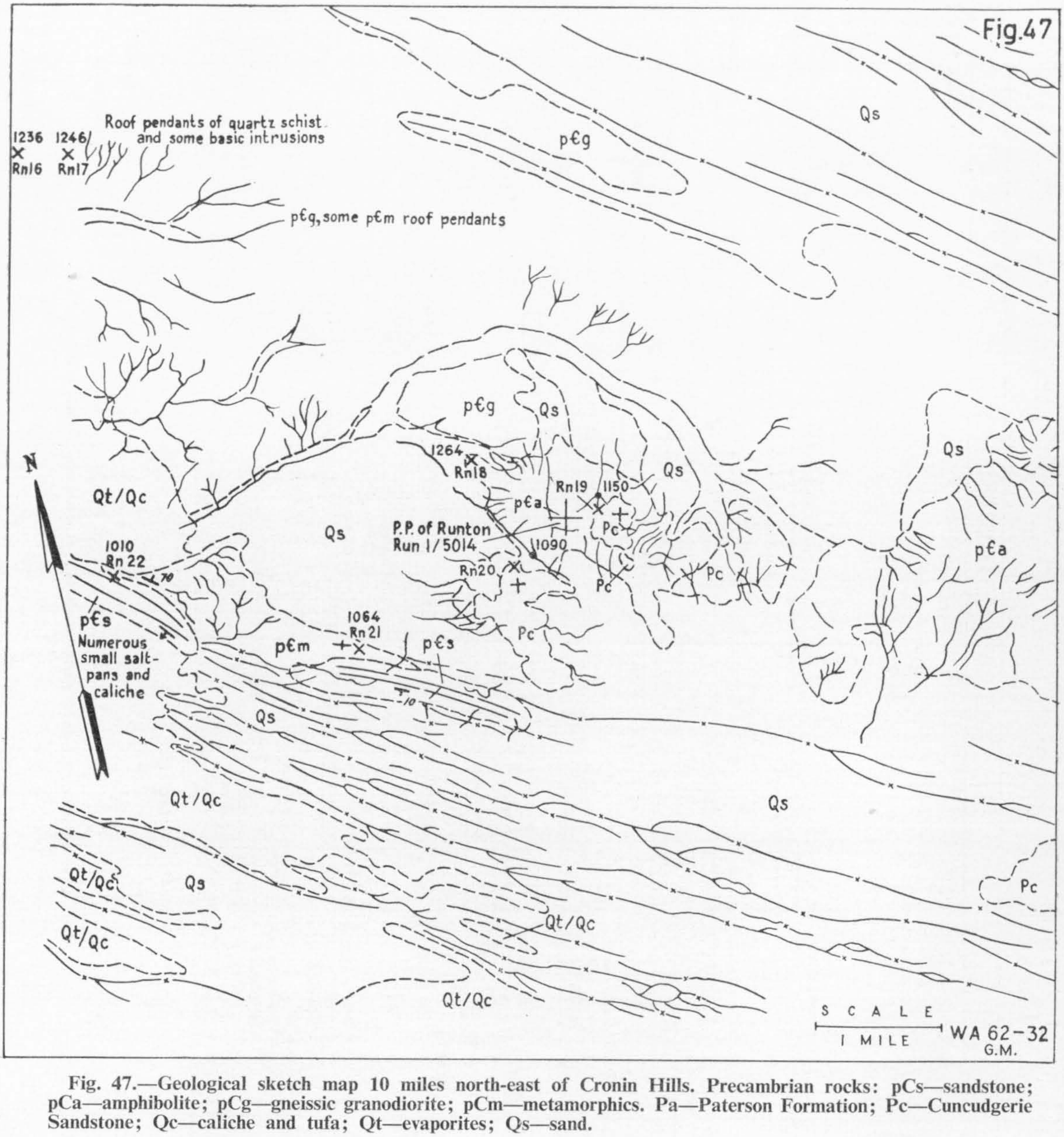


Fig. 47.—Geological sketch map 10 miles north-east of Cronin Hills. Precambrian rocks: pCs—sandstone; pCa—amphibolite; pCg—gneissic granodiorite; pCm—metamorphics. Pa—Paterson Formation; Pc—Cuncudgerie Sandstone; Qc—caliche and tufa; Qt—evaporites; Qs—sand.

siltstone, shale, calcareous sandstone, and sandy limestone, and contains marine fossils. In the Fitzroy Basin, the Noonkanbah Formation grades upward from the Poole Sandstone except in the Poole Range, where the base of the Formation is a conglomerate. The lower half of the Noonkanbah Formation is dominately arenaceous. In the north-east Canning Basin, the Noonkanbah Formation probably rests on the Grant Formation (Casey & Wells). Exposures of this contact are poor, and no angular unconformity was seen. The contact between the Noonkanbah Formation and the overlying Liveringa Formation is obscured in the north-east Canning Basin; it is probably conformable. In the Fitzroy Basin, the two formations are conformable.

Fig. 48.—Shale and thin-bedded fine sandstone (Cuncudgerie Sandstone) near T14, Canning Stock Route.

Outcrops of the Noonkanbah Formation, as exemplified by those of the eastern plunge of the St George Range (Fig. 49), are generally poor; the Noonkanbah Formation underlies black-soil and alluvial plains, and rock occurs in lines of float or in gully exposures. Trends in the formation are indicated by darker lines or bands in the overlying soil. In the area shown by Figure 49, the Noonkanbah Formation dips gently in low-pitching folds.

In the Grant Range area, north of Liveringa Ridge (Fig. 42), the Noonkanbah Formation is deeply weathered, and bedding trends are barely visible beneath clay and black soil.

In many areas of the north-east Canning Basin the poorly exposed Noonkanbah Formation is indistinguishable from parts of the Liveringa Formation. Only 100 feet

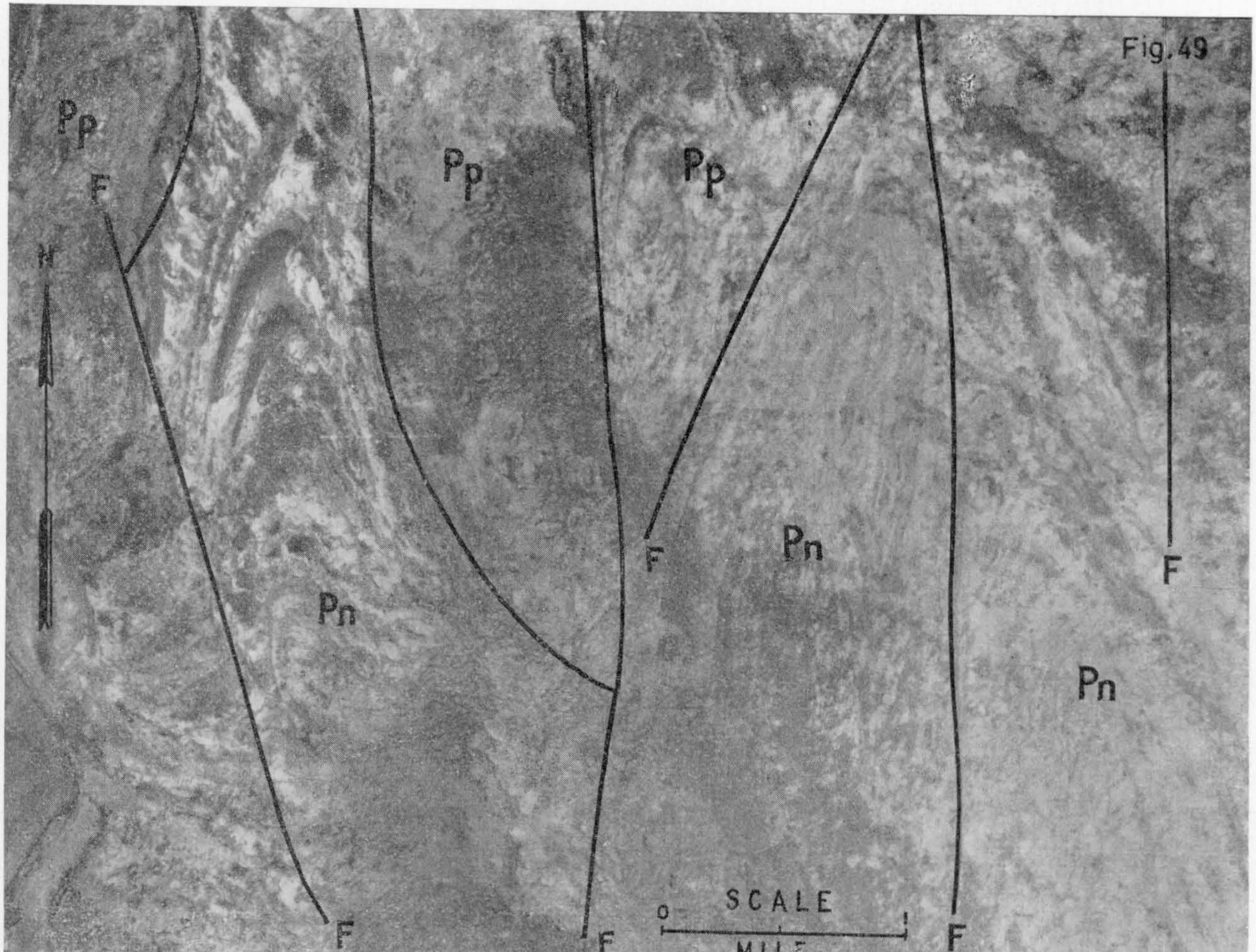


Fig. 49.—Noonkanbah Formation (Pn) and Poole Sandstone (Pp) in the Poole Range. Air photograph reproduced by permission of the RAAF.

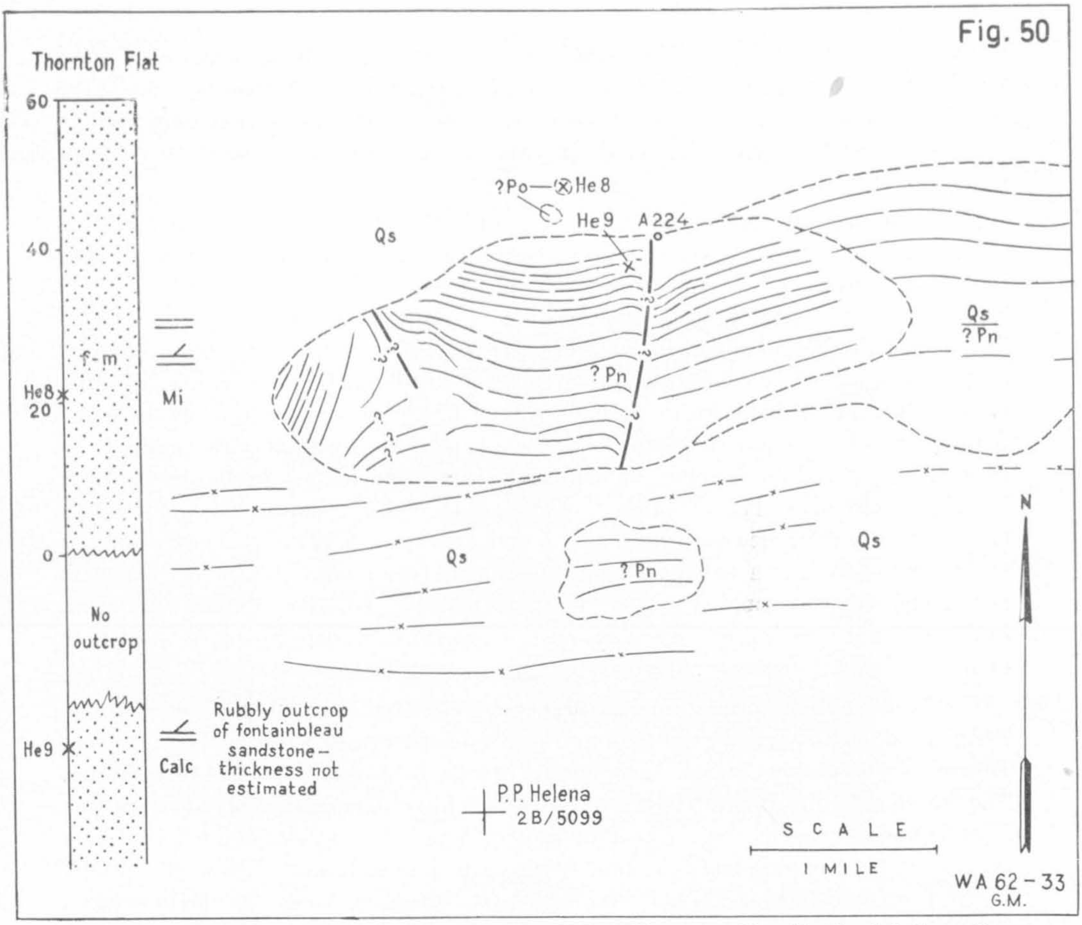


Fig. 50.—Sketch map and section Thornton Flat, Helena Sheet area. Pn—Noonkanbah Formation; Po—Balgo Member, Qs—sand.

Fig. 51.—Scott Bluff, looking at eastern shore of Lake Blanche. East dip-slope in sandstone. Photo: C. St. J. Bremner; reproduced by permission of Wapet.

were seen in any one section. The formation crops out around Balgo Mission, around Lakes Betty, Lonergan, and Jones, south of Christmas Creek Homestead, in the Southesk Tableland, and in the Bishop and Stansmore Ranges. Ferruginous fine sandstone, quartz greywacke, and shale with some coquinites are the main types of outcropping rock.

From their air-photograph pattern, the rocks in the Thornton Flat/Farewell Lakes area, in the north-eastern part of the Helena Sheet area, are interpreted as a succession in ascending order of Noonkanbah Formation, Balgo Member, and Condren Member. Thornton Flat (Fig. 50), a grass-covered gravel flat, has an air-photograph pattern like that of the Noonkanbah Formation (cf. Figs. 49 and 50). Low rubbly outcrops on this flat consist of cross-bedded fontainebleau sandstone (He9, Appendix 2), which is probably interbedded with a siltstone or shale which does not crop out. The Noonkanbah Formation at Thornton Flat is overlain by horizontal cross-bedded fine- to medium-grained quartz-mica sandstone (He8, Appendix 2) of the Balgo Member. The sinuous trends and close faulting of the Noonkanbah Formation indicate that it is less competent than the overlying rocks. A similar section of rocks is exposed 4 miles south-west of Bohemia Downs Homestead, on the south-west side of the Pinnacle Fault. The only outcropping rock in the folded and faulted Noonkanbah Formation of the Bohemia area is fontainebleau sandstone, which is overlain by quartz sandstone of the Liveringa Formation.

The Noonkanbah Formation has been recognized in bores that penetrated the Permian succession, except those along the coast, viz. Fraser River No. 1, Dampier Downs No. 1, Goldwyer No. 1, Samphire Marsh No. 1, and BMR 4, 4A, Wallal. The Noonkanbah Formation in bores consists mainly of fine sandstone (*see* Appendix 2, 5C7) and micaceous shale with thin beds of limestone or calcarenite. Glauconite occurs locally. Foraminifera (Crespin, 1958) are widespread, and occur in Myroodah No. 1 Bore (825-1000 feet, 1445-1800 feet, 2100-2500 feet), Meda No. 1 (1450 feet), BMR 1 Jurgurra Creek (0-75 feet), AFO Nerrima No. 1 (0-700 feet), Roebuck Bay No. 1 (1590-1900 feet), and in the Derby Town Bore (1760-2068 feet). Microspores in the Noonkanbah Formation of these bores, and also of Frome Rocks No. 2, have been studied by B. E. Balme.

The *Dora Shale* (Traves et al.) is known from a few isolated outcrops on the northern edge of Lake Dora, and in 50 to 100-foot cliff sections capped with Triwhite Sandstone on the eastern edge of Lakes Dora and Blanche; Dora Shale probably forms the floor of Lakes Dora, Blanche, Winifred, and George. The Dora Shale consists of micaceous shale and sandstone. The thickest measured section is 40 feet. Its base is not exposed, and it is conformably overlain by the Triwhite Sandstone. The uppermost bed of the Dora Shale on the north-eastern edge of Lake Dora consists of clay pellets and clay breccia derived from the underlying shale. Reeves (1949, unpubl.) records exposures of ferruginous shale and sandstone from Scott Bluff, on the northern edge of Lake Blanche (Fig. 51).

Foraminifera, indeterminate worm trails, and wood remains are recorded from the Dora Shale. Foraminifera from Lake Dora and Scott Bluff were determined by Crespin (*in* Traves et al., p. 54; Crespin, 1958) and form the basis of the correlation between the Dora Shale and the Noonkanbah Formation.

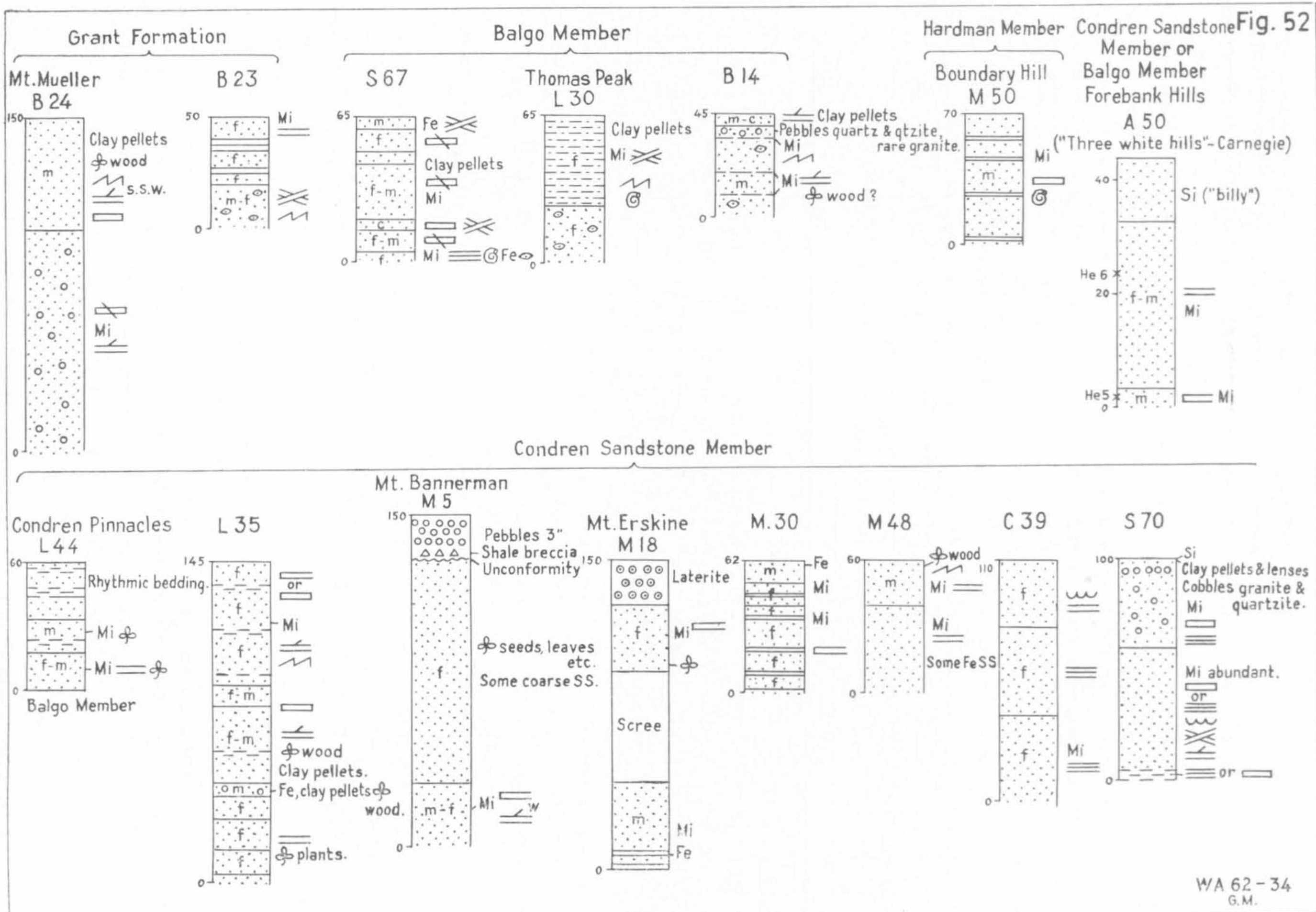


Fig. 52.—Sections of Permian rocks in the north-east Canning Basin.

Liveringa Formation (including Lightjack, Hardman, Balgo, and Condren Members) and Triwhite Sandstone

The outcrop of the *Liveringa Formation* (Guppy et al.) stretches intermittently from King Sound to Waterlander Breakaway and Sufficiency Knob, in the Stansmore and Wilson Sheet areas. The Liveringa Formation is widely distributed in the Fitzroy Basin; it conformably overlies the Noonkanbah Formation, and is overlain, probably unconformably, by the Blina Shale, and unconformably by the Erskine Sandstone, Mudjalla Sandstone, Barbwire Sandstone, and James Sandstone (Fig. 77).

Three members of the Liveringa Formation have been distinguished in the Fitzroy Basin, but only two have been named. The members are the lower marine Lightjack Member, an unnamed middle member that consists of plant-bearing sandstone, and the upper marine Hardman Member.

The *Lightjack Member* (Guppy et al.) consists of richly fossiliferous greywacke and fine quartz sandstone with lenses of oolitic limonite at the base. Its age is upper Artinskian to Kungurian. The Lightjack Member is dark on the air photographs (Fig. 42); the overlying plant-bearing sandstone is lighter.

The middle member consists of fine thin-bedded micaceous sandstone with plants and thin coal seams.

The *Hardman Member* (Guppy et al.) at Mount Hardman consists of 120 feet of richly fossiliferous thin-bedded fine to medium sandstone and massive medium to coarse quartz sandstone. Its age is upper Kazanian to Tartarian.

The rocks between the plant-bearing sandstone and the Hardman Member are poorly exposed, and probably consist of calcareous siltstone and sandstone. The maximum thickness is probably 1200 feet.

The maximum exposed thickness of the Liveringa Formation is about 1850 feet.

Guppy et al. (p. 51) include the plant-bearing sandstone in the Lightjack Member; but on p. 53, they refer to the plant-bearing sandstone as the middle member. McWhae et al. recognize the plant-bearing beds above the Lightjack Member as a separate member, but make no mention of the middle member described by Guppy et al. A. W. Lindner (pers. comm.) considers that the plant-bearing sandstone is not everywhere identifiable. He also holds that another unit probably occurs between the plant beds and the Hardman Member. This unit occurs as calcareous float between the Fitzroy River and Mount Hardman, in the Nerrima area, and south of the Shore Range. This unit probably corresponds to the middle unit described by Guppy et al. The subdivisions of the Liveringa Formation in the Fitzroy Basin require further study.

In the north-east Canning Basin four members of the Liveringa Formation (Figs. 52, 53) have been identified. The Lightjack Member has been traced south-eastwards from the Fitzroy Basin into the Mount Bannerman Sheet area. A well-defined middle plant-bearing member has been mapped by Casey & Wells as the *Condren Sandstone Member*, and an outlier of the Hardman Member has been identified in the north-east corner of the Mount Bannerman Sheet area. White (Appendix 6) has identified the plants in the Condren Member. In the Mount Bannerman Sheet area, the term Lightjack Member is applied to the basal, richly fossiliferous quartz greywacke, siltstone, and sandstone of the Liveringa Formation, which conformably overlies the Noonkanbah Formation. The Condren Member overlies the Lightjack Member with local unconformity. The contact between the Condren Member and the Hardman Member

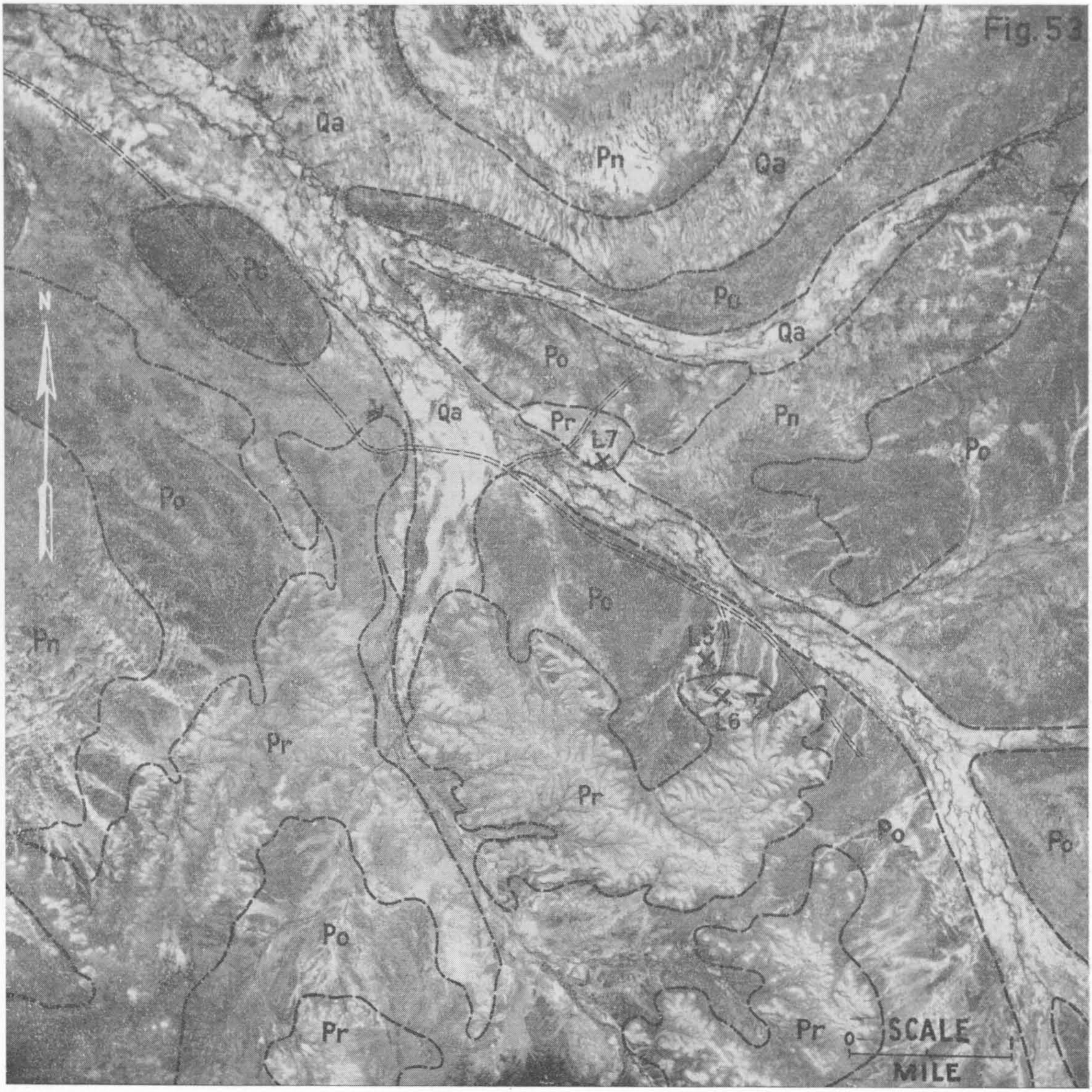


Fig. 53.—Balgo Hills. Pn—Noonkanbah Formation; Po—Balgo Member; Pr—Condren Member. Air photograph reproduced by permission of the RAAF.

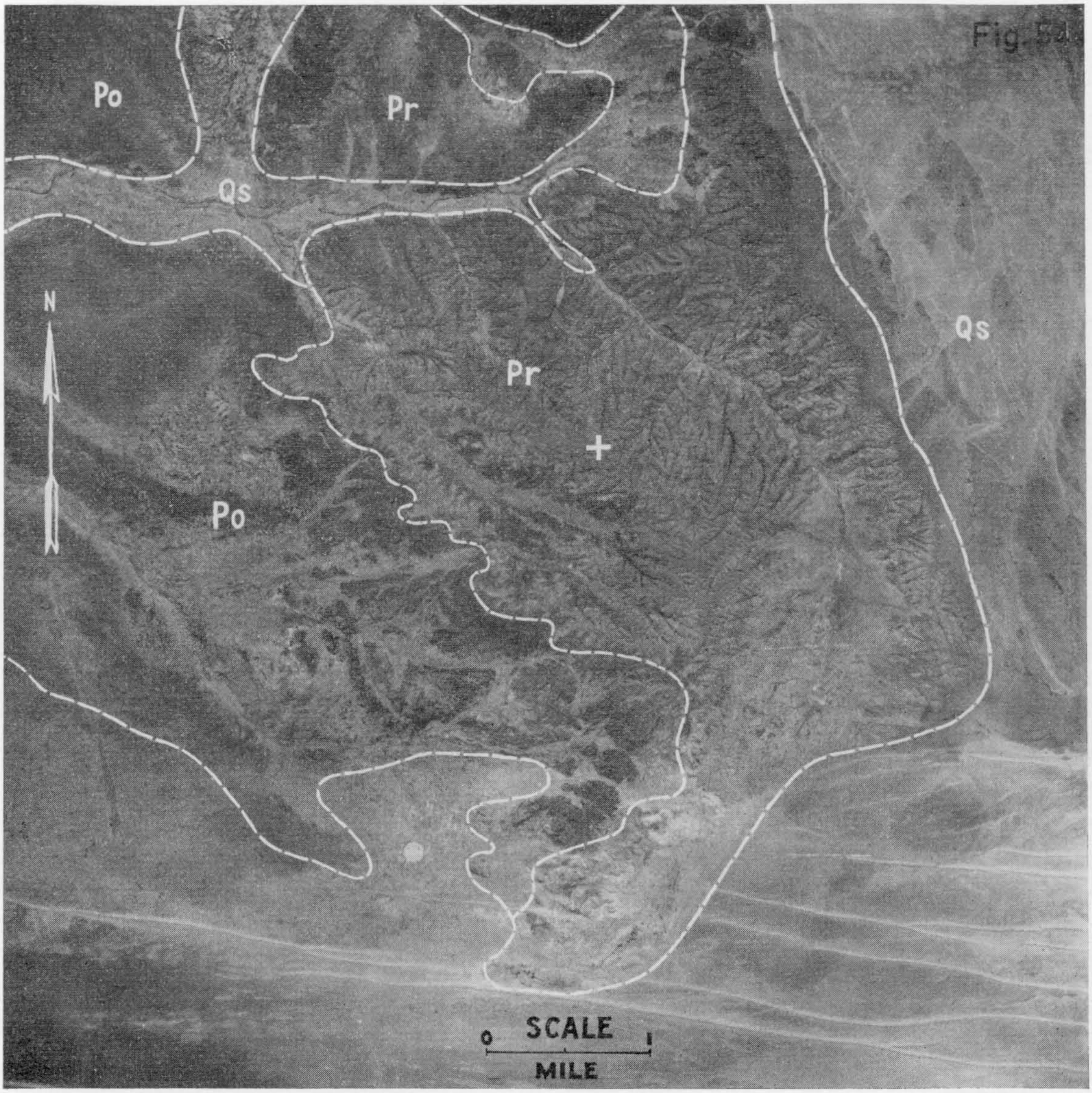


Fig. 54.—Area east of Waterlander Breakaway. Po—Balgo Member; Pr—Condren Member. Air photograph reproduced by permission of the RAAF.

was not seen. The top of the Hardman Member is eroded. Outcrops of the *Balgo Member* lie 50 miles south-east of the nearest outcropping Lightjack Member. The Balgo Member, which is correlated by fossils with the Lightjack Member, consists of fine to medium poorly bedded sandstone with some thin beds of coarse sandstone. Conical worm casts are common; some beds are micaceous and concretionary.

South-east of the Mount Bannerman Sheet area, in the Balgo Hills, the Noonkanbah Formation and the Balgo and Condren Members are readily identifiable. The Condren Member forms prominent buttes and breakaways, which are deeply etched by dendritic drainage. In the air photographs, the Condren Member is white or, at the top of breakaways, grey. The Balgo Member, which is almost black in the air photographs, crops out in low rounded hills or in low rises on a rubble-covered plain. The Noonkanbah Formation is exposed as rubble on silt and clay plains; bedding trends are indicated by broad dark bands. Six miles east of Waterlander Breakaway (Fig. 54), the horizontal Condren Member is distinguished from the Balgo Member by its lighter tone in the air photographs, and intricate drainage.

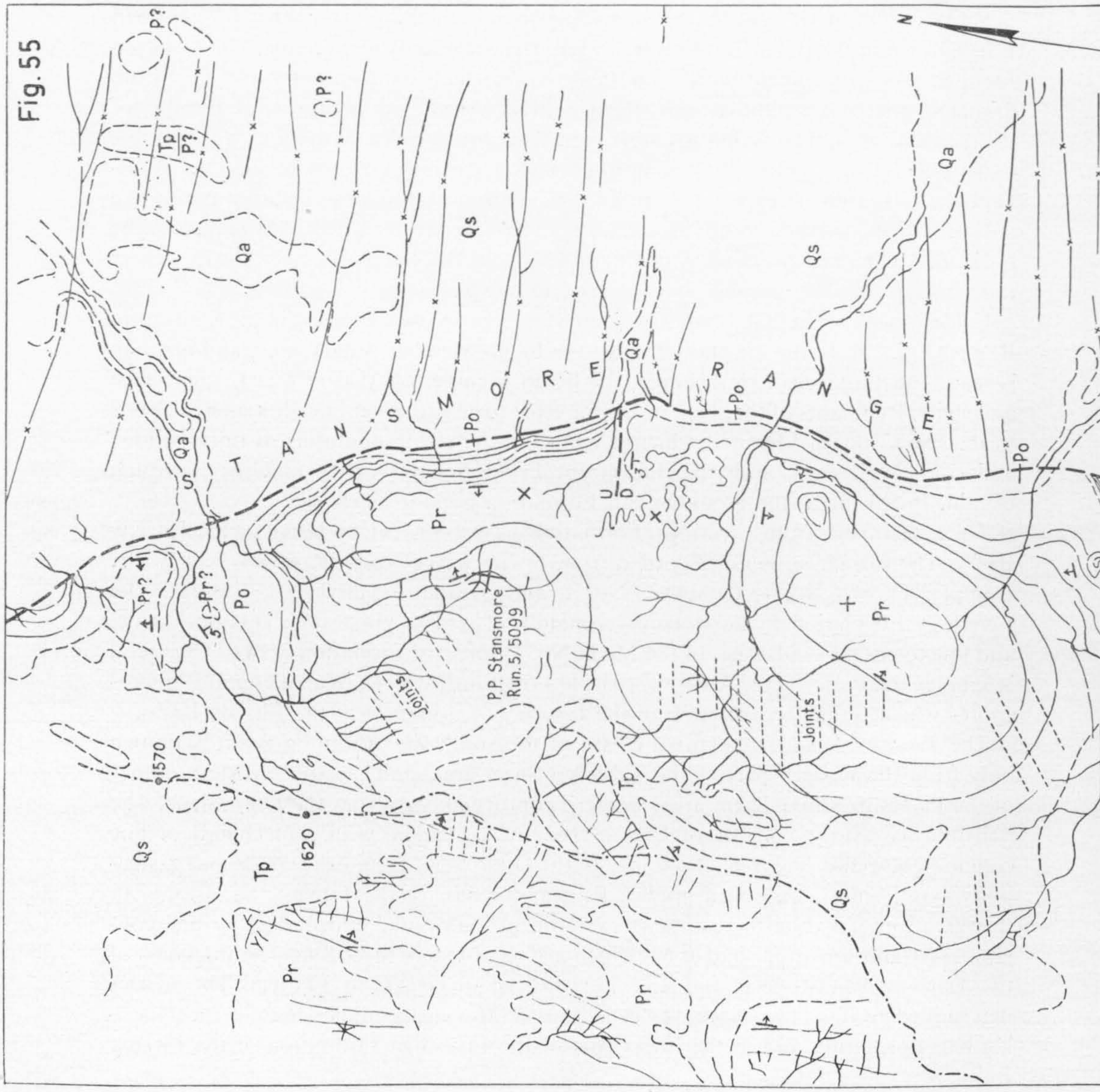
Folded rocks of the Balgo and Condren Members are well exposed in the Stansmore Range (Fig. 55). In the air photographs, the Balgo Member is dark grey, and bedding is readily distinguished. In this area, the Balgo Member consists of quartz greywacke and shale. Remnants of the thick ironstone crust form prominent heights such as Warri Peak. The Condren Member, which is lighter in the air photographs, is thick-bedded and coarsely jointed, and, like the Grant Formation elsewhere underlies a rough terrain. In this area, the Noonkanbah Formation is poorly exposed.

Thick sections of the Liveringa Formation have been cut by bores in the Fitzroy Basin. The formation is not recorded from Fraser River No. 1, Roebuck Bay No. 1, Dampier Downs No. 1, Goldwyer No. 1, and Samphire Marsh No. 1 Bores. The Liveringa Formation in bores consists mainly of quartz greywacke, siltstone, shale, and fine to coarse sandstone. In the Meda No. 1 Bore, the formation (714 to 1303 feet) is sandier than elsewhere. A core (2103-2113 feet) in BMR 4A Wallal contains microspores which Balme records also in the Liveringa Formation of the Fitzroy Basin.

The *Triwhite Sandstone* (Traves et al.) of the south-west Canning Basin is known only from the western part of the Tabletop Sheet area, and the south-eastern corner of the Paterson Range Sheet area, where it conformably overlies the Dora Shale. The Triwhite Sandstone consists of fine to medium sandstone with some bands of fine conglomerate and lenses of claystone. In the Dunn Soak area, pelecypods and gastropods were found in an oolitic greywacke near the base of the Triwhite Sandstone. In this area, the Triwhite Sandstone is overlain, probably unconformably, by fine conglomerate and unsorted sandstone, which are regarded as Mesozoic. The thickness of the Triwhite Sandstone in this area is estimated to be 200 to 300 feet. The species determined by Dickins (*in* Traves et al.) occur also in the upper part of the Noonkanbah Formation and in the lower part of the Liveringa Formation of the Fitzroy Basin.

Undifferentiated Permian rocks

The few outcrops that lie in the area between Wilson Cliffs and Joanna Spring in the central Canning Basin are mapped as undifferentiated Permian. This area, which was crossed by Talbot (1910), and surveyed by the helicopter-borne BMR Canning


STANSMORE RANGE
Qa
Qs
Po
Pr
Tp
P?
Tp
P?
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U
D
P.P. Stansmore
Run. 5/5099
Joints
1570
1620
N
Fig. 55

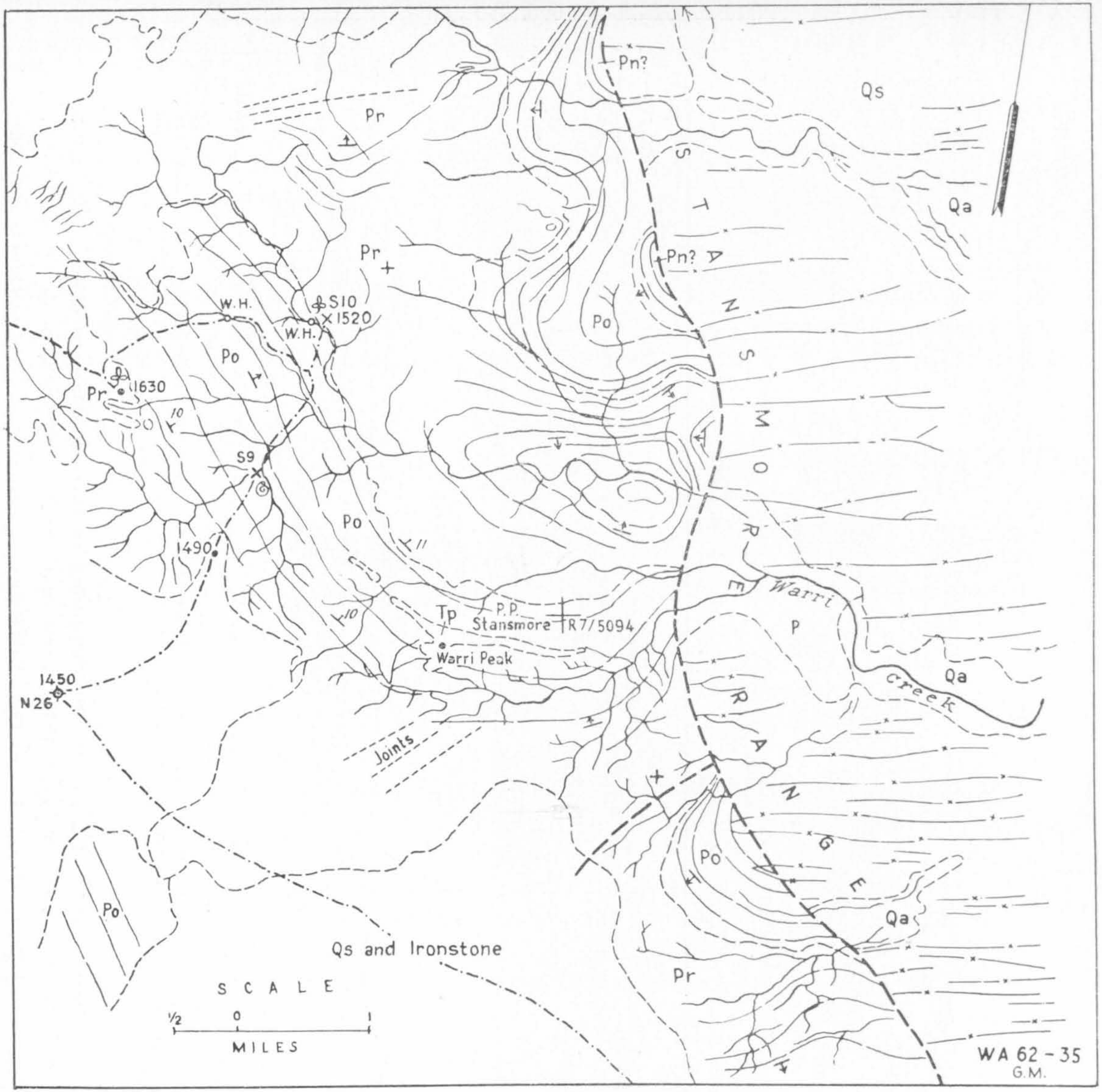


Fig. 55.—Stansmore Range. Pn—Noonkanbah Formation; Po—Balgo Member; Pr—Condren Member.

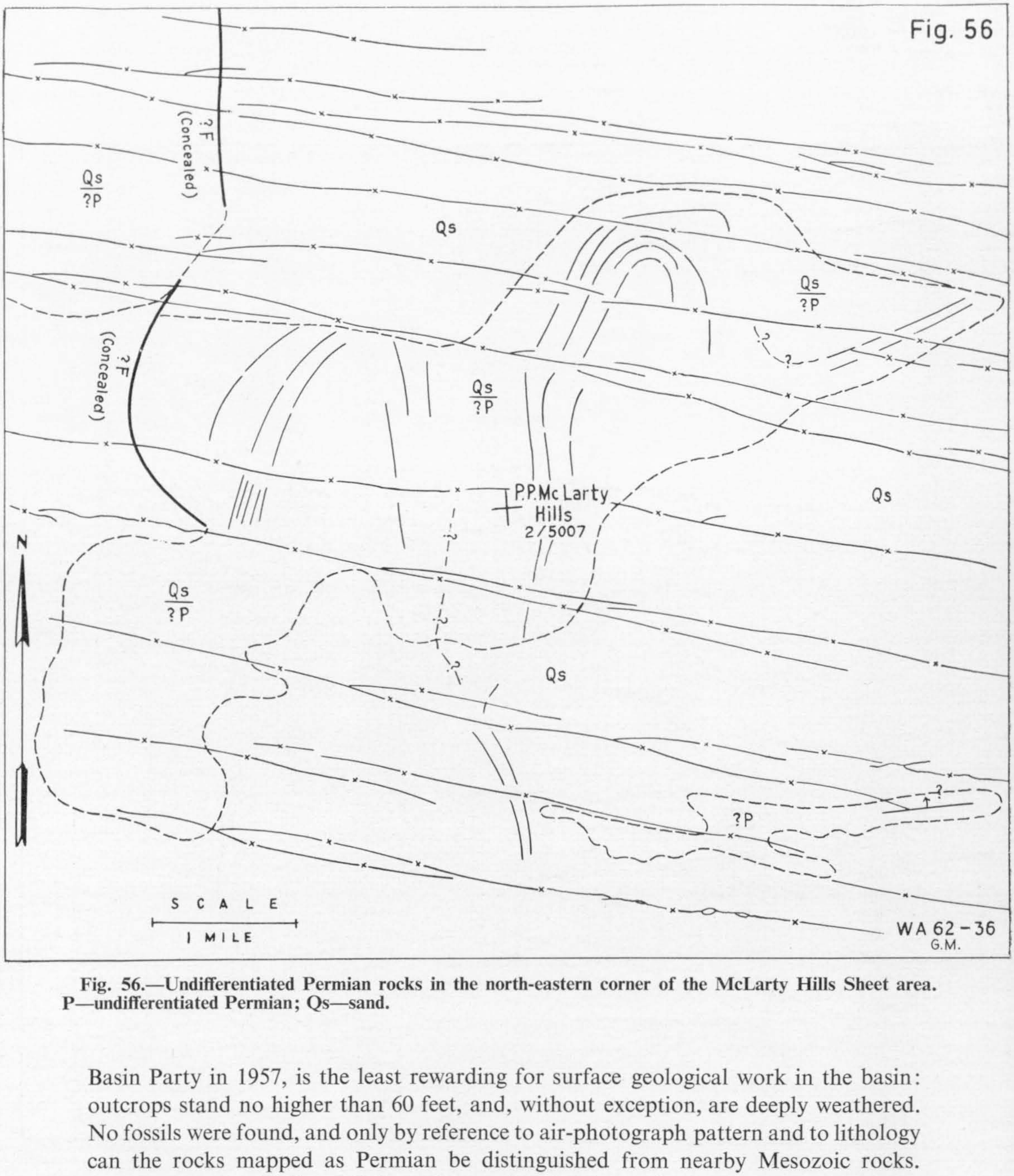
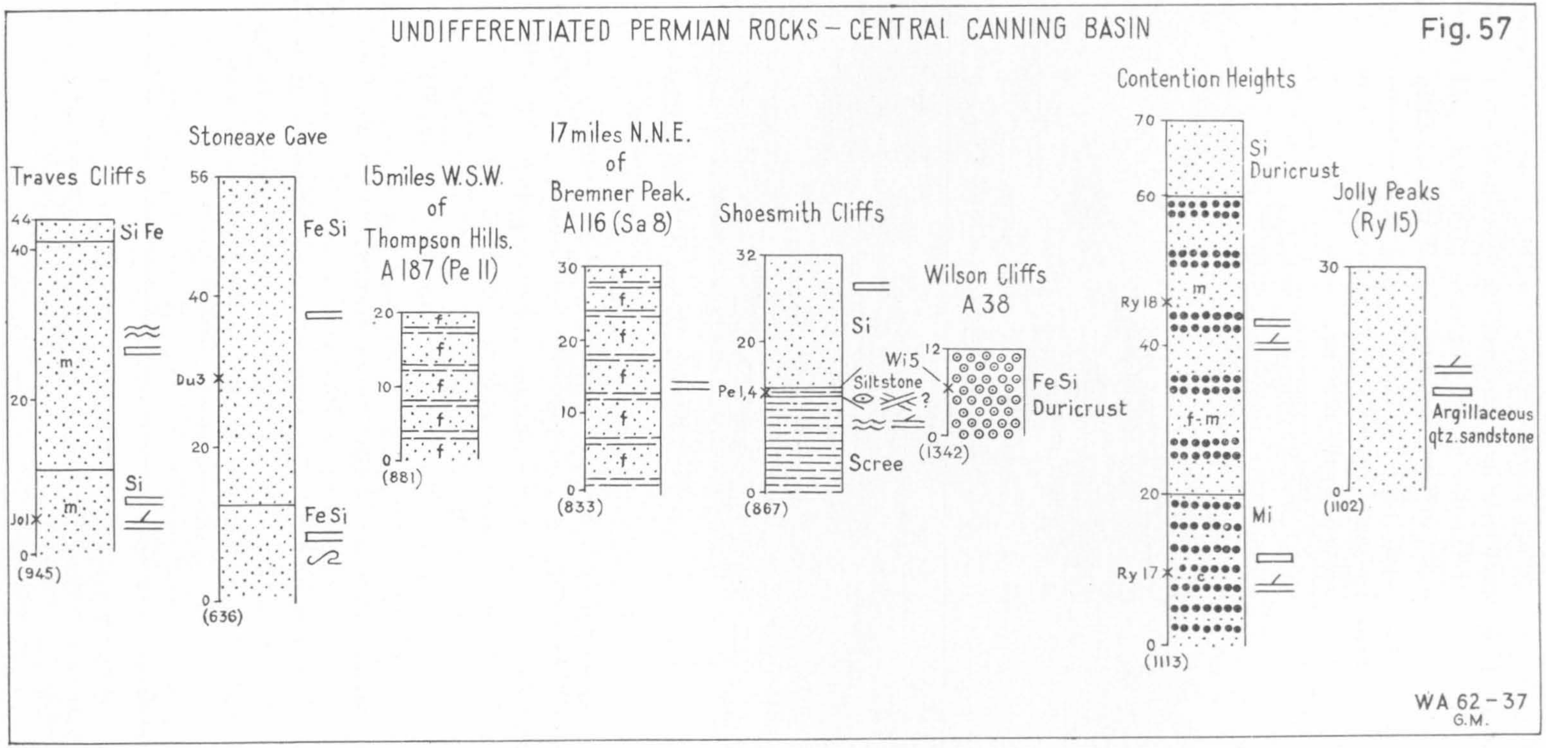


Fig. 56.—Undifferentiated Permian rocks in the north-eastern corner of the McLarty Hills Sheet area. P—undifferentiated Permian; Qs—sand.

Basin Party in 1957, is the least rewarding for surface geological work in the basin: outcrops stand no higher than 60 feet, and, without exception, are deeply weathered. No fossils were found, and only by reference to air-photograph pattern and to lithology can the rocks mapped as Permian be distinguished from nearby Mesozoic rocks. Outcrops south of Wilson Cliffs, at Contention Heights and at Jolly Peaks, cover large areas and warrant longer examination than could be given them in 1957. The outcrops of undifferentiated Permian rocks in the central Canning Basin will be dealt with in order from north-west to south-east.



UNDIFFERENTIATED PERMIAN ROCKS – CENTRAL CANNING BASIN
Fig. 57
Traves Cliffs
Si Fe
Si
Jo1
(945)
Stoneaxe Cave
Fe Si
Du3
Fe Si
(636)
15 miles W.S.W. of Thompson Hills. A 187 (Pe 11)
(881)
17 miles N.N.E. of Bremner Peak. A116 (Sa 8)
(833)
Shoesmith Cliffs
Si
Pe 1,4
Siltstone
Scree
(867)
Wilson Cliffs A 38
Wi 5
Fe Si Duricrust
(1342)
Contention Heights
Si Duricrust
Ry 18
Mi
Ry 17
(1113)
Jolly Peaks (Ry 15)
Argillaceous qtz. sandstone
(1102)
WA 62-37
G.M.

Fig. 57.

A low-dipping cuesta, 20 miles south of Craven Ord Hill in the north-eastern corner of the McLarty Hills Sheet area, has been tentatively identified from the air photographs (Fig. 56) as Liveringa Formation. The sand plain north and north-west of this outcrop is covered by straight or gently curved parallel lines of vegetation interpreted as bedding trends; the prominent line along the western side of this area is interpreted as a concealed fault. The pattern of these trends is like that of the outcropping Liveringa Formation on the northern side of the Fenton Fault, 25 miles away.

Fig. 58.—Shoesmith Cliffs on the Percival Lakes. Siltstone overlain by siliceous duricrust.

Traves Cliffs (Fig. 57), a line of 50-foot-high breakaways situated in the eastern part of the Joanna Spring Sheet area, consist of medium-grained quartz sandstone (*see* Appendix 2, Jo1) with a thin duricrust. On the air photographs, the breakaway scarps, in which almost fresh rock is exposed, are readily distinguishable from the dark duricrust and the dark iron-stained gravel on the pediment. The undulate bedding of the upper part of the section dips 3° south-westward. More extensive outcrops west of Traves Cliffs have the same air-photograph pattern, which is readily distinguished from that of the nearby Mesozoic rocks.

The rocks exposed at Stoneaxe Cave, in the northern part of the Dummer Sheet area, are deeply weathered, and few original minerals and structures are preserved. From their air-photograph pattern, the rocks on the northern edge of the Dummer Sheet area, 10 miles north-west of Stoneaxe Cave, are interpreted as Noonkanbah Formation overlain by the Lightjack Member of the Liveringa Formation.

Sections of horizontal leached interbedded fine friable quartz sandstone and siltstone are exposed in the Percival Sheet area at A187, 15 miles west-south-west of Thompson Hills, and at A116, 17 miles north-north-east of Bremner Peak.

The only original rock preserved in a 32-foot section exposed at Shoesmith Cliffs (Fig. 58), on the eastern edge of Percival Lakes, is a cross-bedded quartz siltstone with

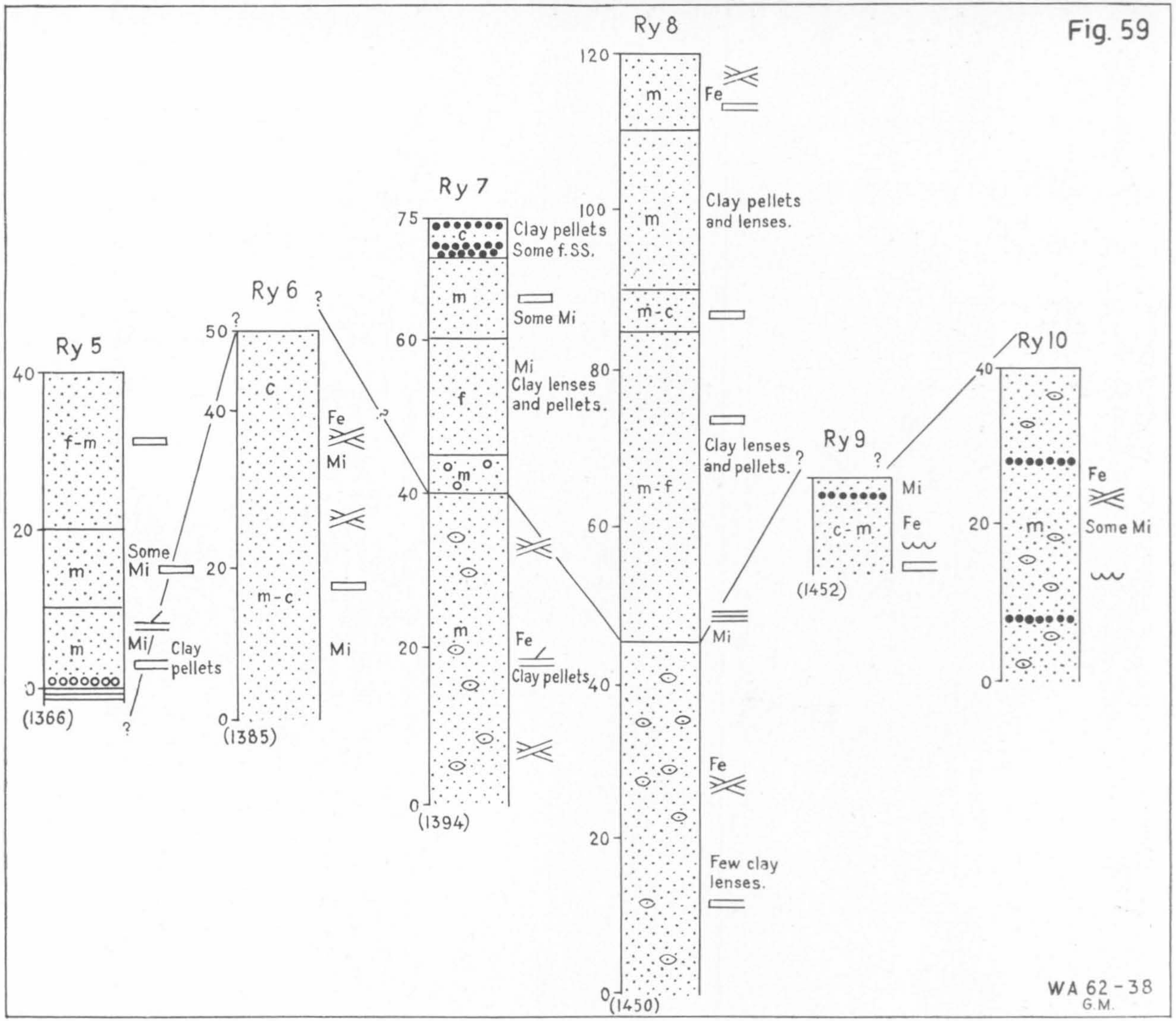


Fig. 59.—Sections of undifferentiated Permian rocks, Ryan Buttes.

Fig. 60.—Ryan Buttes. Air photograph reproduced by permission of the RAAF.

indeterminate worm tracks. The upper half of this section is a siliceous duricrust. At Thompson Hills, 25 miles west-north-west of Shoesmith Cliffs, a 20-foot-thick duricrust is exposed (*see* Appendix 2, Pe2). The Wilson Cliffs are also a duricrust, 12 feet high.

At Sufficiency Knob, on the eastern edge of the Wilson Sheet area, 20 feet of cross-bedded gritty quartz sandstone with clay pellets is identified with nearby outcrops of the Balgo Member farther north and in Waterlander Breakaway.

60 feet of interbedded cross-bedded quartz-mica grit and sandstone (*see* Appendix 2, Ry17) with 10 feet of duricrust are exposed at Contention Heights, in the southern part of the Wilson Sheet area. 30 miles south-eastward, at Jolly Peaks, 30 feet of cross-bedded argillaceous quartz sandstone is exposed.

Ryan Buttes is a range of buttes, mesas, and west-facing breakaways, in which 120 feet of horizontal rock is exposed (Figs. 59, 60). These rocks are ferruginized, and are almost black in the air photographs. The rocks at localities Ry5 to Ry10 are medium and coarse sandstone with concretions and worm trails, and fine to medium sandstone with clay lenses and pellets. Bedding is thick except in rare laminated sandstone; cross-bedding and ripple marks are common. These rocks are lithologically like the Lightjack and Balgo Members of the Liveringa Formation, and are so tentatively identified.

At Yam Hill (Fig. 63), 30 feet of massive, medium to fine sandstone with thin beds of ripple-marked siltstone are tentatively identified as Permian by comparison with Permian rocks elsewhere in the basin.

Geological History

For several reasons, few details of the Permian history of the Canning Basin can be told. First, about half the area of Permian rocks is presumably obscured by younger rocks, and within the obscured area, only along the coast and in the Edgar Range area have bores revealed the underlying Permian rocks. Secondly the lower half of the succession, which includes most of the Grant Formation, is not seen at the surface, and only two bores, Grant Range No. 1 and Fraser River No. 1, and possibly a third, AFO Nerrima No. 1, have passed through the lower part of the Grant Formation into the underlying Upper Carboniferous rocks (the Anderson Formation), which likewise do not crop out. Thirdly, whereas macrofossils occur abundantly in many outcropping rocks and have been intensively studied, few are known from bore sections. Furthermore, the Grant Formation, which makes up the bulk of the succession, is barren both in outcrop and in bores, except for microspores, rare plants, and rare foraminifera. Correlation between outcrops and bores is therefore tentative. Fourthly, microspores are sufficiently abundant in bore sections to attempt correlation between bores, but few results in this field have been published. Finally, little work on the petrology of the Permian rocks has been done. The prerequisite of a sound geological history, the precise dating of the rocks, still remains to be done. The geological history presented below is therefore necessarily tentative.

The palaeogeography of the Canning Basin during the Westphalian and early Stephanian (Upper Carboniferous) is shown in Figure 61A. The only parts of the mainland known to have been covered by water during this period are the Fraser River No. 1 Bore area, the Grant Range No. 1 Bore area, and possibly the AFO

Nerrima No. 1 Bore area. Water possibly extended over the area which now contains 15,000 feet or more of Phanerozoic sediments (Pl. 2). More than 5000 feet of sediments (the Anderson Formation) accumulated in this area, which, as the fauna of conchostracans, pelecypods, and *Lingula* indicates, was a shallow bay with restricted marine circulation. Devonian and Lower Carboniferous rocks, including carbonates, and Precambrian rocks were exposed north and east of the bay, and Ordovician and Devonian rocks on its southern shore. Most of the sandstone, siltstone, and shale of the Anderson Formation was probably derived from the Lower Carboniferous sandstone and siltstone in the Sisters No. 1 Bore area, and from Upper Devonian sandstone and siltstone and possibly also from Lower Carboniferous rocks in the Frome Rocks No. 2 area, which were stripped off before the Sakmarian. Coarser-grained rock, mainly sandstone, in the Fraser River No. 1 Bore was probably derived from outcropping Precambrian rock in the Sunday Island area. Probably in the late Upper Carboniferous (Fig. 61B), the conchostracans, brachiopods, and pelecypods

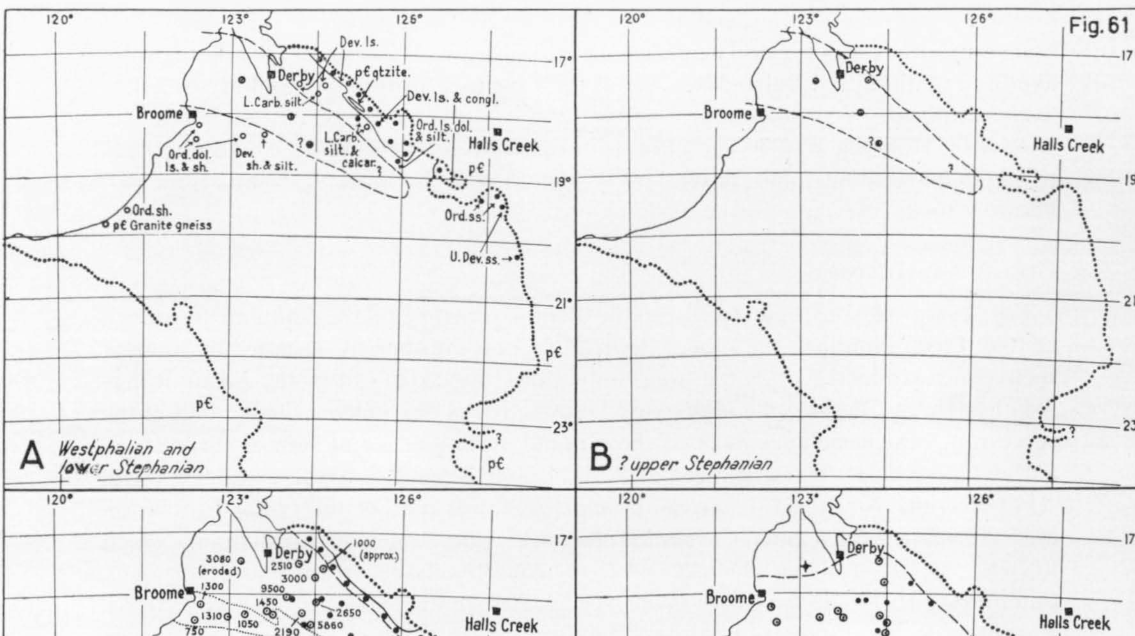
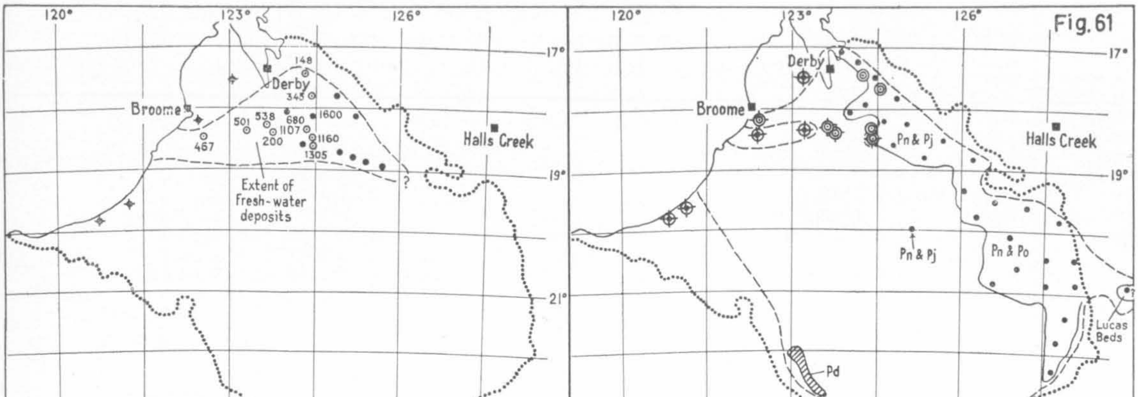


Fig. 61.—Palaeogeographic maps Westphalian (Upper Carboniferous) to

were driven from the area, the water advanced a short distance northward into the Meda No. 1 Bore area, and the basal part of the Grant Formation was deposited. Erratics 200 feet above the base of the Grant Formation in the Grant Range No. 1 Bore, at a depth of 7719 feet, probably indicate that the change was caused by the onset of glaciation. The late Upper Carboniferous rocks of the Grant Formation are similar to the younger, Sakmarian part of the formation, but have a calcareous cement and contain thin beds of sandy limestone. The lower part of the Grant Formation was probably derived from the sandstone of the Precambrian King Leopold Beds, and calcareous cement from the surrounding area of carbonate rocks. Carbonate cement is probably characteristic of marine glacial sediments.

In the Sakmarian (Fig. 61C), the sea advanced over most of the basin. The floor of the former Upper Carboniferous bay continued to subside rapidly, and about 7000 feet of Grant Formation were deposited in it. Elsewhere, 1700 feet or less of Grant Formation were deposited. The possible existence of a long broad swell or



Tartarian (Upper Permian). Figures in C indicate thickness of Grant Formation.

submarine ridge along the southern margin of the Fitzroy Basin is indicated by the thin Grant Formation (1300 feet or less). The extension of the swell south-east of the bores is indicated by the thin sedimentary cover (less than 5000 feet; *see* Pl. 2, and p. 217 for discussion). The thin Grant Formation in BMR 4A Wallal (110 feet) probably indicates that the shore was close by. The depth of water in which the Grant Formation was deposited can be estimated only within wide limits. If the foraminifera recorded by Crespin (1958) in Roebuck Bay No. 1 Bore actually came from the Grant Formation, this is direct evidence that at least this part of the formation is marine. Indirect evidence is provided by a comparison of the Grant Formation and present-day sediments around polar regions. Stetson & Upson (1937) describe the marine till which mantles the continental shelf and slope in the Ross Sea area of Antarctica up to 500 miles from the coast and down to a depth of 2000 fathoms. The core samples studied by Stetson & Upson contained many rock fragments, only one of which was striated. According to these authors (pp. 63-64):

> 'The continental ice sheet is responsible for this deposit, which has all the characteristics of a till laid down on land. The remarkable fact is how little influence the sea appears to have had upon it. Such a complete lack of sorting is unusual for marine deposits. Futhermore, the material deposited directly in front of the ice barrier is the same as that laid down 300 miles seaward. The uniform distribution is apparently characteristic of the whole width of this belt of sediment which surrounds the continent. . . . The heterogeneous mixture of coarse and fine particles would indicate that deposition is constantly taking place throughout the whole region. Marine currents have had little or no sorting effect upon the sediment, either while it was settling out or after its deposition.'

Stetson & Upson (1937) also touch on sediments collected in the Davis Strait region of the Arctic. In this area, sandier, better-sorted sediments than those from the Ross Sea indicate the action of marine currents on the originally heterogeneous material dropped from icebergs. Hough (1950) describes core samples collected within the area of pack ice of the Ross Sea from depths of about 10,000 feet or more, and 225 miles or more distant from land. The cores consist of alternating coarse glacial sediment with pebbles and non-glacial fine-grained laminated sediment.

The Braeside Tillite was probably deposited in the valleys of glaciers. These glaciers did not reach the sea, which lay north of the present outcrops of the Braeside Tillite. The outcropping Paterson Formation is probably also a terrestrial deposit. We interpret the Paterson Formation as a fluvioglacial formation deposited in front of retreating glaciers. This interpretation explains the 'transgression' of the Paterson Formation over the Precambrian rocks of the basin margin.

The Grant Formation exposed along the northern margin of the Fitzroy Basin and along the north-eastern margin of the north-east Canning Basin is also interpreted as a fluvioglacial deposit. Like the Paterson Formation, the fluvioglacial fringe of the Grant Formation is 'transgressive'; in the Oscar Range (*see* Lennard River Geological Sheet), residuals of Grant Formation step across Devonian rocks to rest direct on Precambrian rocks. The shore-line of the Sakmarian sea lay on the basin side of these terrestrial deposits, but its precise position is not known.

Doubtful occurrences of other glacial rocks are the rocks exposed in the core of the dome at Woolnough Hills, and the outcrop in the south-eastern corner of the Ryan Sheet area, which has the same air-photograph pattern as the Grant Formation.

Glaciation finished at the end of the Sakmarian. In the basal Artinskian (Fig. 61D), a shallow sea remained in at least part of the Canning Basin. Marine deposits of this age are known in the Fitzroy Basin (Nura Nura Member of the Poole Sandstone), and in the south-west Canning Basin (Cuncudgerie Sandstone). During this period the shore-line lay north of the Wallal/Samphire Marsh area, and south of the Fraser River area. After the basal Artinskian, the shallow sea retreated from the Canning Basin, and the rest of the Poole Sandstone was deposited. Cross-bedding, abundant plants, and thin coal seams indicate that this is a shallow freshwater deposit. The known distribution of the freshwater part of the Poole Sandstone is shown in Figure 61E. The southerly extent of deposition is not known: in the south-west Canning Basin, the section between the eroded top of the Cuncudgerie Sandstone and the exposed base of the Dora Shale is not exposed.

In the upper part of the Artinskian (Fig. 61F), a shallow sea covered almost the entire basin as it had done in the Sakmarian, except the Lake Lucas area, where the sea possibly extended 60 miles farther eastward than the Sakmarian sea, and in the Wallal, Samphire Marsh, and Goldwyer Bore and Fraser River areas, which were dry land. The Roebuck Bay Bore area was a small embayment. The Noonkanbah Formation was deposited in the Fitzroy Basin and north-east Canning Basin, and the Dora Shale and possibly part of the Triwhite Sandstone in the south-west Canning Basin. The Lucas Beds were possibly deposited at the same time. At least in the marginal part of the north-east Canning Basin, the Noonkanbah Formation overlapped the Poole Sandstone to rest directly on the Grant Formation.

The Kungurian sea remained in roughly the same area, except perhaps for the Lake Lucas area, and is represented by the Lightjack Member of the Liveringa Formation and possibly by the Triwhite Sandstone.

The sea retreated during the Kazanian. The Condren Member of the Liveringa Formation and the unnamed plant-bearing part of the Liveringa Formation in the Fitzroy Basin are the only known deposits of this age. The original area of deposition has probably been reduced by erosion to the present area of outcrop, which corresponds roughly with that of the Noonkanbah Formation and Lightjack Member, except that Kazanian rocks are not known south of the Fenton Fault. Coal seams in the Kazanian rocks of the Fitzroy Basin indicate deposition in fresh water.

The Hardman Member of the Liveringa Formation is the only known upper Kazanian or Tartarian deposit in the basin (Fig. 61F). It occurs only in synclinal areas, and its original distribution was probably much wider than that of today. The Hardman Member indicates the return of a shallow sea at least to the Fitzroy Basin.

The Blina Shale and Erskine Sandstone are the final products of the phase of deposition that started in the Upper Carboniferous and continued, presumably without a break, to the Lower Triassic. The Blina Shale is probably Lower Triassic, and was deposited in an estuary. The Erskine Sandstone succeeds the Blina Shale, and was probably deposited in fresh water. These Triassic formations are described in a following chapter.

As shown in Table 7, three and a half rhythmic alternations of shallow marine and shallow freshwater or estuarine deposition took place in the Canning Basin in the interval Upper Carboniferous to Lower Triassic. During this interval rocks at least 20,000 feet thick were deposited. Several authors have already pointed out the comparable deposition during the Permian in eastern and western Australia, but hitherto precise correlation between the areas has not been established. Dickins & Thomas (1960) date the 'Lower Marine Series' as Sakmarian to basal Artinskian, the 'Lower Coal Measures' as lower Artinskian, and the 'Upper Marine Series' as upper Artinskian to Kungurian. Balme (pers. comm.) finds similar microspore assemblages in the 'Upper Coal Measures' and the plant-bearing sandstone of the Liveringa Formation. We are not qualified to go into the question of whether or not eustatic change in sea level during the Upper Carboniferous and Permian was the chief reason for rhythmic deposition. The growing volume of information on the Permian rocks of Australia, however, will soon warrant a detailed enquiry into this problem.

TABLE 7

CORRELATION OF PERMIAN ROCKS OF CANNING BASIN AND NEW SOUTH WALES

AGE	FORMATION		ENVIRONMENT OF DEPOSITION	RHYTHMIC ALTERNATION
	Canning Basin	New South Wales		
Lower Triassic	Erskine sandstone* and Blina Shale*	Narrabeen Gp., Hawkesbury Sandstone, Wianamatta Gp.	Estuarine, freshwater	3½
Tartarian	Hardman Member		Shallow marine	3
Kazanian	Condren Member, plant beds in Liveringa Formation	Newcastle and Tomago Coal Measures ('Upper Coal Measures')	Freshwater	
Kungurian-upper Artinskian	Lightjack Member Triwhite Sandstone Dora Shale Noonkanbah Formation	Maitland Group ('Upper Marine Series')	Shallow marine	2
lower Artinskian	Rest of Poole Sandstone	Greta Coal Measures ('Lower Coal Measures')	Freshwater	
basal Artinskian	Nura Nura Member Cuncudgerie Sandstone	Dalwood Group ('Lower Marine Series')	Shallow marine	1
Sakmarian-upper Stephanian	Grant Formation Paterson Formation† Braeside Tillite†		Marine glacial, youngest part freshwater at margin of deposition	
upper Stephanian-Westphalian	Anderson Formation		Estuarine	

* Correlation doubtful. † Probably freshwater and terrestrial.

Eustatic change of sea level in the Canning Basin is probably connected with glaciation, as McWhae et al. (p. 139) suggest. During the Sakmarian glaciation, the sea covered most of the Canning Basin; at the end of this glaciation, the sea probably retreated, owing to isostatic uplift of the land. In the interval lower Artinskian to Tartarian, eustasy explains, but not uniquely, the alternation of coarse-grained freshwater rocks (lower sea level, greater marginal run-off) and finer-grained marine rocks (higher sea level, less run-off). Whether this rhythmic deposition was caused by regularly repeated checks in the rate of subsidence of the basin, or by repeated eustatic changes in sea level remains a key problem in Western Australian, and, indeed, in Australian geology.

(?) PERMIAN

Lucas Beds

The Lucas Beds (Casey & Wells) consist of friable, dull purple, well-sorted, medium fontainebleau sandstone, with clay pellets and interbedded thin-bedded claystone. Outcrops are poor, but regional mapping indicates that the Lucas Beds underlie an area of about 400 square miles. The best exposures are in very low scarps on the eastern margin of the large salt lake 5 miles east of Lake Lucas; no exposures were seen on the bed of the lake, but the striking air-photograph pattern (Fig. 62) indicates that the Beds form the impermeable floor of the salt lake. The rhythmic alternation of dark sandstone and lighter claystone is responsible for the well-defined bedding trends and distinct pattern on the lake floor. Most lineaments on the lake bed are joints, but in some places small displacements indicate minor dip faults. The curved bedding planes near joints are caused by meteoric water excavating shallow depressions along the joints. The beds dip 2° eastward.

Areas outside Lake Lucas believed to be underlain by the Lucas Beds have a mantle of clay, alluvium, rubble, isolated boulders, or a thicker cover of travertine. One exception is Yam Hill (Fig. 63), where about 10 feet of medium calcareous sandstone of the Lucas Beds are exposed. They are conformably overlain by probable Permian rocks (*see* p. 99). Outcrops around Yam Hill are poor, and most are almost obscured by travertine, alluvium, claypans, and mulga scrub. Strikes trend north-easterly, and the beds possibly dip at a low angle to the south-east. Most of the distinct lineaments trend at right angles to the strike; they are either joints or faults which have been subsequently filled with limestone and chalcedony but are still visible through the travertine. The low rounded hills of travertine near Yam Hill (Fig. 63) have a lightly impressed radial drainage.

The areas in which clay flats and mulga scrub are underlain by the Lucas Beds have a marked dark and light wavy photo pattern, and the scrub follows arcuate lines. Numerous small clay flats between the lines of scrub are almost bare.

The very low breakaway north-east of Yam Hill has a smooth dark upper surface and a lighter-coloured scarp, and consists of medium sandstone with a cap of pisolitic ironstone. This sandstone is either a remnant of probable Permian rocks, formerly continuous with those at Yam Hill, or is part of the Lucas Beds.

No direct contacts with older rocks were seen, but as the basin in which the sediments are found is rimmed by Precambrian sedimentary rocks, it is presumably floored by them also. North of Lake Lucas, outcrops photo-interpreted as Precambrian sedimentary rocks are surrounded by sediments of the Lucas Beds.

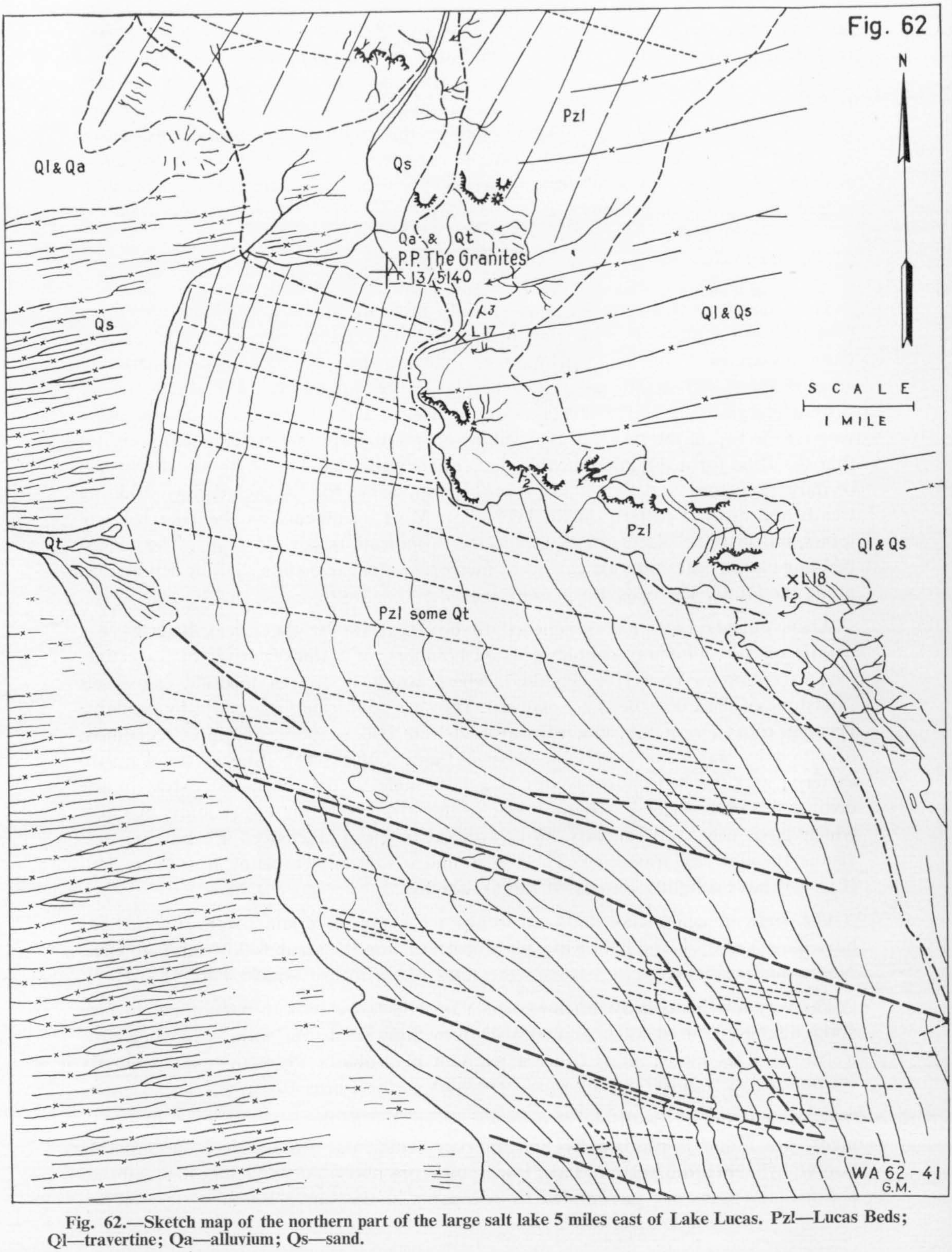


Fig. 62.—Sketch map of the northern part of the large salt lake 5 miles east of Lake Lucas. Pzl—Lucas Beds; Ql—travertine; Qa—alluvium; Qs—sand.

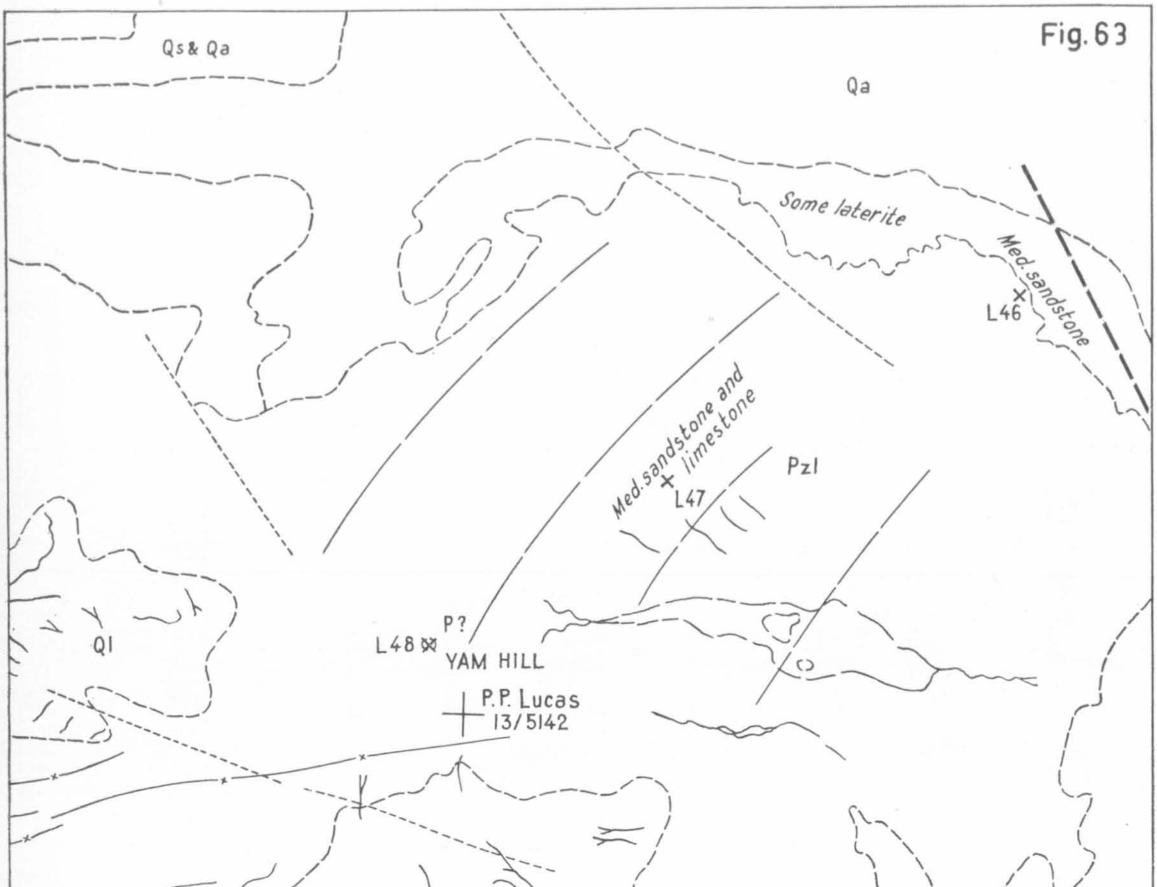


Fig. 63.—Yam Hill area, 10 miles north-west of Lake Lucas. Pzl—Lucas Beds; P—undifferentiated Permian rocks; Qa—alluvium; Qs—sand.

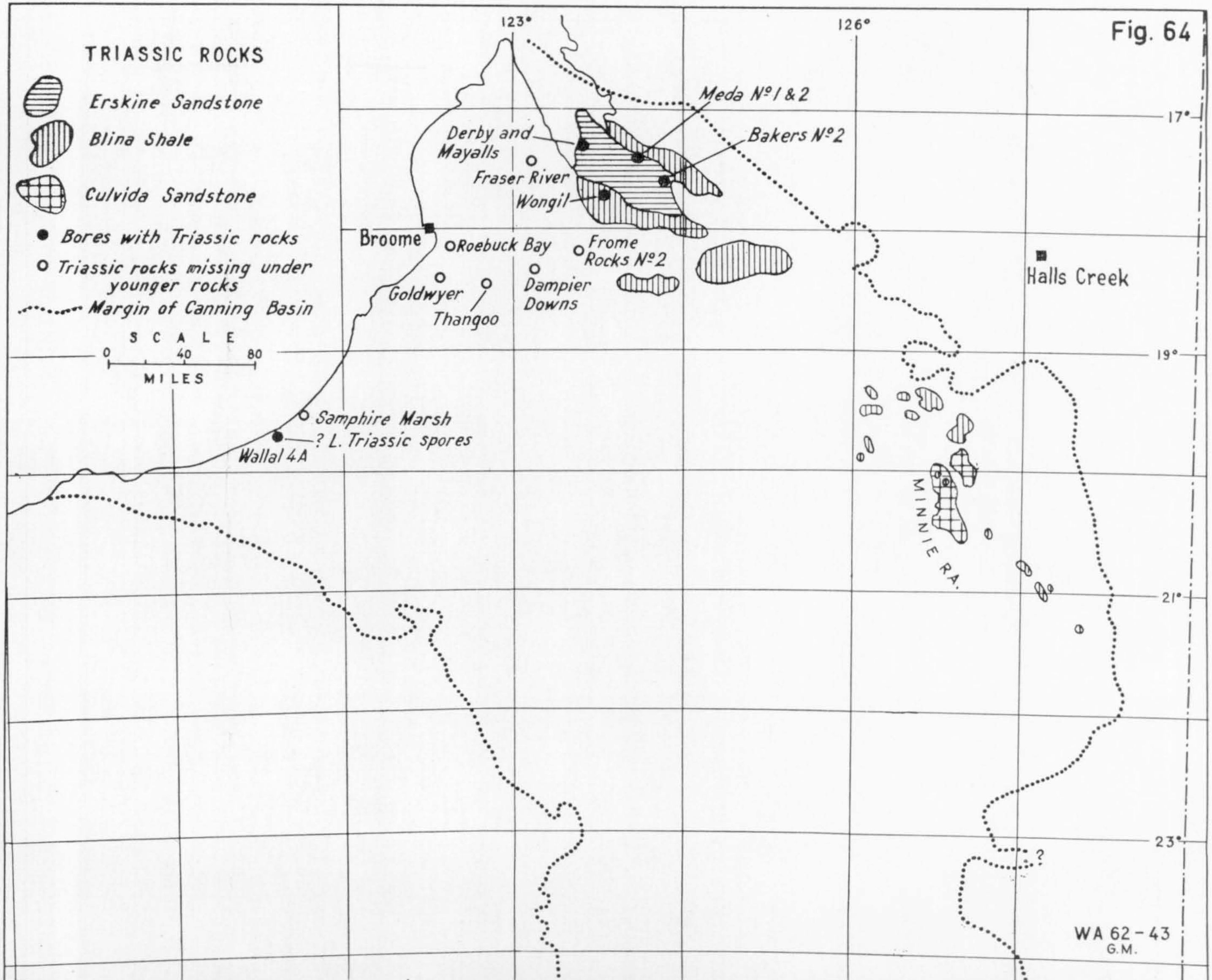


Fig. 64
TRIASSIC ROCKS
Erskine Sandstone
Blina Shale
Culvida Sandstone
Bores with Triassic rocks
Triassic rocks missing under younger rocks
Margin of Canning Basin
SCALE
0
40
80
MILES
123°
126°
17°
19°
21°
23°
Meda Nº1 & 2
Bakers Nº2
Derby and Mayalls
Fraser River
Wongil
Broome
Roebuck Bay
Frome Rocks Nº2
Halls Creek
Goldwyer
Thangoo
Dampier Downs
Samphire Marsh
? L. Triassic spores
Wallal 4A
MINNIE RA.
?
WA 62-43
G.M.

Fig. 64

On the eastern margin of the lake east of Lake Lucas, the Lucas Beds are overlain by a hard vuggy sandy caliche. This caliche is, on the average, 10 feet thick, horizontal, and therefore was possibly formed after the Lucas Beds were tilted and eroded.

The Lucas Beds may have been deposited during an extensive marine transgression in the Permian. Their lithology is closest to that of the Noonkanbah Formation.

TRIASSIC

Triassic rocks (Fig. 64) are known from the Fitzroy Basin, the north-east Canning Basin, and the Wallal area in the south-west Canning Basin. These rocks are roughly 1800 feet thick in the Derby area of the Fitzroy Basin, and much thinner elsewhere. In the Fitzroy Basin, a conchostracan-bearing shale, the Blina Shale, was deposited in a bay, and succeeded by a plant-bearing, probably continental sandstone, the Erskine Sandstone. In the north-east Canning Basin, the Blina Shale is underlain by a plant-bearing, probably continental sandstone, the Culvida Sandstone. The probable Triassic rocks at Wallal include siltstone and shale.

No descriptions of the Triassic fossils from the Canning Basin have been published. The Blina Shale contains the conchostracan *Isaura*, the pelecypod *Pseudomonotis*, the worm burrow *Diplocraterion*, the brachiopod *Lingula*, fish teeth, reptiles, microspores, and microplankton. The Erskine Sandstone and the Culvida Sandstone contain plants only. Because none of these fossils is suitable for precise correlation with rocks in other basins, estimates of the precise age of the Triassic rocks vary.

We refer to the time-scale in which the Triassic is subdivided into three parts, the Lower (Scythian), Middle (Anesian and Ladinian), and Upper (Carnian and Norian) Triassic.

Blina Shale (Reeves, 1951; Brunnschweiler, 1954; Guppy et al.; McWhae et al.)

In the Fitzroy Basin, the Blina Shale is found in low-lying synclinal areas; outcrops are poor, and in most places consist of debris on black-soil plains. The uppermost 95 feet of the Blina Shale are exposed at the base of Erskine Hill, and this is the thickest recorded exposure. The 8-mile solid geology map of the Fitzroy Basin (Guppy et al.) shows four areas of outcrop: between Langey Crossing and Erskine Hill, between Yarrada Hill and the Sisters Plateau, the Dry Corner Syncline, and east of Mount Hardman. Several shallow bores in the Noonkanbah and Derby Sheet areas and six deep bores in the Derby Sheet area have cut the Blina Shale.

The Blina Shale consists of light blue-grey to yellow shale and claystone, with minor sandy shale, and coquinas of *Isaura*, and, near the base, a 10-foot bone bed. In the Meda No. 1 Bore, the Shale consists of interbedded shale and siltstone, with lenses of fine sandstone. In the interval 280 feet to 450 feet, the fine sandstone contains silicified bone fragments, fish teeth, and *Isaura*, and fine grains of glauconite. The basal section, from 450 feet to 714 feet, also contains fine glauconite. The thickest section of the Blina Shale is roughly 1000 feet in the Derby Town Bore.

The Blina Shale rests on the Liveringa Formation, and in places is conformably overlain by the Erskine Sandstone; elsewhere its top is eroded. Poor outcrops have led to conjecture on the relation of the Blina Shale to the underlying Liveringa Formation. On the one hand, Brunnschweiler (1954, pp. 43-44) argues that

'The folding in the Fitzroy Basin . . . took place towards the end of the Permian and during early Triassic time. The angular unconformity between the Liveringa Group (folded) and the Blina Shale (unfolded), and especially the bone bed near the base of the latter, proves that the surface of the Fitzroy Basin had emerged from the sea during the tectonic activity. Lower Triassic marine sediments are therefore not likely to be found in this area, and the Blina Shale must indeed be of Upper Triassic age as indicated by the abundance of *Isaura.*'

On the other hand, Lindner (*in* McWhae et al., p. 83)

'believes that, as no certain unconformable relationship with the Upper Permian Liveringa Formation has yet been established, the Blina Shale might be early Triassic in age. Recent work by Balme on samples from the Derby Town Bore supports this concept, as he found no considerable break in the microplankton suites in passing from the Blina Shale to the Permian Liveringa Formation in the bore. Balme finds that the microflora and microplankton of the Blina Shale closely resemble those from the Kockatea Shale of the Perth Basin.'

New evidence from the BMR Beagle Ridge Bore (McTavish, 1960, MS.) indicates that the Kockatea Shale is Lower Triassic. Balme's work on spores (*in* McWhae et al.) indicates that the overlying Erskine Sandstone is a little younger than the Blina Shale, and is also Lower Triassic.

In our view, these conflicting opinions cannot be resolved until the following questions are answered: (a) Are the Blina Shale and Erskine Sandstone folded with the underlying Permian rocks, or are they horizontal?

(b) Does the Erskine Sandstone overlap the Blina Shale to rest direct on the Liveringa Formation, as Brunnschweiler suggests?

(c) Does the 10-foot bone bed near the base of the Blina Shale indicate the sudden death of a fauna, caused by changed conditions, or does it merely indicate slow deposition?

We incline to the view that in the Fitzroy Basin the Blina Shale succeeds the Liveringa Formation without hiatus, and that the Permian and Triassic rocks of the Fitzroy Basin were folded together during the interval Middle Triassic to Lower Jurassic.

In the north-east Canning Basin, the Blina Shale is mapped in the Stansmore and Bishop Ranges, at Bababuru Rock-Hole (Fig. 65), at Chilpada Chara (Fig. 66), and in the central part of the Mount Bannerman Sheet area. In these areas, the Blina Shale is at least 150 feet thick, and consists of pale brown to white shale, locally micaceous, and sandstone locally interbedded with shale. Fossils include *Isaura*, *Lingula*, and cf. *Pseudomonotis* (all determined by R. O. Brunnschweiler, pers. comm.), and *Diplocraterion* (determined by A. A. Öpik). The Blina Shale overlies the Balgo and Condren Members of the Liveringa Formation, and undifferentiated Lightjack-Noonkanbah Formation; so the Permian rocks were eroded to various levels in the north-east Canning Basin before the Blina Shale was laid down. At Chilpada Chara, the Blina Shale conformably overlies the Culvida Sandstone (see below).

The association of *Lingula* and *Isaura* indicates that most of the Blina Shale was deposited in a shallow bay. The glauconite in the Meda No. 1 Bore probably indicates that the Blina Shale in this area was deposited in the open sea outside the bay.

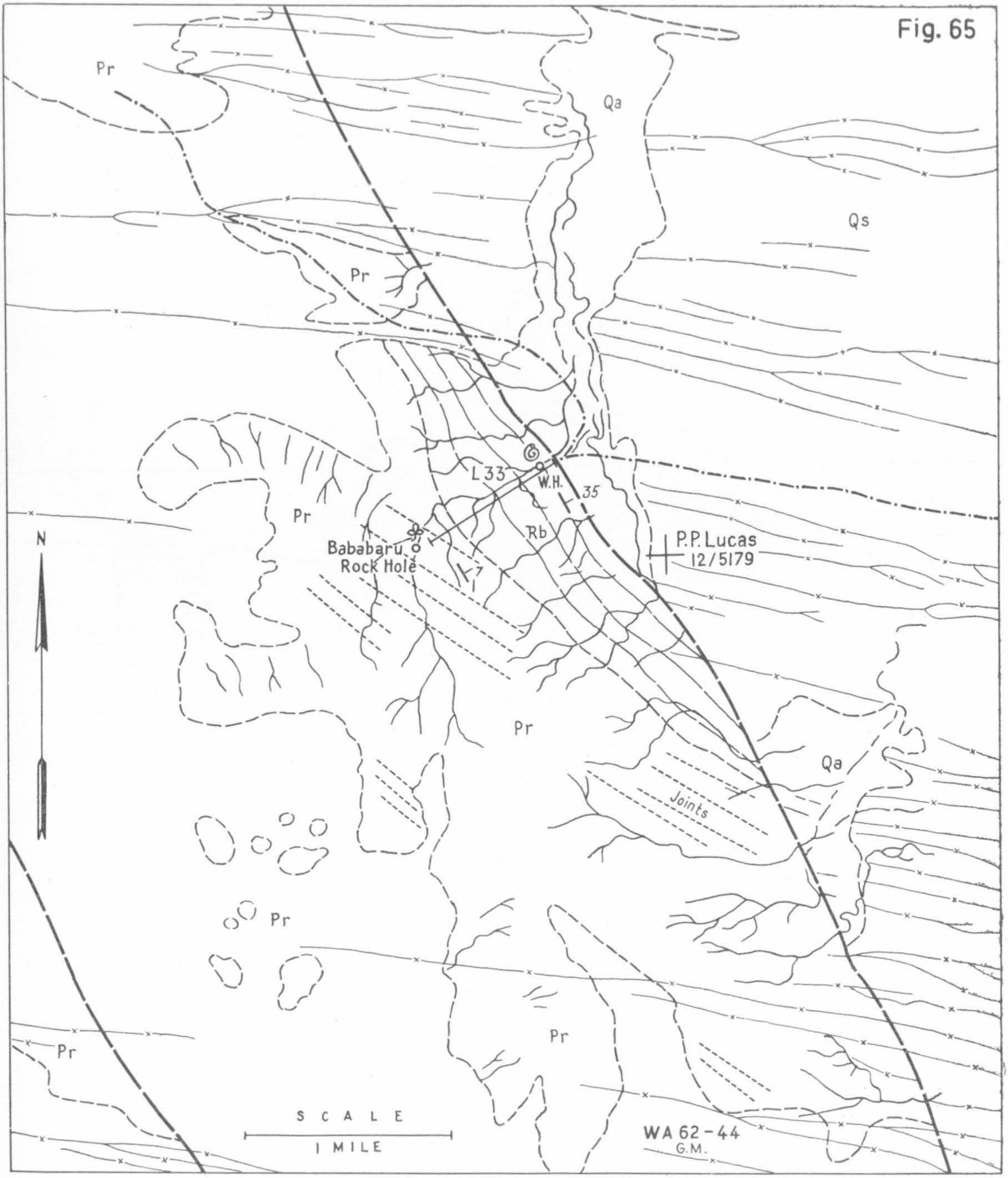
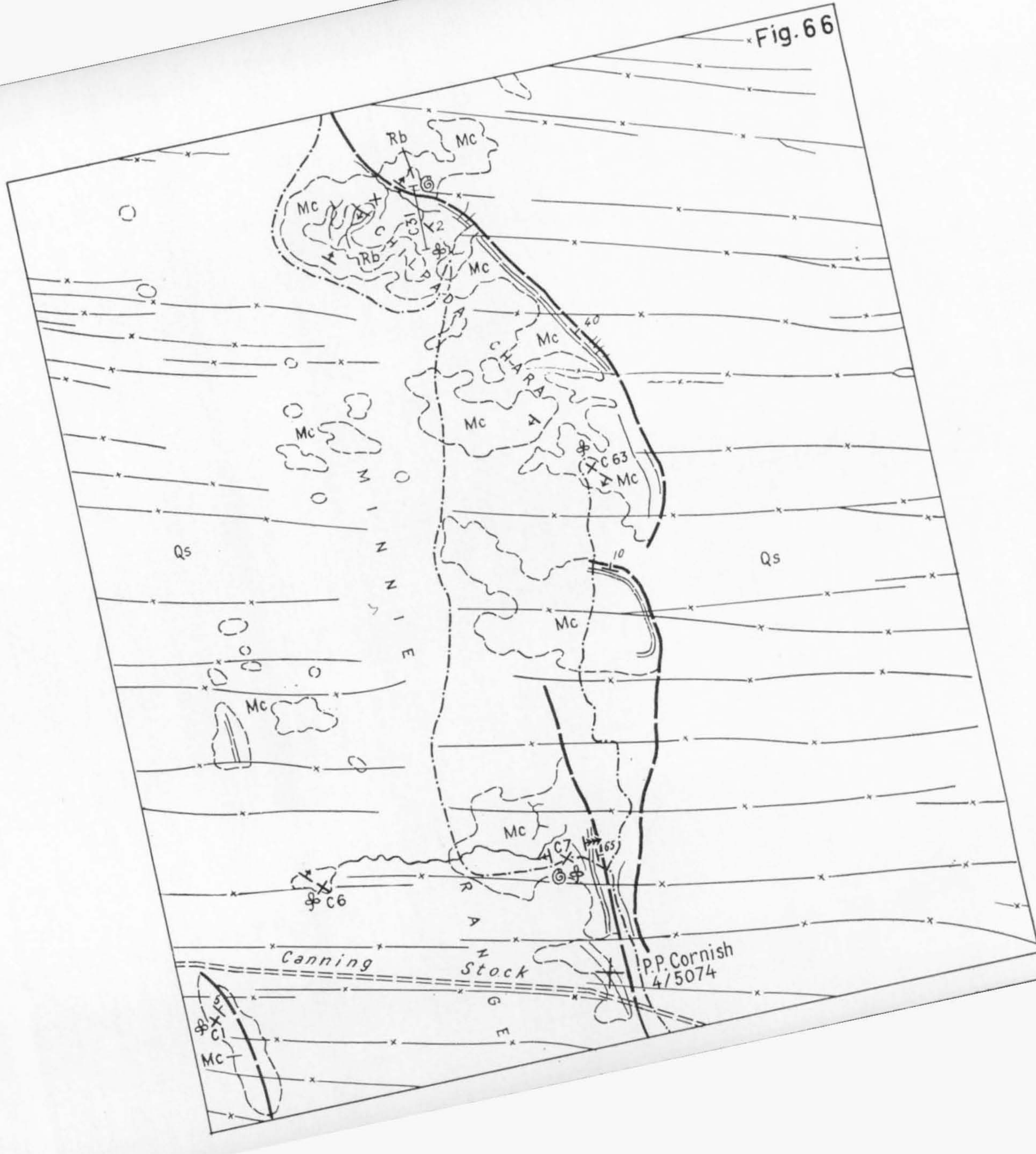


Fig. 65.—Bababaru Rock Hole area. Pr—Condren Member; Rb—Blina Shale; Qa—alluvium; Qs—sand.



Rb
Mc
Qs
M I N N I E
R A N G E
C 63
C7
C6
C1
Canning
Stock
P.P. Cornish
4/5074

Fig. 66

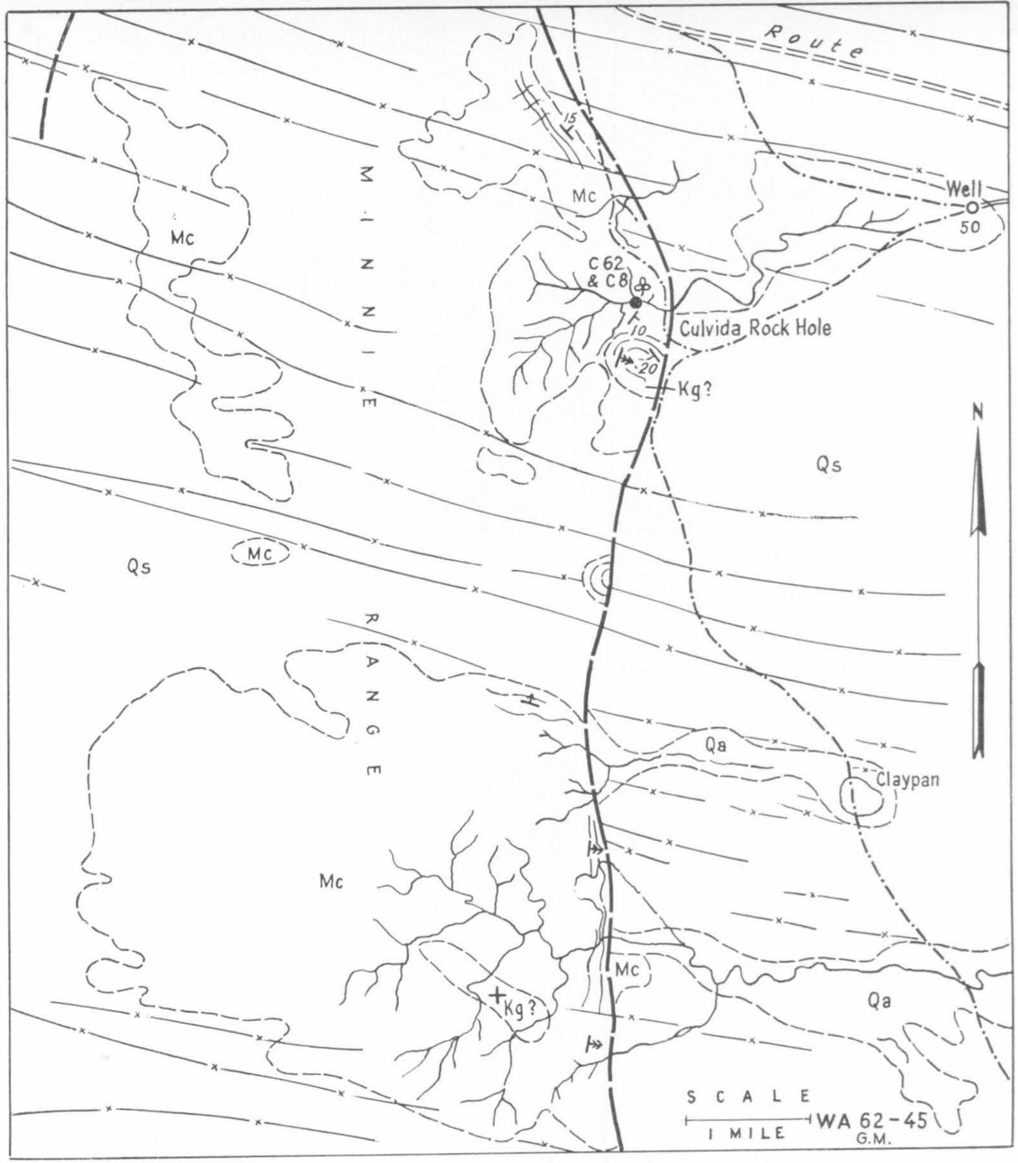


Fig. 66.—Chilpada Chara/Well 50/Culvida Rock Hole area. Rb—Blina Shale; Mc—Culvida Sandstone; Kg—Godfrey Beds; Qa—alluvium; Qs—sand.

TABLE 8

BLINA SHALE IN BORES

BORE	INTERVAL (feet)	THICKNESS (feet)	LITHOLOGY	PALAEONTOLOGY
Meda No. 1 (Pudovskis, 1960)	60–714	654+ (top eroded)	Shale & siltstone	L. Triassic microspores and *Isaura*
BMR 4A, Wallal (Pulley, 1960, MS.)	?1900–?2000	<100	Includes siltstone & shale	L. Triassic microspores
Derby Town Bore (Guppy et al.)	852–1860	1008	Mainly shale (details not known)	L. Triassic microspores & microplankton
Bakers No. 2 Bore (Guppy et al.)	50–1000+	950+	?	*Isaura* and L. Triassic microspores
Myalls Bore (Guppy et al.)	0–1056 (T.D.)	Erskine Sandstone and Blina Shale; probably bottomed in Liveringa Formation	?	*Lingula* & *Isaura* at 1012 feet (Teichert, 1950)
Wongil Bore (Guppy et al.)	0–767 (T.D.)	767 (probably bottomed in Liveringa Formation)	Mainly shale	

In a core of grey siltstone and shale with a few sandstone laminae from BMR 4A Wallal Bore (1993 feet to 2001 feet), Balme (*in* Pulley, 1960, MS.) found a microfloral assemblage similar to that in the Blina Shale in the Derby Town Bore, and similar to that in the Kockatea Shale. The thickness of the probable Lower Triassic rocks in the bore is not known. This is the only record of probable Triassic rocks in the south-west Canning Basin.

Culvida Sandstone (Casey & Wells)

Outcrops of the Culvida Sandstone are known only in the Minnie Range (Fig. 66), the northern part of the Cornish Sheet area, and the southern part of the Mount Bannerman Sheet area; exposures are found in low hills and isolated peaks. The Culvida Sandstone consists of thick-bedded cross-bedded quartz sandstone, which contains clay lenses and laminae, interbedded with thick-bedded plant-bearing siltstone. Ripple marks and infilled mudcracks are common The thickest exposed section is 200 feet. According to White (Appendix 6), the plants indicate Middle Triassic.

The base of the Culvida Sandstone is not exposed; the nearest outcrops are of Condren Member; the top of the Culvida Sandstone is eroded, and in the southern part of the Minnie Range is overlain by probable Godfrey Beds, the base of which is obscured. At Chilpada Chara (Fig. 66) and at M29, 4 miles northward, the Culvida Sandstone is conformably overlain by *Isaura*-bearing fine micaceous sandstone and shale, which is identified as the Blina Shale.

Erskine Sandstone (Brunnschweiler, 1954)

Massive to thin-bedded, friable, medium-grained to fine-grained cross-bedded sandstone that conformably overlies the Blina Shale in the Derby Sheet area of the Fitzroy Basin is called the Erskine Sandstone. In places, it is disconformably overlain by the Meda Formation, and elsewhere its top is exposed. The type section of the Erskine Sandstone at Erskine Hill is 110 feet thick; according to McWhae et al. (p. 83), the Erskine Sandstone is 836 feet thick in the Derby Town Bore. Exposures are poor except at Erskine Hill and on The Sisters Plateau. According to Brunnschweiler (1954, p. 45), the plants in the Erskine Sandstone indicate Upper Triassic (Keuper). As already noted, Balme's study of the microflora indicates that the Erskine Sandstone is Lower Triassic. White (Appendix 6) examined long-ranging plants from the type locality. No marine fossils, even microplankton, have been found in the Erskine Sandstone, which is probably continental.

Geological History

As pointed out in the Permian chapter, the Triassic rocks of the Canning Basin were probably deposited as the last rhythmic alternation of marine and estuarine or freshwater deposition that started in the Upper Carboniferous. The extent of the arm of the sea in which the Blina Shale was deposited is not known. Triassic rocks have not been found beneath Jurassic rocks in bores south of the Fitzroy Basin except in BMR 4A Wallal Bore. Except at Wallal, the Permian rocks south of the Fitzroy Basin are eroded to various depths, and if Triassic rocks had been deposited over this area, most of them would have been stripped off by erosion before the Middle Jurassic. The Upper Permian spores determined by Balme (*in* Pulley, 1960, MS.) from the rocks underlying the Triassic rocks in the BMR 4A Wallal Bore confirm the idea that in this area erosion before the deposition of the Triassic rocks was negligible. The probable Lower Triassic rocks in the Wallal Bore pose a problem, at present insoluble, in Triassic palaeogeography. Were these rocks deposited in sea-water, and, if so, did the sea extend southward from the Fitzroy Basin, or did an arm of the sea simply cover the Wallal area?

Two conflicting interpretations of the Triassic history of the basin may be given. The first interpretation (which we favour) is that the late Permian sea, whose extent is possibly indicated by the outcrops of the Hardman Member (Fig. 61G), became a narrow bay in the Lower Triassic. The lower part of the Blina Shale was deposited in this bay in the early Triassic, and at the same time in the north-east Canning Basin the Condren, Balgo, and Lightjack Members and possibly the Noonkanbah Formation, which were exposed after the retreat of the sea in the Upper Permian, were locally eroded. Some of the erosion products of these rocks were deposited as the Culvida Sandstone on the landward side of the shore. Later in the Lower Triassic, the Culvida Sandstone and the eroded Liveringa Formation were overlain by the upper part of the Blina Shale, which transgressed at least as far south-eastward as the Stansmore Range. The sea retreated after the deposition of the Blina Shale; in the Derby Sheet area, still in the Lower Triassic, the Blina Shale was covered by the Erskine Sandstone, which was probably deposited near the shore by rivers. Later in the Triassic, or in the Lower Jurassic, the Triassic and Permian rocks were folded.

The second interpretation is that the Permian rocks were folded at the end of the Permian, eroded during the Lower and Middle Triassic, and overlain by the continental Culvida Sandstone, estuarine Blina Shale, and continental Erskine Sandstone in the Upper Triassic.

These conflicting interpretations indicate the need for further work on the Triassic rocks.

JURASSIC AND CRETACEOUS

The Jurassic and Cretaceous rocks of the Canning Basin form a thin sheet, probably nowhere thicker than 2500 feet, that covers an area of about 100,000 square miles. Most of these rocks were deposited in a shallow sea, conglomeratic sandstone onshore, and claystone and pyritic glauconitic siltstone offshore. Sediments were deposited with minor breaks from the Middle Jurassic almost to the end of the Lower Cretaceous, and deposition was therefore slow, as is independently indicated by the accumulation of glauconite. As is to be expected under these conditions, the formations are diachronous, and, by itself, lithology is no guide to correlation. The slow deposition of the Jurassic and Cretaceous rocks is probably matched today by deposition on the Rowley Shelf.

We use the European subdivisions of the Jurassic and Cretaceous in the Canning Basin, first because no Australian scale is applicable, and secondly because nearly all authors dealing with the Canning Basin have used European terms. Further drilling in these rocks might provide enough new information to establish a local, more precise, time-scale.

Of the Jurassic and Cretaceous rocks in the basin, the Kimmeridgian, Tithonian, and Neocomian are the best known. Most of the older Jurassic rocks are obscured by younger rocks, and the post-Neocomian rocks are isolated by erosion.

Folds and faults in the Jurassic and Cretaceous rocks are rare, and all are local; they probably originated by compaction of sediments over pre-existing structures, except at Woolnough Hills, where salt intrusion probably caused the folding. Viewed regionally, these rocks are horizontal, and worthwhile exposures are consequently found only in the rare hills that from place to place break the monotonously flat sand plain.

The Jurassic and Cretaceous rocks of the basin are treated together because they were probably deposited during a single episode of transgression and regression that started in the Middle Jurassic and ended towards the end of the Lower Cretaceous. Conglomerate and coarse to conglomeratic plant-bearing sandstone and siltstone were deposited near the transgressive and regressive shore-line, and claystone and sandy pyritic and glauconitic siltstone in deeper water offshore. In fairly complete sections of the Jurassic and Cretaceous rocks (Fig. 68), the sequence is conglomerate or coarse to conglomeratic sandstone at the bottom, claystone or siltstone in the middle, and conglomerate or coarse to conglomeratic sandstone at the top. For the purpose of description, we refer to the rocks in the top and bottom parts of the succession as coarser-grained rocks, and those in the middle as finer-grained rocks.

The best-exposed Jurassic rocks extend from the Fenton Fault south-west to the Edgar Range. Farther south and west, Jurassic rocks form prominent outcrops in the

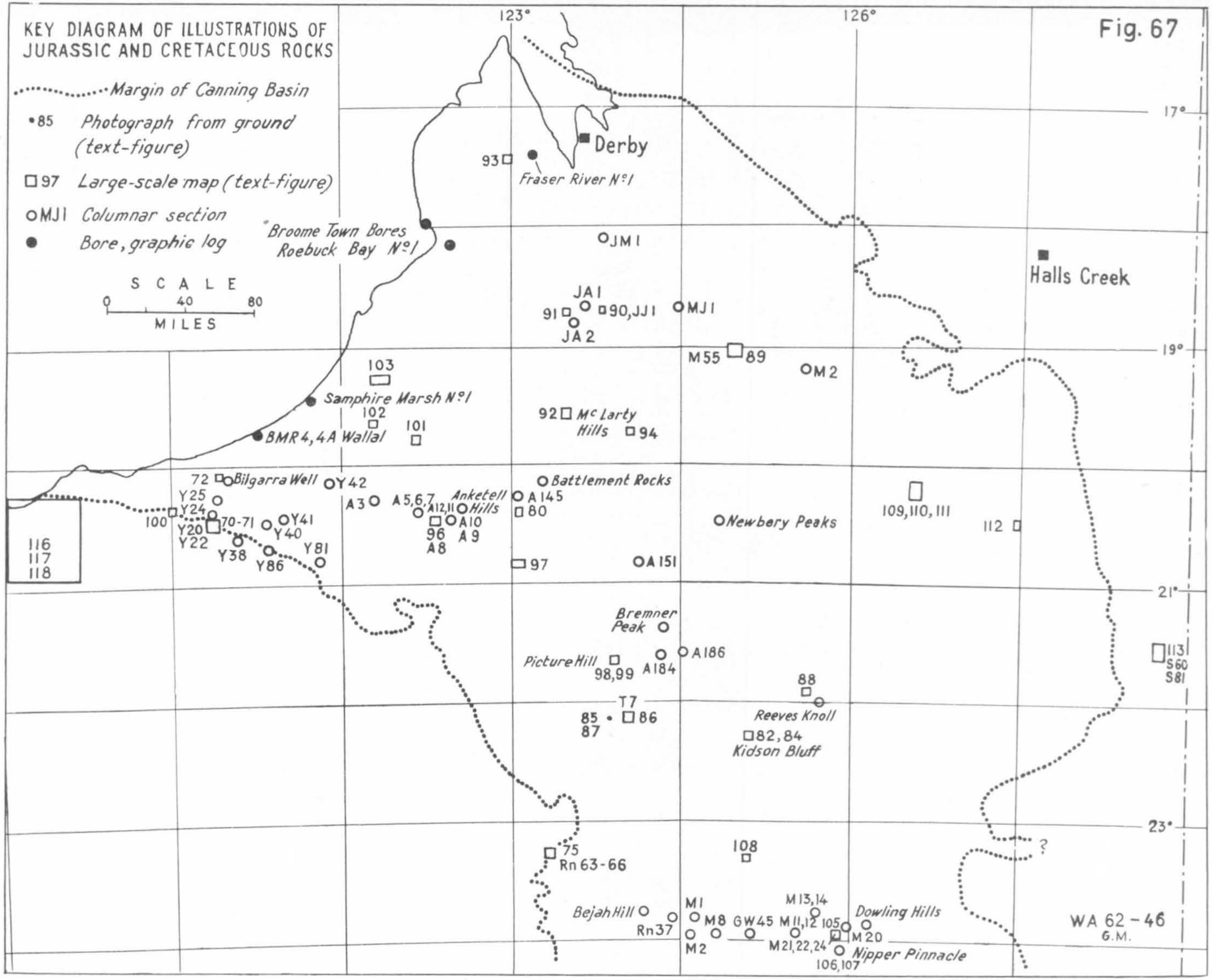

KEY DIAGRAM OF ILLUSTRATIONS OF JURASSIC AND CRETACEOUS ROCKS
Margin of Canning Basin
85 Photograph from ground (text-figure)
97 Large-scale map (text-figure)
MJ1 Columnar section
Bore, graphic log
SCALE
0 40 80
MILES
Fig. 67
123°
126°
17°
19°
21°
23°
Derby
Fraser River No 1
Broome Town Bores
Roebuck Bay No 1
Halls Creek
JM1
JA1
JA2
90, JJ1
MJ1
M55
89
M2
103
Samphire Marsh No 1
102
101
BMR 4, 4A Wallal
92
Mc Larty Hills
94
72
Bilgarra Well
Y42
Battlement Rocks
A3
A5,6,7
Anketell Hills
A12,11
A10
A9
96
A8
A145
80
Newbery Peaks
109,110,111
112
Y25
Y24
100
70-71
Y41
Y40
Y20
Y22
Y38
Y86
Y81
116
117
118
97
A151
Bremner Peak
A186
Picture Hill
98,99
A184
113
S60
S81
88
T7
Reeves Knoll
85
87
86
82,84
Kidson Bluff
75
Rn 63-66
108
M13,14
Dowling Hills
Bejah Hill
Rn37
M1
M8
GW45
M11,12
105
M20
M2
M21,22,24
Nipper Pinnacle
106,107
WA 62-46
G.M.

Fig. 67.

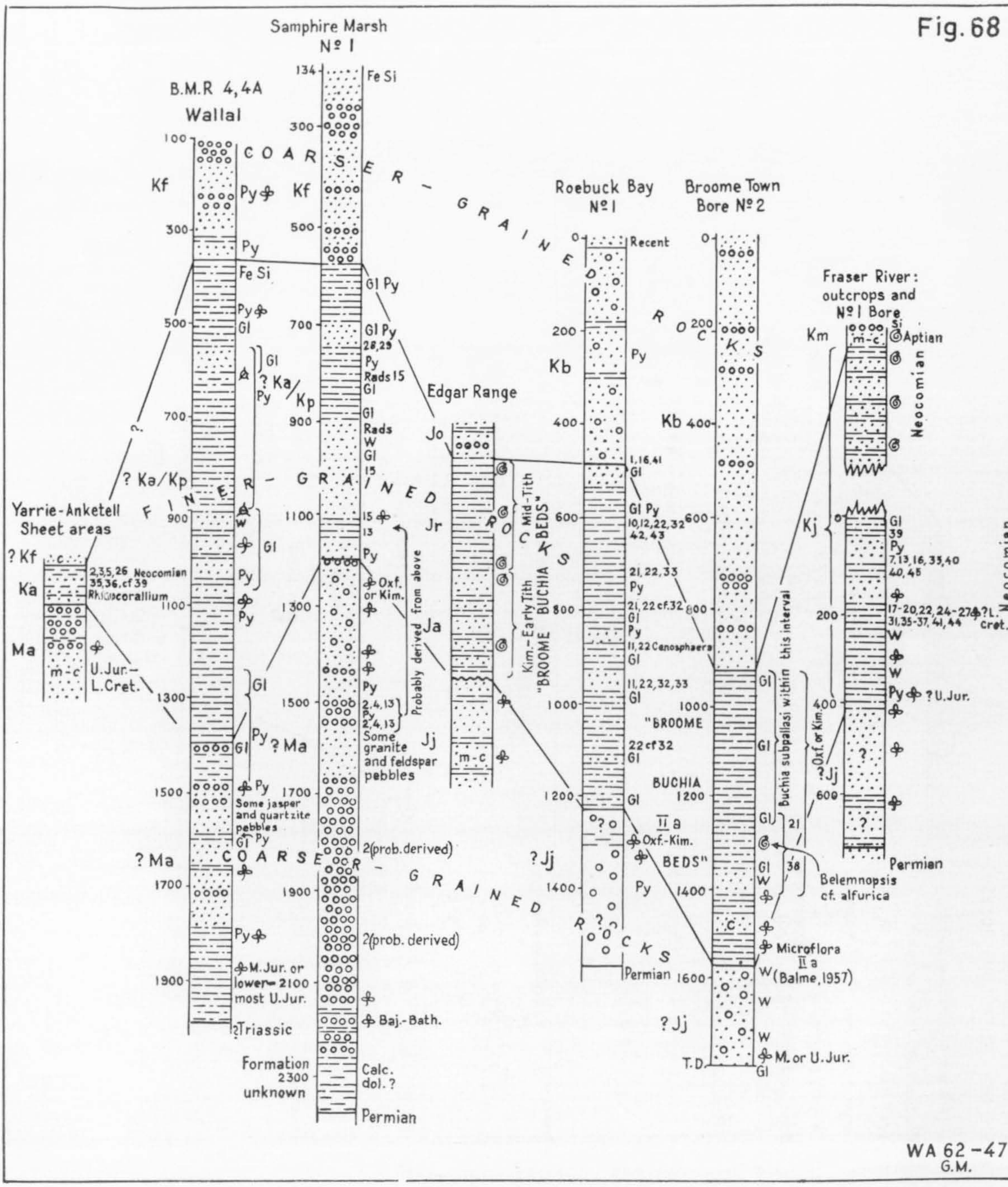


Fig. 68
Samphire Marsh Nº 1
B.M.R 4,4A Wallal
Yarrie-Anketell Sheet areas
Edgar Range
Roebuck Bay Nº 1
Broome Town Bore Nº 2
Fraser River: outcrops and Nº 1 Bore
COARSER-GRAINED ROCKS
FINER-GRAINED ROCKS
COARSER-GRAINED ROCKS
"BROOME BUCHIA BEDS"
Kim.-Early Tith
Mid-Tith
Probably derived from above
Buchia subpallasi within this interval
Oxf. or Kim.
Belemnopsis cf. alfurica
Microflora II a (Balme, 1957)
Some jasper and quartzite pebbles
Some granite and feldspar pebbles
M. Jur. or lower-most U. Jur.
Baj.-Bath.
Formation unknown
Calc. dol.?
Permian
?Triassic
Recent
Aptian
Neocomian
U.Jur.-L.Cret.
WA 62-47
G.M.

McLarty Hills, Grabowsky Range, Colorado Outcrop, and Callawa Hills. South-eastward, Jurassic exposures are intermittent and poor, and their dating less reliable. The Cretaceous rocks in this south-eastern area are no better exposed, but because they form an almost continuous sheet are more reliably identified. Only one part of the area of exposed Jurassic rocks is precisely dated; this is the Langey Crossing-Edgar Range-McLarty Hills area, which is rich in shelly fossils. Other exposures are approximately dated only. Most exposures of Jurassic rocks in the southern area are deeply weathered so that little unaltered rock is visible at the outcrop. The deep weathering in some areas has produced characteristic outcrops that are readily identified in air photographs; but in other areas, outcrops of probable Jurassic rocks are barely distinguishable from Permian rocks, and suspected Jurassic rocks are likewise barely distinguishable from Cretaceous rocks; but the Jurassic terrain of isolated dark conical hills generally contrasts with the Cretaceous terrain of low mesas.

Exposures of Cretaceous rocks are poor except in the Godfrey Tank area, along the coast, and in the Fraser River area. A few miles from the coast, the Cretaceous rocks are almost completely concealed by Recent sand and coastal sediments; farther inland, almost continuous outcrops of Cretaceous rocks are deeply weathered, and fresh rock is available only at breakaway scarps. The best outcrops reveal only 300 feet of rock, and throughout most of the basin less than 50 feet are exposed. Such poorly exposed and poorly preserved rocks require special methods of study. We have found air-photograph interpretation particularly successful, except in the coastal area north of Mount Phire—for example, at Gourdon Bay, where three disconformable formations are exposed, it is profitless, at least by us. The failure of air-photograph interpretation in this area is more than compensated for by many bores. Farther north, in the Fraser River area, Cretaceous rocks are exposed in mesas and buttes, and some information is consequently shown by the air photographs.

Detailed published descriptions of exposed Jurassic and Cretaceous rocks in the basin are rare, and we have consequently taken pains to present descriptions of key exposures. Large-scale maps based on air-photograph interpretation, and columnar sections are our main means of description (Fig. 67).

←Fig. 68.—Sections of Jurassic and Cretaceous rocks in the western part of the Canning Basin. Kf—Frezier Formation; Km—Melligo Quartzite; Kb—Broome Sandstone; Kj—Jowlaenga Formation; Kp—Parda Formation; Ka—Anketell Formation; Jo—Mowla Formation; Jr—Jarlemai Siltstone; Ja—Alexander Formation; Jj—Jurgurra Sandstone; Ma—Callawa Formation. Numbers refer to the following species of foraminifera determined by Miss Crespin:

1. *Ammobaculites* aff. *alaskaensis* Tappan; 2. *A. fisheri* Crespin; 3. *A. minuta* Crespin; 4. *A. minimus* Crespin; 5. *Ammobaculoides romaensis* Crespin; 6. *Ammodiscus* cf. *cretaceus* (Reuss); 7. *A. gaultinus* (Reuss); 8. *A.* sp.; 9. *Bigenerina* sp.; 10. *Enantiodentalina* sp.; 11. *Epistomina* sp.; 12. *Guttulina physalia* Loeblich & Tappan; 13. *Haplophragmoides chapmani* Crespin; 14. *H. dickinsoni* Crespin; 15. *H.* sp.; 16. *Hyperammina* sp.; 17. *Lagena apiculata* (Reuss); 18. *L. laevis* Montagu; 19. *L. sulcata* (Walker & Jacob); 20. *Lenticulina australiensis* Crespin; 21. *L.* cf. *audax* Loeblich & Tappan; 22. *L.* sp.; 23. cf. *Lituotuba* sp.; 24. *Marginulina* sp.; 25. *Marssonella* sp. nov.; 26. *Reophax* sp.; 27. *Robulus* sp. aff. *gaultinus* Berthelin; 28. *R. gunderbookaensis* Crespin; 29. *R.* sp.; 30. *Saracenaria* cf. *angularis* Natland; 31. *S.* sp. aff. *frankei* Ten Dam; 32. *S. oxfordiana* Tappan; 33. *S.* sp.; 34. cf. *Sigmoilina* sp.; 35. *Spiroplectammina cushmani* Crespin; 36. *S. edgelli* Crespin; 37. *S.* sp.; 38. cf. *Tolypammina* sp.; 39. *Trochammina minuta* Crespin; 40. *T. raggatti* Crespin; 41. *T.* sp.; 42. *Vaginulina curva* Franke; 43. *V.* cf. *inspissata* Loeblich & Tappan; 44. *Vaginulinopsis* sp.; 45. *Verneuilina howchini* Crespin.

Attempts at identifying Jurassic and Cretaceous formations in bores some distance from outcrops and other bores are premature. By themselves, fossils are little or no help, because these formations are diachronous. Gross features of outcropping formations such as geomorphological form, differential weathering, colour at the outcrop, and jointing, to name but a few, are of course not found in bores. Many formations, especially conformable formations of similar lithology, e.g. the Jarlemai Siltstone and Alexander Formation, are differentiated in outcrop by these features, and in bores are consequently difficult to recognize. For this reason we consider it generally inadvisable at this date to claim firm identification of certain formations in bores far distant from outcrops and other bores.

In correspondence, B. E. Balme points out that he has made no systematic study of Mesozoic spores from the Canning Basin, and that his determinations for Wapet are based on isolated samples from various parts of the basin. The stratigraphical implications of plant microfossils in the Canning Basin are therefore not established.

Twenty-five Jurassic or Cretaceous formations in the Canning Basin have been named. A widespread, probably composite unit, indicated as undifferentiated Mesozoic (M *in* Pl. 1), and several units in bores have not been named. All twenty-five formations, except the Poondano Formation and probably the Cronin Formation, are thought to be marine or paralic, and they may be classified broadly as either coarser-grained rocks (conglomeratic sandstone), finer-grained rocks (siltstone or claystone), or a mixture of the two. The coarser-grained rocks at the bottom of the Jurassic and Cretaceous succession will be described first, then the finer-grained rocks and the mixed rocks, and finally the coarser-grained rocks at the top of the succession. The freshwater Poondano Formation will be described separately at the end.

Coarser-grained Rocks at the Bottom of the Jurassic-Cretaceous Succession

Broome No. 2, Samphire Marsh No. 1, BMR 4, 4A Wallal, Roebuck Bay No. 1 Bores (Fig. 68)

The oldest known Jurassic rocks in the Canning Basin, with the possible exception of some Triassic-Jurassic rocks, are the 'white sand and boulders' (driller's log) between depths of 1555 and 1773 feet and 'sandy shale' between 1773 and 1775 feet (total depth) in Broome No. 2 Bore (Fig. 68) and the conglomeratic sandstone with thin siltstone near its base in Samphire Marsh No. 1 between depths of 1162 and 2258 feet and in BMR 4A Wallal between 1400 and 1980 feet. Balme (pers. comm.) examined part of the core from 1773 to 1775 feet in Broome No. 2 Bore, and found that the very few spores recovered probably indicate Middle or Upper Jurassic. The 'white sand and boulders' underlie Oxfordian or Lower Kimmeridgian rocks, and hence are at the youngest Oxfordian. The interval 1240 to 1560 feet in Roebuck Bay No. 1 consists of medium-grained to coarse-grained carbonaceous pebbly sandstone with thin claystone; Balme (1957) identified his Microflora IIa, which he considers Oxfordian to Kimmeridgian, from 1295 to 1305 feet in this bore.

Balme (*in* Johnstone, 1960) determined spores from three beds in the conglomeratic sandstone at the base of the Jurassic-Cretaceous succession in Samphire Marsh No. 1 Bore. Cuttings from 1260 to 1270 feet yielded an assemblage of spores and pollen grains which Balme considers Oxfordian or Kimmeridgian and similar to that found in the lower part of what he identifies as the Jarlemai Siltstone in the Broome boreholes. The other samples of cuttings, from 2190 to 2200 feet and 2240 to 2250 feet, are considered probably Middle Jurassic (Bajocian to Bathonian). The section penetrated between 1162 and 2258 feet (Johnstone, 1960) 'consists predominantly of coarse sandstone and fine conglomerate, with thin beds and lenses of grey carbonaceous siltstones and black lignite'.

The unfossiliferous rocks in the interval 2258 to 2373 feet, which overlie Permian rocks, consist of 'grey-brown slightly sandy, calcareous and ?dolomitic siltstone, interbedded with white calcareous to very calcareous mudstone'. The age and identification of these beds are unknown.

Balme (*in* Pulley, 1960, MS.) examined Core 5 of BMR 4A Wallal (1905 to 1912 feet) and recovered spores which he determined as probably Middle Jurassic or lowermost Upper Jurassic. The interval between 1400 and 1800 feet in this bore consists of pebbly sandstone with thin beds of quartz greywacke and siltstone, underlain by 180 feet (from 1800 to 1980 feet) of sandy siltstone with a thin bed of quartz greywacke at the base. Pyrite and wood fragments are common throughout the interval 1400 to 1980 feet.

In Samphire Marsh No. 1 and BMR 4A Wallal, the succession of plant-bearing siltstone overlain by pebbly sandstone corresponds with the type section of the Callawa Formation, 60 miles south-west of Wallal. The Callawa Formation crops out almost continuously from the type locality to within 20 miles of Wallal, and we tentatively identify the intervals 1400 to 1980 feet in BMR 4A Wallal, and 1200 to 2258 feet in Samphire Marsh No. 1, as Callawa Formation. The occurrence of rocks identified as Anketell-Parda Formation above 1200 feet in Samphire Marsh No. 1, and above 1400 feet in BMR 4A Wallal confirms this identification. The uppermost pebbly band is recorded at 1200 feet in Samphire Marsh No. 1, and at 1400 feet in BMR 4A Wallal, and the top of these pebble bands is consequently chosen as the boundary between Callawa Formation and Anketell-Parda Formation. Johnstone (1960) placed a formation boundary at 1162 feet, and thus included in the conglomeratic sandstone 38 feet of fine to medium-grained sandstone, which we consider is better included in the overlying formation. The occurrence of glauconite above and below the top of the Callawa Formation in BMR 4, 4A Wallal indicates that this boundary is transitional, and hence that in this area the Anketell-Parda Formation succeeded the Callawa Formation without a break. The pebbles of feldspar and granite reported by Johnstone from the interval 1162 to 2258 feet in Samphire Marsh No. 1 Bore, and pebbles of jasper and quartzite reported by Pulley from 1540 to 1560 feet in BMR 4, 4A Wallal indicate that these intervals and the type section of the Callawa Formation were derived from the same kind of Precambrian rocks.

Callawa Formation (Ma*) (Reeves, 1951, p. 2491; Traves et al., 1957, pp. 26-28; McWhae et al., pp. 108-109)

Reeves introduced the name Callawa boulder beds for the 200- to 300-foot-thick 'boulder beds and cross-bedded sandstones with Jurassic plant beds at base. Occupy Callawa Hills in southwest corner of basin'. Traves et al. changed the name to Callawa Formation because claystone and sandstone also are important constituents. We

* Letter symbol.

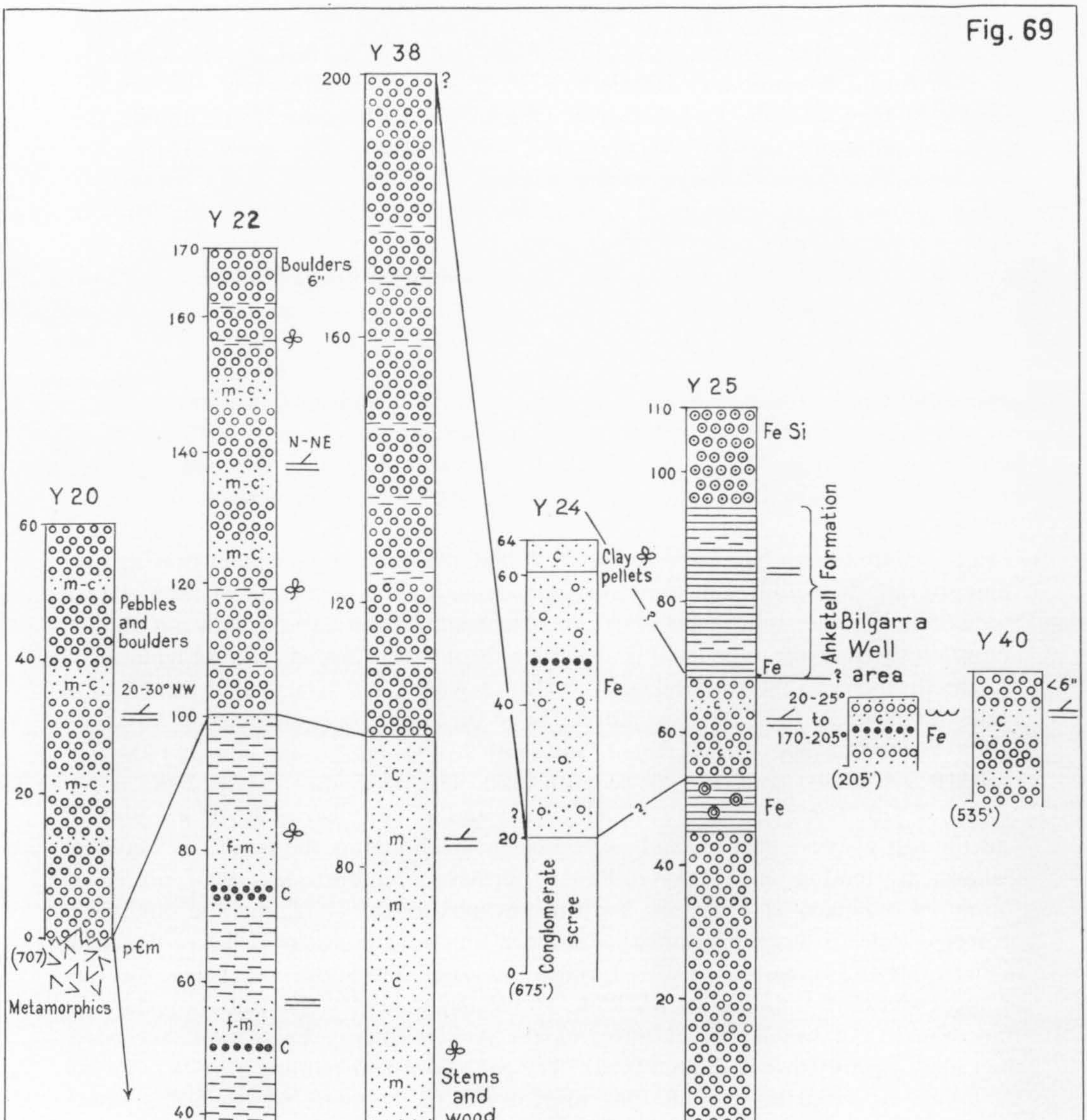


Fig. 69.—Callawa Formation. See Yarrie geological map for localities.

redefine the Formation as follows: the Callawa Formation is the sequence of conglomerate, conglomeratic sandstone, sandstone, and claystone resting unconformably on Permian or Precambrian rocks and overlain conformably by the Anketell Formation. Columnar sections, including the type, are shown in Figure 69. The thickest measured section (Y38) is 200 feet thick, and consists of 100 feet of medium- to coarse-grained sandstone overlain by 100 feet of conglomerate and thin interbedded sandstone and claystone. According to Traves et al. the section at Y38 is overlain by Y24, and, in turn, Y24 is overlain at Y25 by shales of the Anketell Formation. According to these identifications, the Callawa Formation has a composite exposed thickness of about 250 feet. The Callawa Formation rests unconformably on either Permian or Precambrian rocks; its top is either eroded, or it is overlain, conformably in Samphire Marsh No. 1 Bore, apparently conformably elsewhere, by the Anketell Formation.

At the type locality (Figs. 70, 71), the Callawa Formation is exposed in the south as residuals on Precambrian rocks, in the north-west as rubbly rises beneath Anketell Formation (except in the extreme north-west, where low conical hills rise above the rubble), and in the central and north-eastern parts as continuous outcrop bounded by a scarp along part of its southern margin. On air-photograph pattern, the Callawa Formation in the type area is divisible into five parts:

(a) Lightly incised rocks that weather into soft smooth forms, light-grey on air photographs; extends from two miles east of Y35 north-west to Y23. This is the outcrop of the lower half of the Callawa Formation, that consists of interbedded claystone and sandstone.

(b) An area incised by finely dendritic watercourses (the headwaters of the south-flowing Eel Creek, Wattle Creek, and the unnamed creek east of Wattle Creek); on air photographs darker grey than (a). This is the outcrop of the junction between the claystone and sandstone of the lower half of the formation and the conglomerate of the upper part.

(c) Rising above (a) and (b), and forming the residuals in the south is the outcrop of the conglomerate. On the air photographs this is dark-grey to black, and very rough. A scarp on its southern margin divides the conglomerate from (a) or Quaternary sand. Joints are prominent in the eastern part of (c). In the east and north-east, the outcrop of (c) passes imperceptibly into

(d) Groups of isolated conical hills, black in air photographs. No drainage channels cross this area. West of (d) are

(e) Mesas of Callawa Formation capped by Anketell Formation, incised at the edges, black in air photographs. The Anketell Formation is deeply weathered.

Farther north in the basin, the patterns of (d) and (e) are the only ones visible in air photographs until the northernmost Jurassic outcrops near the Fenton Fault (Millyit, Barbwire Ranges) are reached, when (b) and (c) reappear. For example, (d) prevails near Bilgarra (No. 2 Desert) Well (Fig. 72); north-trending joints in the Callawa Formation are indicated by elongate outcrops and by lines of trees; the conical hill (with a cairn) west of Bilgarra Well consists of ferruginous coarse sandstone, grit and conglomerate, and fine white micaceous sandstone. Some beds are ripple-marked, others cross-bedded.

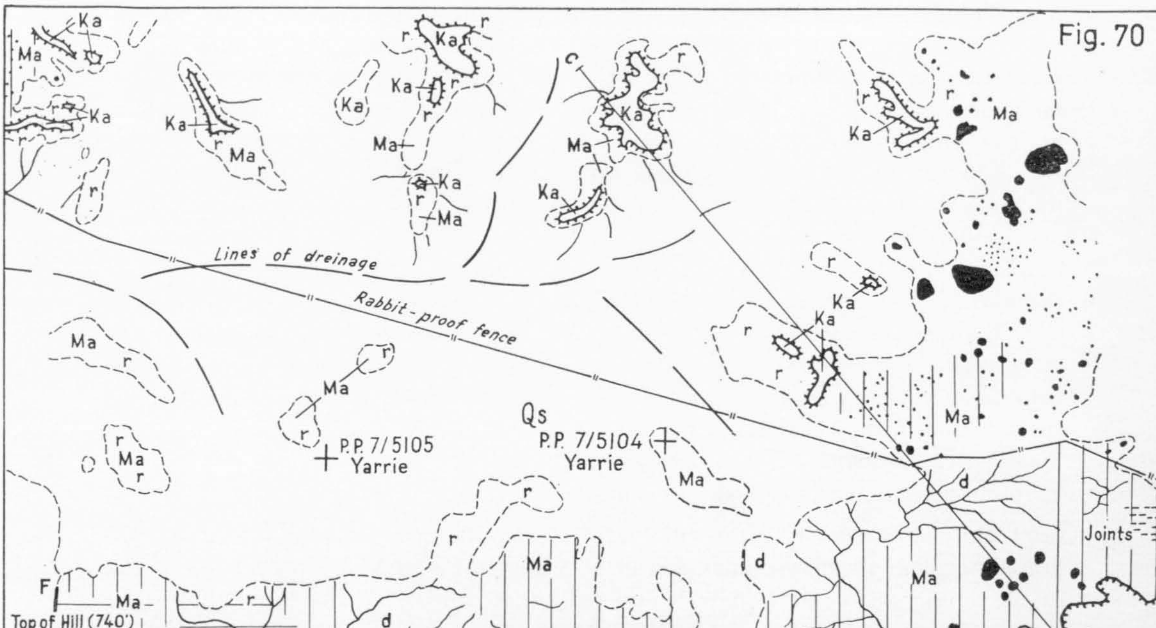


Fig. 70.—Type locality of Callawa Formation. Adapted from Yarrie geological map. r—rubbly outcrop; Ka—Anketell Formation; Ma—Callawa Formation; Pb—Braeside Tillite; pCs—Precambrian sediments and volcanics; pCb—Precambrian breccia; pCm—Precambrian metamorphics; x—measured section.

Outcrops of the Callawa Formation extend west almost to the coast, and east to the Anketell Hills (Fig. 73). Some of these outcrops are described in the section dealing with the Anketell Formation. As noted above, the Callawa Formation probably extends beneath the surface to Wallal and Samphire Marsh. Reeves (1951, p. 2495) recorded 'Callawa boulder beds' from No. 3 Desert Bore, 25 miles north-north-west of Callawa Homestead. Outcrops of coarse sandstone east and south of Anketell Hills probably belong to the Callawa Formation but because these rocks are little known, they are called undifferentiated Mesozoic (M). Among these is the exposure of pebbly sandstone four miles east of Lake Auld (T5), described by Traves et al. (p. 28).

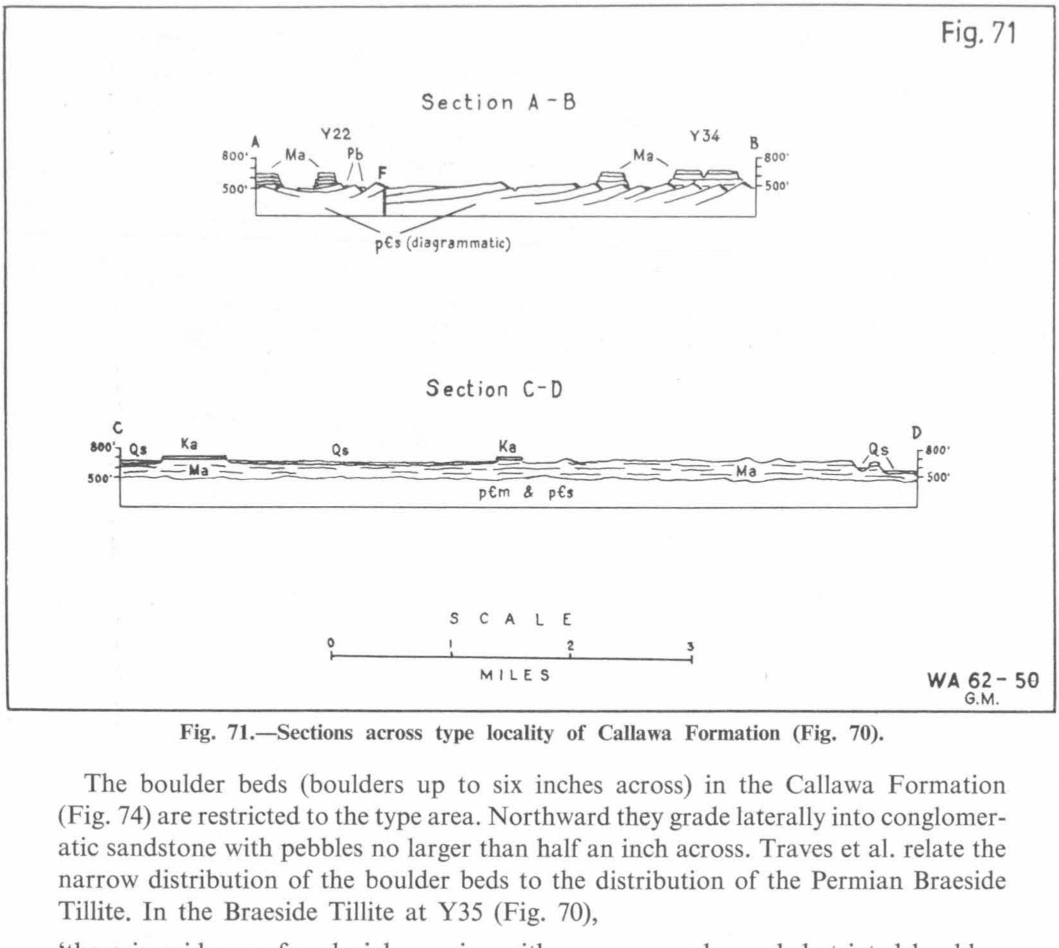


Fig. 71.—Sections across type locality of Callawa Formation (Fig. 70).

The boulder beds (boulders up to six inches across) in the Callawa Formation (Fig. 74) are restricted to the type area. Northward they grade laterally into conglomeratic sandstone with pebbles no larger than half an inch across. Traves et al. relate the narrow distribution of the boulder beds to the distribution of the Permian Braeside Tillite. In the Braeside Tillite at Y35 (Fig. 70),

'there is evidence of a glacial moraine with numerous subrounded striated boulders and pebbles of quartz, granite, gneiss, quartzite, vesicular basalt, jasper, quartz-hematite, chert-breccia, and sandstone; all these rocks crop out in the Precambrian of the Yarrie Four Mile sheet. The moraine is unsorted, unstratified, and unwashed, and is a mixture of boulders of all sizes up to four feet. Overlying the moraine and extending northwards (basinwards) from it is a succession of 50 feet of banded brown, red, and white varved shales; some beds contain rock fragments ranging from $\frac{1}{4}''$ to 3″, over and around which the fine varves have been deposited.'

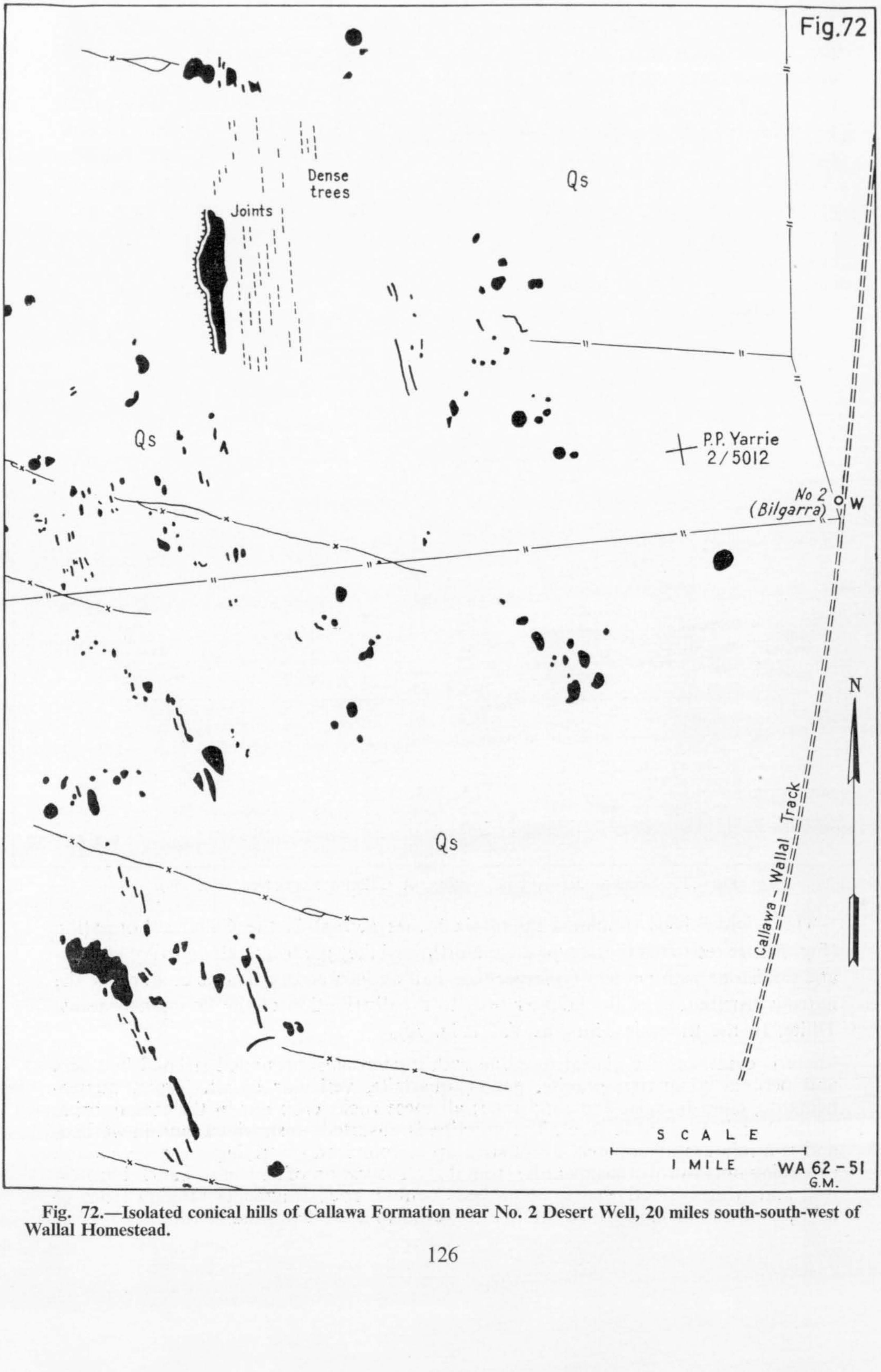


Fig. 72.—Isolated conical hills of Callawa Formation near No. 2 Desert Well, 20 miles south-south-west of Wallal Homestead.

In short, Traves et al. believe that the boulders in the Callawa Formation were 'ready-made' before the Callawa Formation was deposited, and that during deposition of the Callawa Formation, the Braeside Tillite was reworked and redistributed by rivers into boulder beds. The varved shales at the top of the Braeside Tillite were eroded first and were probably deposited as the basal, fine-grained part of the Callawa Formation. The deposition of boulders derived from the base of the Braeside Tillite over the fine beds of the Callawa Formation completed a 'mirror-image' or reverse cycle of deposition. Traves et al. (p. 22) believe that 'the Braeside Tillite was, at least

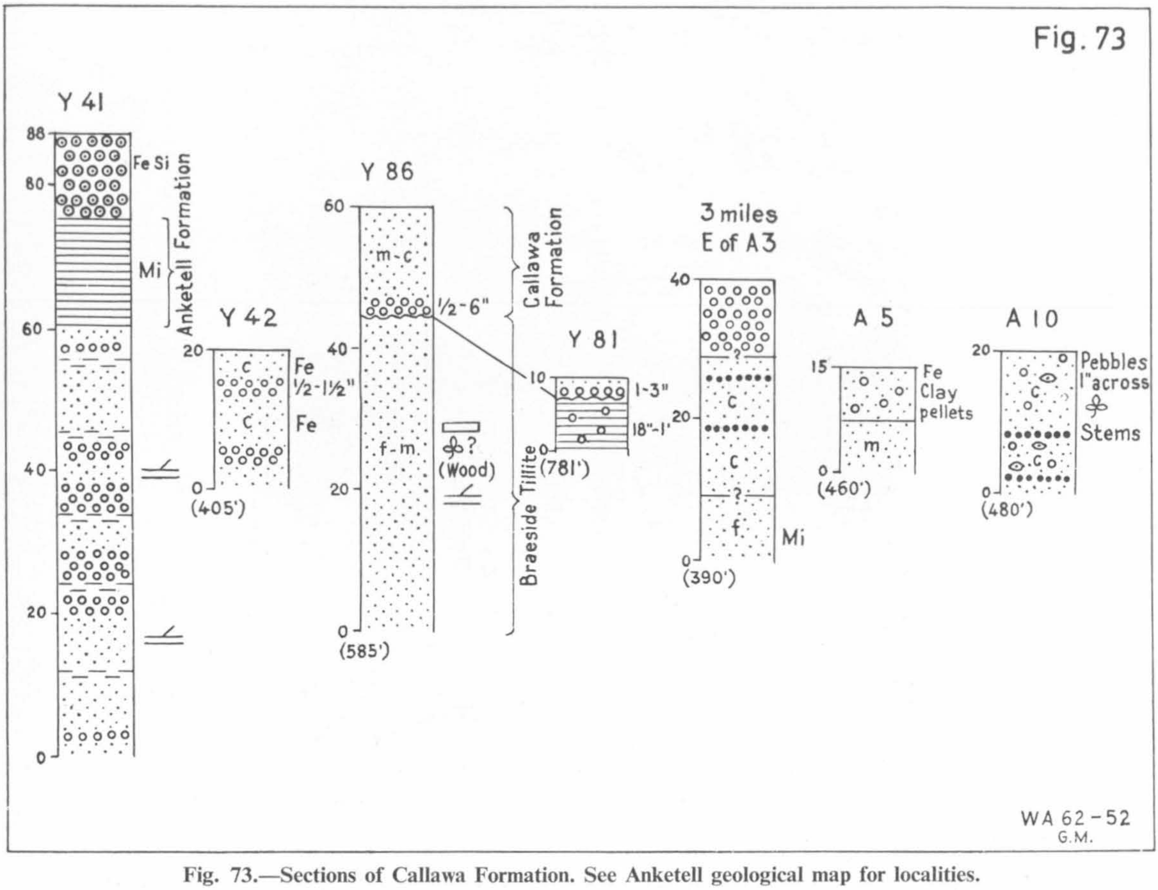


Fig. 73.—Sections of Callawa Formation. See Anketell geological map for localities.

in part, a terrestrial deposit formed by glaciers flowing down an old Nullagine-Oakover Valley'. Hence boulder beds are not expected far from this source.

The only fossils known from the outcropping Callawa Formation are plants, which Brunnschweiler (*in* Traves et al., pp. 49-50) determined as probably Triassic or Jurassic. White (Appendix 6) regards them as Upper Jurassic or Lower Cretaceous. In outcrops the top of the Callawa Formation lies apparently conformably beneath the Neocomian Anketell Formation; in the Samphire Marsh and Wallal Bores, the Callawa Formation lies conformably beneath the Neocomian Anketell-Parda Formation; its upper limit therefore is probably uppermost Jurassic. Balme dates the top of the Callawa Formation in Samphire Marsh No. 1 Bore as Oxfordian to Kimmeridgian, and its base as pre-Oxfordian (Bajocian to Bathonian).

McWhae et al. (p. 109) suggest that the Callawa Formation is Lower Cretaceous because it probably grades laterally into the Parda Formation. This suggestion is dismissed by the argument given above.

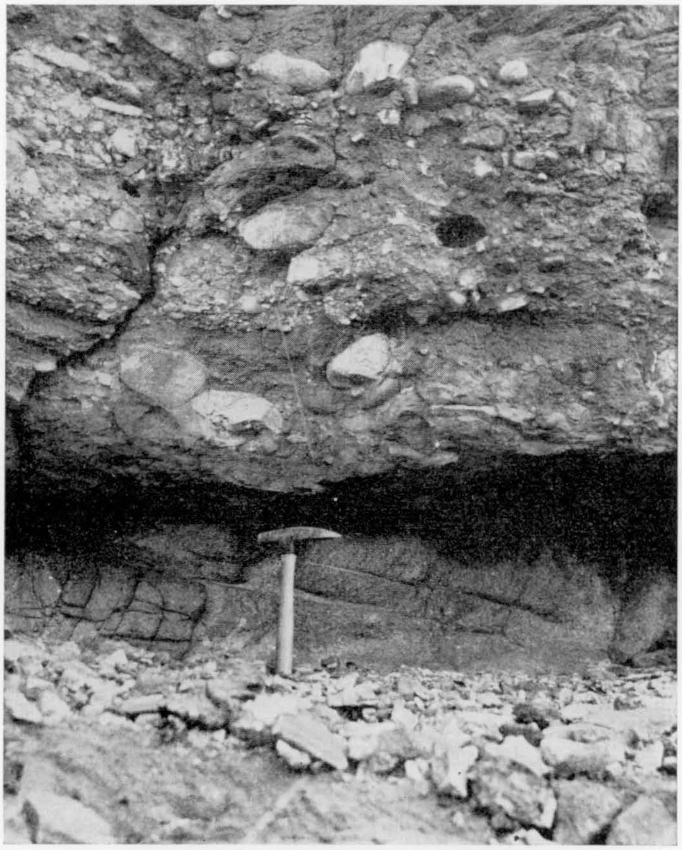


Fig. 74.—Unconformity between Precambrian volcanics and Callawa Formation at Y20 (for locality, see Figure 70).

Cronin Sandstone (Mr) (new name)

The name Cronin Sandstone is introduced for the sandstone with minor beds of shale, siltstone, and fine conglomerate that is exposed in the Cronin Hills (23° 15′ S, 123° 20′ E) (Fig. 75). The type section, Ru65 (Fig. 76), from top downwards, consists of:

- 40 feet coarse cross-bedded and massive sandstone interbedded with fine conglomerate which contains angular pieces of fine-grained sandstone;
- 30 feet thin-bedded fine-grained cross-bedded sandstone, coarse towards top;
- 2 feet conglomerate;
- 2 feet fine-grained sandstone with plant fossils;
- 3 feet shale.

The Cronin Sandstone overlies the Paterson Formation (Permian) disconformably and Precambrian quartzite, sandstone, and shale unconformably. Its top is eroded. The Cronin Sandstone is known from the type locality only. It forms isolated hillocks and rounded hills, some bounded by low scarps, standing above rubbly outwash covered with mulga. On the air photographs, the Cronin Sandstone is white to light-grey, and in places shows horizontal bedding. This pattern is not distinguishable from that of nearby outcrops of Paterson Formation.

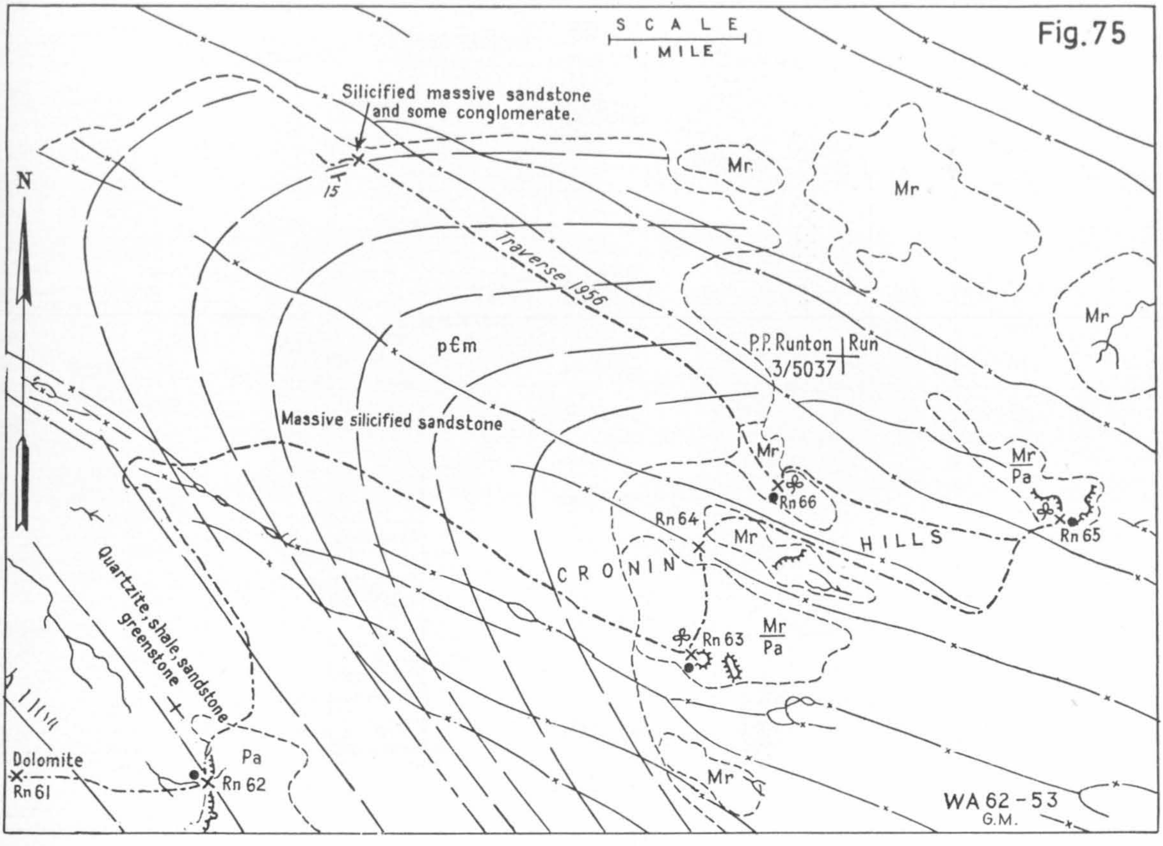


Fig. 75.—Type locality of Cronin Sandstone (Mr). Pa—Paterson Formation; pCm—Precambrian metamorphic rocks; • measured stratigraphic section.

The plant fossils in the Cronin Sandstone are well preserved, and, according to White (Appendix 6), indicate Upper Triassic or Jurassic.

The Cronin Sandstone was probably deposited in fresh or brackish water in a coastal lagoon or estuary. Its isolation, probably by erosion, from other Mesozoic rocks rules out an estimate of the original distribution. The Callawa Formation in the type locality resembles the Cronin Sandstone in overlapping Permian glacial rocks, in lithology, and in containing plants. The wide extent of the Callawa Formation, its glauconite in BMR 4, 4A Wallal and the comminuted state of most of its plants, indicate that it was deposited, except perhaps at its landward edge, in sea-water. In the type locality, the Callawa Formation, like the Cronin Sandstone, was probably deposited at the mouth of a river.

Jurgurra Sandstone (Jj) (Brunnschweiler, 1954, pp. 46-47)

Brunnschweiler introduced the name Jurgurra Sandstone for the quartz sandstone that disconformably underlies the Alexander Formation in the Edgar Range near

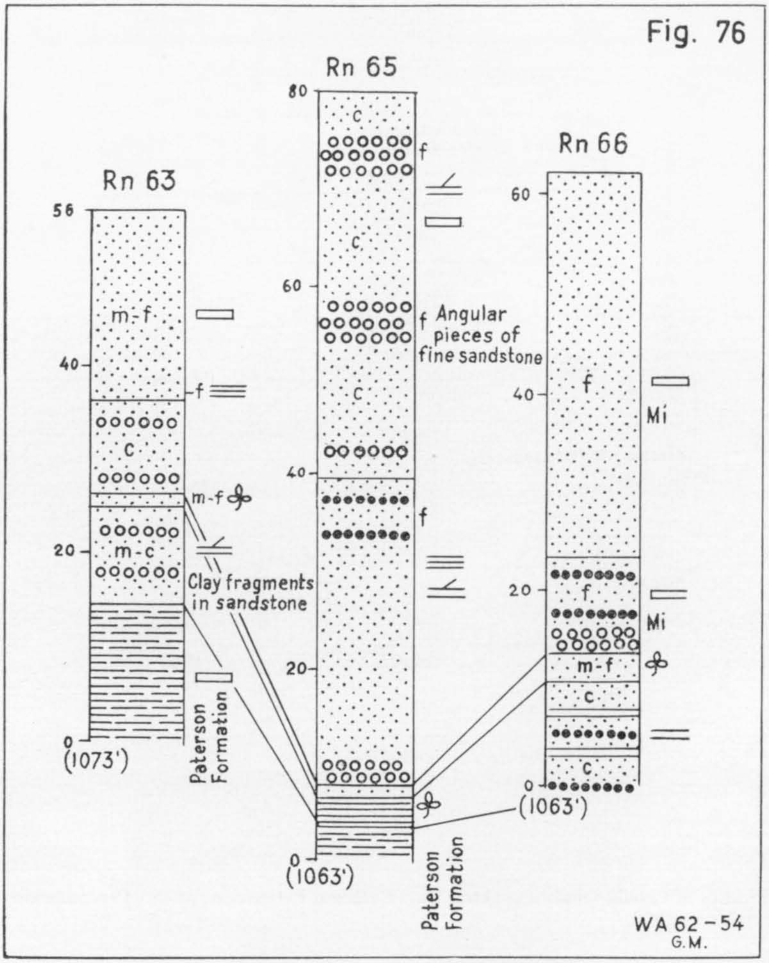


Fig. 76.—Sections of Cronin Sandstone.

Mount Alexander and near Goorda Tower. The type locality is the southern bank of Jurgurra Creek just south of Mount Alexander. Here only the uppermost 15 feet are exposed (Fig. 77, Section JA1).

'The formation consists of massive medium-grained quartz sandstone, fairly clean, buff to cream in colour, and commonly crossbedded. In places it contains friable clay pellets and some fossil wood. The Jurgurra Sandstone is a marine deposit. This is indicated by the presence of small marine pelecypods. They are rare and not sufficiently well preserved for generic or specific identification.'

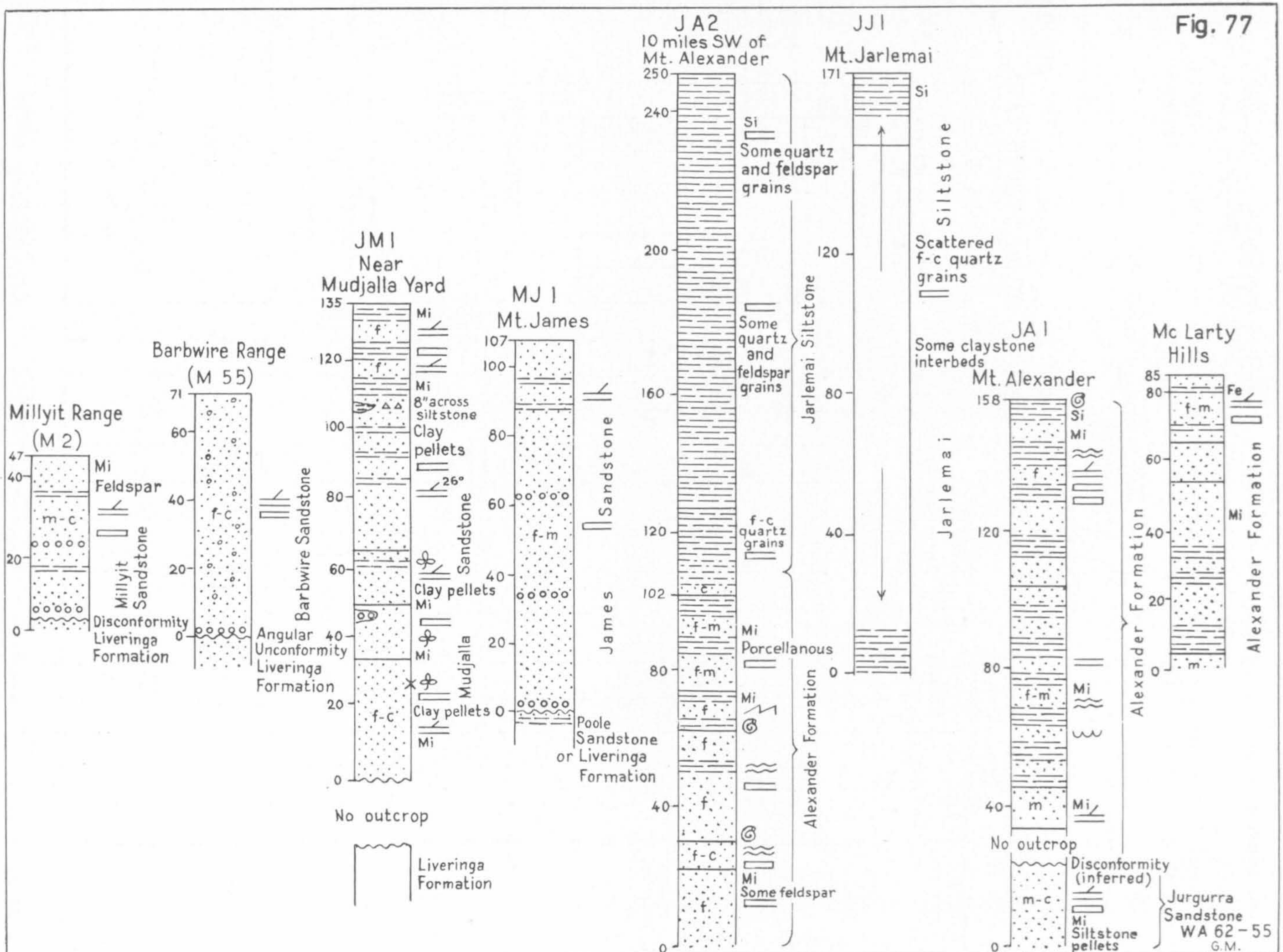


Fig. 77.—Sections of Jurassic rocks Fenton Fault/Edgar Range/McLarty Hills area. Section at McLarty Hills measured by Wapet.

Brunnschweiler regards the Jurgurra Sandstone as Jurassic because 'the nature of the disconformity between the Jurgurra Sandstone and the overlying Alexander Formation suggests that the non-depositional interval may not have been a long one'. Drilling in 1955, 24 miles north of Mount Alexander (BMR 1 Jurgurra Creek) revealed Permian rocks near the surface, and indicated the possibility that the Jurgurra Sandstone is Permian (Henderson, 1956, unpubl.). Certain parts of the Permian Grant Formation are similar to the Jurgurra Sandstone, but pelecypods have nowhere been found in the Grant Formation, although foraminifera have. The Permian

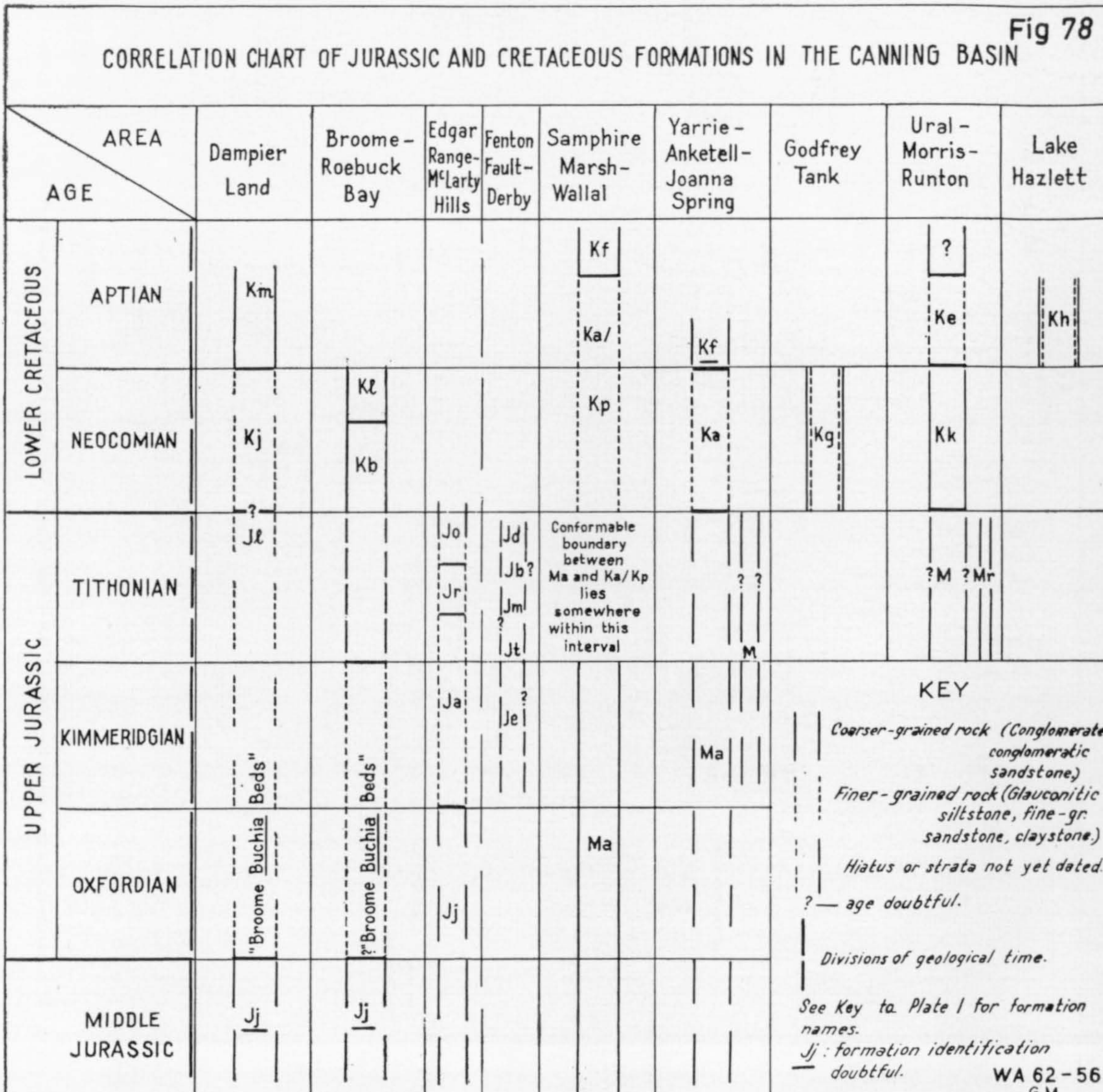


Fig. 78.

Fig. 79

METHODS OF DATING JURASSIC AND CRETACEOUS ROCKS IN THE CANNING BASIN

Age \ Method	1. By fossils regionally compared.	2. By fossils locally compared.	3. By superposition	4. By interfingering.	5. By palaeogeographical considerations
APTIAN	Kf near LaGrange homestead (pelecypods) Km (pelecypods belemnites) Ka/Kp top part in Samphire Marsh No.1 Bore (Radiolaria)	Ke (Radiolaria like those in S.M. No.1) Kh (Radiolaria like those in S.M. No.1)	Kf overlies Ka/Kp in S.M. No.1 Bore Unnamed coarse sandstone overlying Ke ?Kf overlies Ka in Anketell area; top part Ka/Kp in S.M. Bore overlies Ka/Kp with Neocomian forams Kf overlies Kp at C.Gourdon		
NEOCOMIAN	Kl (Rhizocorallium, Inoceramus) Kj (pelecypods, ammonites, belemnites, forams). Kb type area (plants)	Kg, Kk (Rhizocorallium) Ka/Kp S.M. No.1 Bore (forams) Ka type locality (forams, Rhizocorallium)	Kp overlies Kb at C.Gourdon. Kb Cape Leveque conformably underlies Kl Jo overlies Jr	Kp interfingers with Ka	
TITHONIAN	Jl (belemnites, ammonites, infusoria, pelecypods) Ma type area (plants) Jr type locality (pelecypods) Ja		Jo overlies Jr Ma underlies Ka (Samphire Marsh-Yarrie-Anketell area) M underlies Ka and Kk (Ural-Morris area)		Jd Jb Jm Jt Mr Derby - Fenton Fault - Joanna Springs Areas
KIMMERIDGIAN	(type locality) Ja Ammonites, pelecypods, brachiopods, ophiuroids "Broome	Ja, McLarty Hills (pelecypods)			Je M
OXFORDIAN	Buchia Beds" (Belemnites, pelecypods, forams, spores, microplankton) Ma (S.M.No.1) (spores)		Jj underlies Ja (Edgar Range)		
MIDDLE JURASSIC (Undifferentiated)			?Jj underlies "Broome Buchia Beds" at Broome and Fraser River		

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Fig. 79.—Ka—Anketell Formation; Kb—Broome Sandstone; Ke—Bejah Beds; Kf—Frezier Sandstone; Kg—Godfrey Beds; Kh—Hazlett Beds; Kj—Jowlaenga Sandstone; Kk—Kidson Beds; Km—Melligo Quartzite; Kp—Parda Formation; Ma—Callawa Formation; Mr—Cronin Sandstone; M—undifferentiated Jurassic and Cretaceous; Jd—Meda Formation; Je—James Sandstone; Jj—Jurgurra Sandstone; Jm—Mudjalla Sandstone; Jo—Mowla Sandstone; Jr—Jarlemai Siltstone; Jt—Millyit Sandstone.

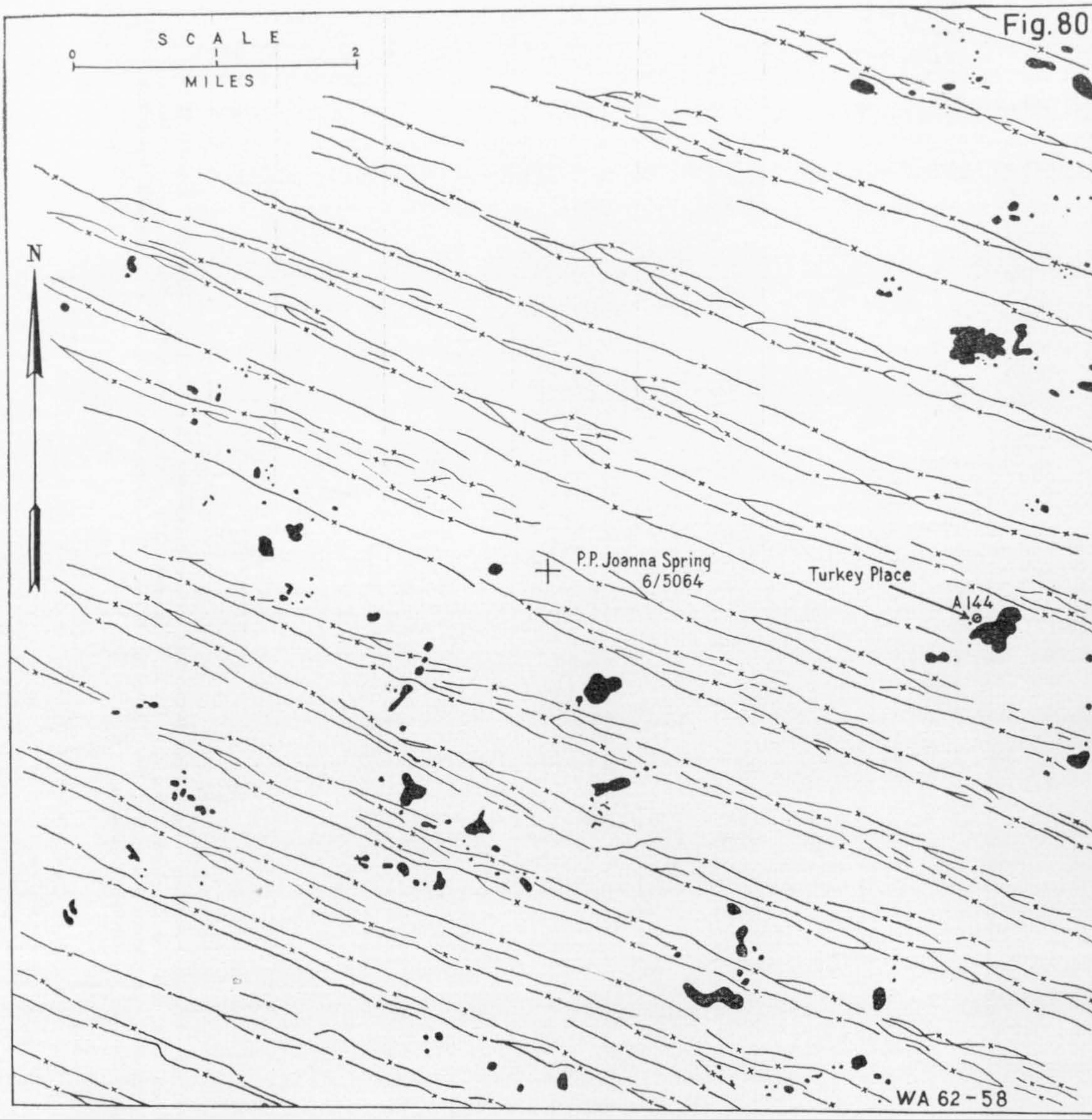


Fig. 80.—Isolated conical hills of undifferentiated Mesozoic sandstone in the Grabowsky Range (Joanna Spring Sheet area).

Liveringa Formation contains pelecypods, and some beds are like the Jurgurra Sandstone. We follow Brunnschweiler in regarding the Jurgurra Sandstone as Jurassic, but at the same time admit the possibility that it is Permian. Only five outcrops of the Jurgurra Sandstone are known; they are found in watercourses in the Edgar Range area, but are too small to form distinctive patterns in the air photographs.

The intervals 547 to 734 feet in Frome Rocks No. 1 and 30 to 206 feet in Frome Rocks No. 2 Bores are tentatively identified as Jurgurra Sandstone. These intervals consist of medium-grained thin-bedded and cross-bedded micaceous sandstone with some silty and conglomeratic lenses; some beds are ferruginous, others pyritic. Evans (*in* Elliott, 1960) recovered microplankton and spores from side-wall core 11 (655 feet) of Frome Rocks No. 1, and tentatively dated them as Lower to Middle Jurassic. He also indicated the possibility that the microfossils were derived from reworked Blina Shale.

The conglomeratic sandstone at the bottom of the Mesozoic succession of Broome No. 2 and Roebuck Bay No. 1 (*see* p. 120) contains Upper Jurassic spores, and underlies the equivalent of the Alexander Formation: it is therefore probably part of the Jurgurra Sandstone. Farther south, somewhere between Broome and Samphire Marsh, the Jurgurra Sandstone and the Callawa Formation probably interfinger. The Callawa Formation probably ranges to a younger age than the Jurgurra Sandstone (Figs. 78, 79), as the Jurgurra Sandstone is probably equivalent to the bottom half only of the Callawa Formation.

The sandstone that lies between the Jowlaenga Formation and dated Permian rocks in the interval 420 to 720 feet in the Fraser River No. 1 Bore (Fig. 68) is barren, and hence its identification is doubtful; it could be Jurgurra Sandstone, and this speculation is shown in Figures 68 and 78; or it could be Triassic or Permian. Crespin (1955, unpubl.) found glauconitized foraminifera and radiolaria in cuttings from this formation in Fraser River Corehole No. 1, but these are cavings from glauconitic rocks higher in the hole. No cores of Mesozoic rocks were taken in this hole.

Undifferentiated Mesozoic Rocks, Mainly Sandstone (M)

In comparing the Mesozoic rocks of the Canning Basin with those of central and eastern Arabia, Brunnschweiler (1954, p. 51) pointed out that

> 'The Arabian sequence appears to be more complete; however, the presence of additional (pre-Kimmeridgian) formations in the Canning Desert is quite possible. The Jurgurra Sandstone may only be the youngest of these.'

We regard many outcrops in the central and southern parts of the Canning Basin as Jurassic, but no firm evidence is available to prove this, and these outcrops have consequently been mapped as undifferentiated Mesozoic.

(i) *Outcrops at Battlement Rocks, Turkey Place, Newbery Peaks, Bremner Peak Area*

Seventy feet of medium to coarse-grained quartz sandstone and grit with minor siltstone and conglomerate are exposed at Battlement Rocks (*see* Appendix 2, Jo8) and Turkey Place. These rocks are cross-bedded, grey to red-brown, micaceous, and feldspathic. Their base is concealed, and their top eroded. No fossils have been found. They form isolated conical hills which are black in the air photographs (Fig. 80). Their air-photograph pattern is indistinguishable from that of the Alexander Formation at McLarty Hills (cf. Figs. 80 and 92), but as an indicator of similar rock composition the air photographs are misleading, because the Alexander Formation consists of interbedded sandstone and siltstone with only a few cross-bedded strata, whereas the exposures at Battlement Rocks are mainly strongly cross-bedded grits (cf. columnar sections in Figs. 77 and 81). Eight miles north-east of Battlement Rocks, at Yarrana Heights, outcrops with the same air-photograph pattern consist of thin-bedded medium-grained grey and red-brown micaceous quartz sandstone containing rare quartz grains 5 mm. across. None of these strata is cross-bedded. Guppy et al. (p. 59) note that in places the base of the Alexander Formation consists 'of a variable thickness of strongly cross-bedded medium and coarse quartz sandstone with intercalated lensing beds of white siltstone'. The Yarrana Heights section resembles parts of the Alexander Formation, and the Battlement Rocks section the base of the Alexander Formation. Forty miles of sand plain separates these outcrops from the nearest known Alexander Formation (at McLarty Hills), and whether this similarity indicates identity or is just coincidental cannot be proved. The Battlement Rocks section and the Millyit Sandstone are strikingly similar, but these outcrops are 160 miles apart.

Exposures similar to those at Yarrana Heights and Battlement Rocks were seen at Newbery Peaks, and in the Bremner Peak area (Fig. 81). At Newbery Peaks, cross-bedded coarse micaceous sandstone (*see* Appendix 2, Du2) with bluish quartz and some feldspar grains and thin pebble beds, and at A131, six miles north-east of Bremner Peak, strongly cross-bedded quartz grit and micaceous quartz sandstone (*see* Appendix 2, Sa7) recall the Battlement Rocks section. Most exposures at A184 and A186, 20 miles south and south-east of Bremner Peak, consist of micaceous quartz sandstone (*see* Appendix 2, Pe10) like that at Yarrana Heights. The sections at A184 and A186 lie apparently conformably beneath inferred Lower Cretaceous rocks, and hence are probably high in the Jurassic.

(ii) *Redknap Mound, Dowling Hills*

Farther south-east, the rocks mapped as undifferentiated Mesozoic are more poorly exposed, and their stratigraphical position is more doubtful. This doubt is indicated on the map, which shows the Redknap Mound (22° 14′ S, 126° 17′ E) (*see* Appendix 2, Wi3) exposures as Mesozoic or Permian.

A hundred and twenty miles south of Redknap Mound are the Dowling Hills (23° 45′ S, 126° 12′ E), a group of small low isolated hills in which are exposed 44 feet of fine to coarse, massive to flaggy quartz sandstone with very thin beds of claystone and shale (Fig. 81). The upper half of the exposed section contains clay pellets, and one section, Ry3, contains rare pebbles one inch across. Notable features of these rocks are the angular quartz grains and thin beds with large mica flakes (up to 5 mm.). No fossils were found. The base of the sandstone is not exposed, and the top is eroded. These rocks are different from those twenty miles east in the Ryan Range, which contain numerous worm tracks and ironstone concretions, and are tentatively assigned to the Permian. Dowling Hills lie only a few miles east of outcropping Bejah Beds (Lower Cretaceous), and though the junction was not seen, the rocks at Dowling Hills apparently underlie the Bejah Beds. Only 20 miles west of Dowling Hills, at Nipper Pinnacle, the Bejah Beds (claystone and shale) grade downward into sandstone, coarse in places, which therefore is also Cretaceous (probably Lower Cretaceous Kidson Beds). The rocks at Dowling Hills are post-Permian and pre-Aptian; accordingly they are mapped as undifferentiated Mesozoic.

Kidson Beds (Kk) (new name)

The name Kidson Beds is introduced for the medium- to coarse-grained quartz sandstone (*see* Appendix 2, Ur3) with grit bands that is exposed in the Ural and

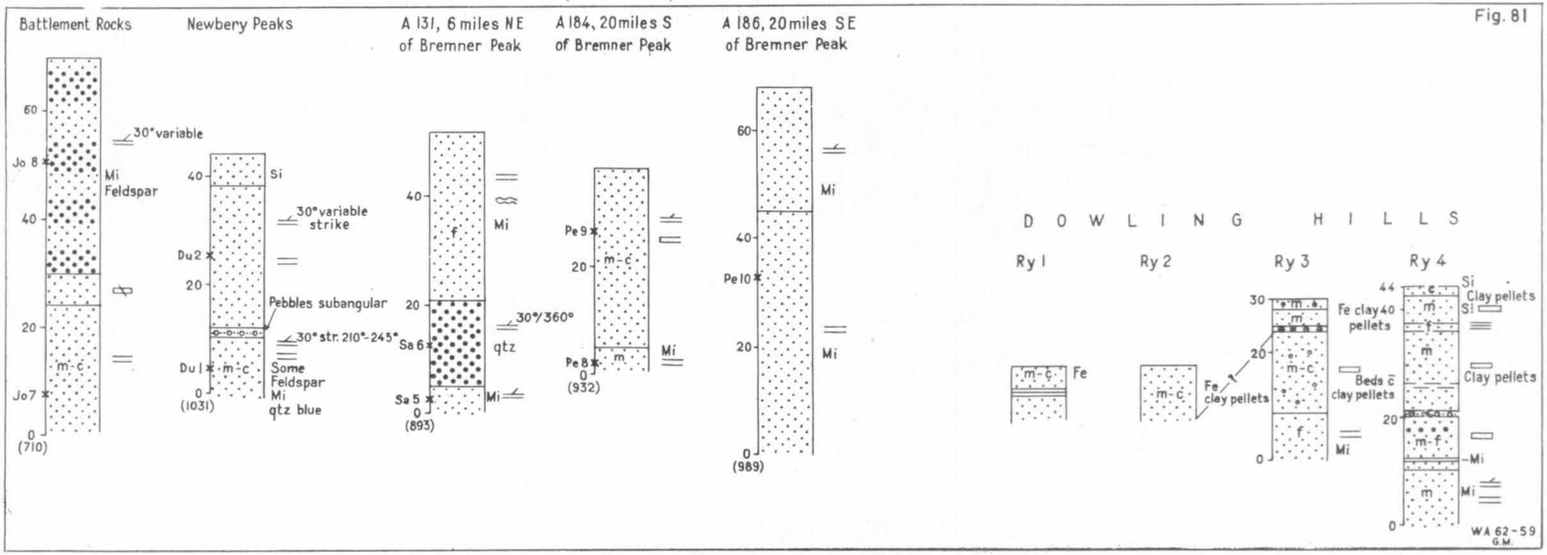


Fig. 81.—Undifferentiated Mesozoic sandstone, central Canning Basin.

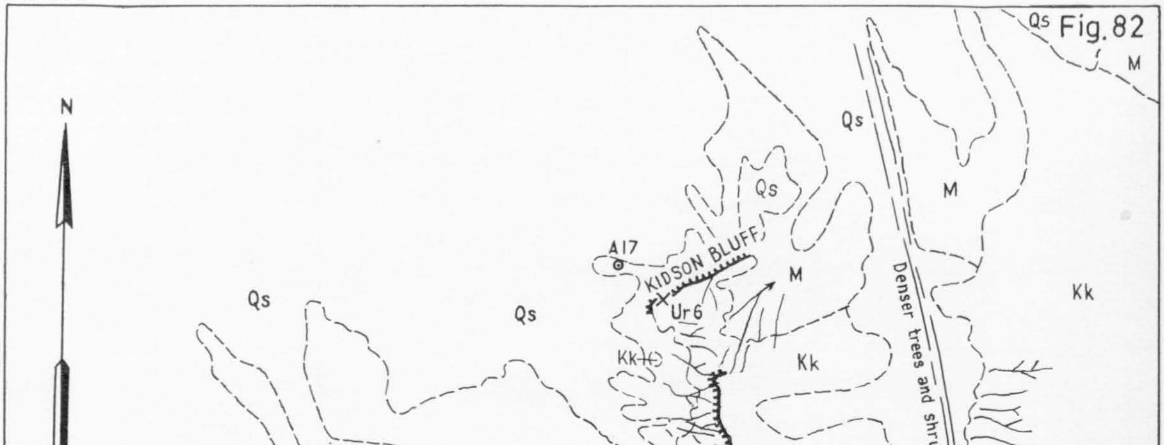


Fig. 82.—Kidson Bluff. Kk—Kidson Beds; M—undifferentiated Mesozoic rocks; Qs—sand.

Tabletop 4-mile Sheet areas. The rocks mapped as 'Anketell Sandstone' on the Tabletop 4-mile Geological map are Kidson Beds. The Kidson Beds crop out as 102 feet of sandstone and grit at Kidson Bluff (22° 16′ S, 125° 03′ E) (Figs. 82, 83). Other measured sections are at Reeves Knoll and T7 (Figs. 83, 86; Traves et al., p. 29). T7 was originally the type section of the 'Anketell Sandstone' but in our revision of this unit we have restricted the name to rocks in the Anketell 4-mile Sheet area and farther west, and reselected a type section within the type locality.

The Kidson Beds overlie undifferentiated Mesozoic rocks (Figs. 82, 85) except in the eastern part of the Ural 4-mile Sheet area, where they overlie undifferentiated Mesozoic or Permian rocks. The base of the Kidson Beds has not been seen in the field. The top is eroded except perhaps in the Morris 4-mile Sheet area, where the Kidson Beds are probably overlain by the Bejah Beds.

Good sorting, and structures such as scour-and-fill, ripple-mark, undulate bedding, and cross-bedding indicate deposition from strong currents.

The Kidson Beds have been eroded to mesas (Fig. 87) which are capped with a thick duricrust. Kidson Bluff (Fig. 82) is part of the northern scarp of a large dissected mesa of Kidson Beds that occupies most of the Ural Sheet area. Sand-filled dendritic valleys that divide into smaller channels extend back into the mesa. At its edge, fairly fresh Kidson Beds appear in the air photographs as a dissected light-grey strip between dark-grey duricrust above and knobby dark-grey undifferentiated Mesozoic sandstone below. At T7 (Fig. 86), where the relief is lower than it is at Kidson Bluff,

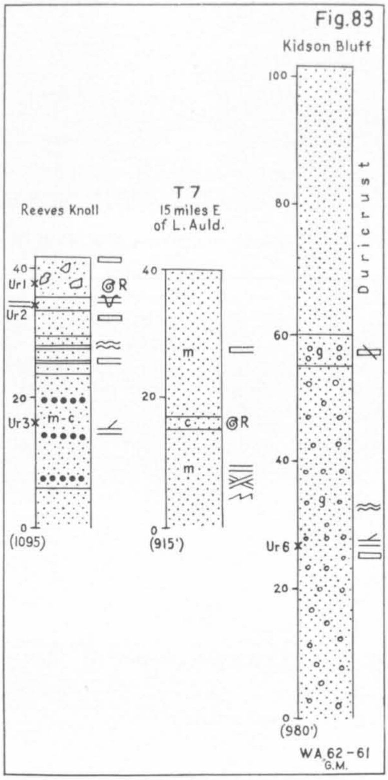


Fig. 83.—Sections of Kidson Beds.
R—*Rhizocorallium*.

the fresh Kidson Beds appear again in the air photographs as a light-grey to white strip between dark-grey duricrust above and light-grey sandy clay-soil with lines of vegetation below. In the Wardabunna Rockhole (Well 38) area (Fig. 88), 40 miles north-east of Kidson Bluff, and 10 miles north-west of Reeves Knoll, a dissected area of rock that appears almost white on the air photographs is interpreted as Kidson Beds, and the underlying darker rock as undifferentiated Mesozoic rocks. This outcrop is surrounded by an extensive area of lightly dissected dark-grey talus. The only fossil found in the Kidson Beds is *Rhizocorallium* at T7 (Traves et al., p. 29) and Reeves Knoll (Veevers, 1961). In the Canning Basin, *Rhizocorallium* probably indicates Lower Cretaceous.

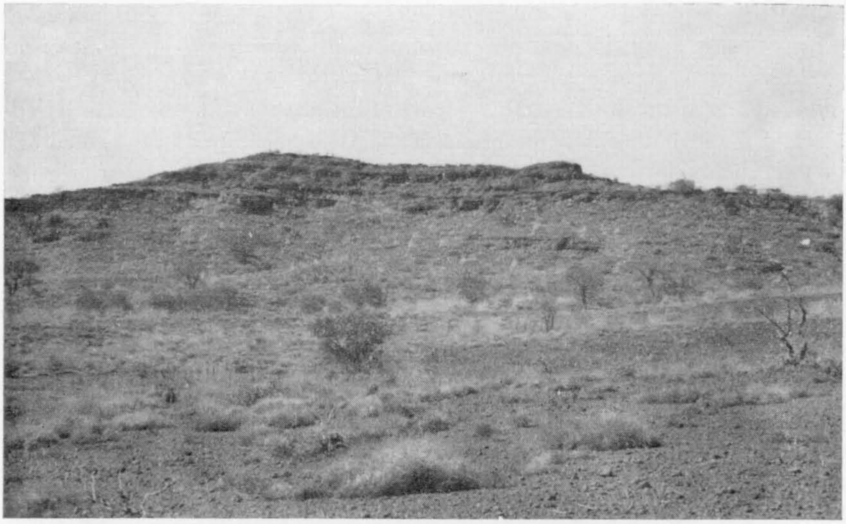


Fig. 84.—Looking north-east at Kidson Bluff.

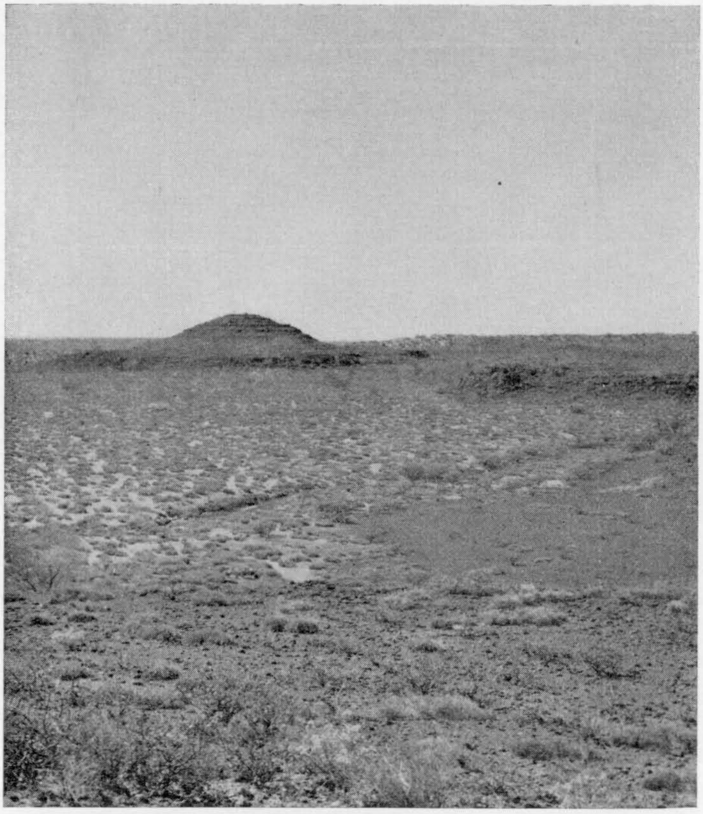


Fig. 85.—Kidson Beds overlying Mesozoic conglomerate near T6, east of Lake Auld.

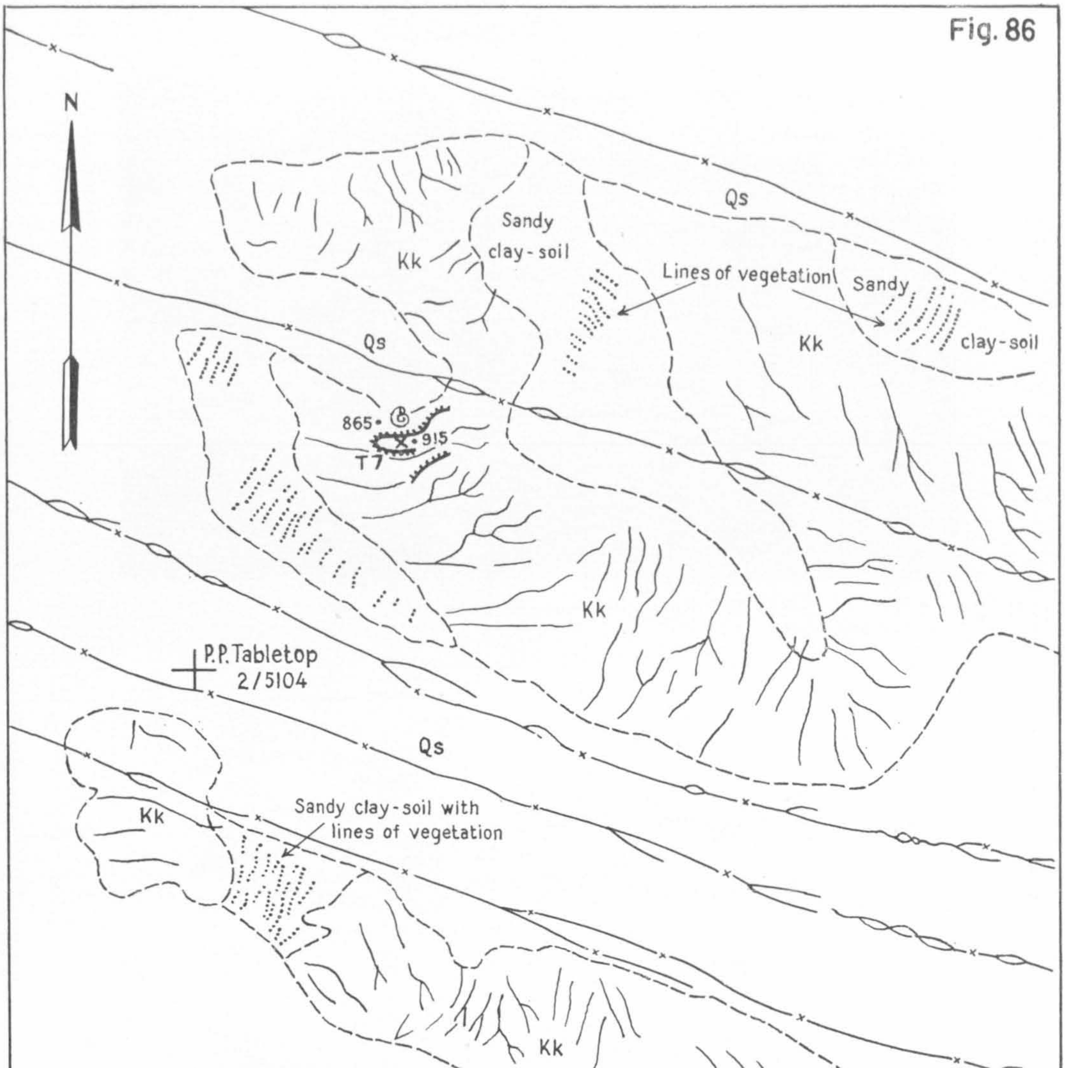


Fig. 86.—Kidson Beds (Kk) with *Rhizocorallium*, 15 miles east of Lake Auld.

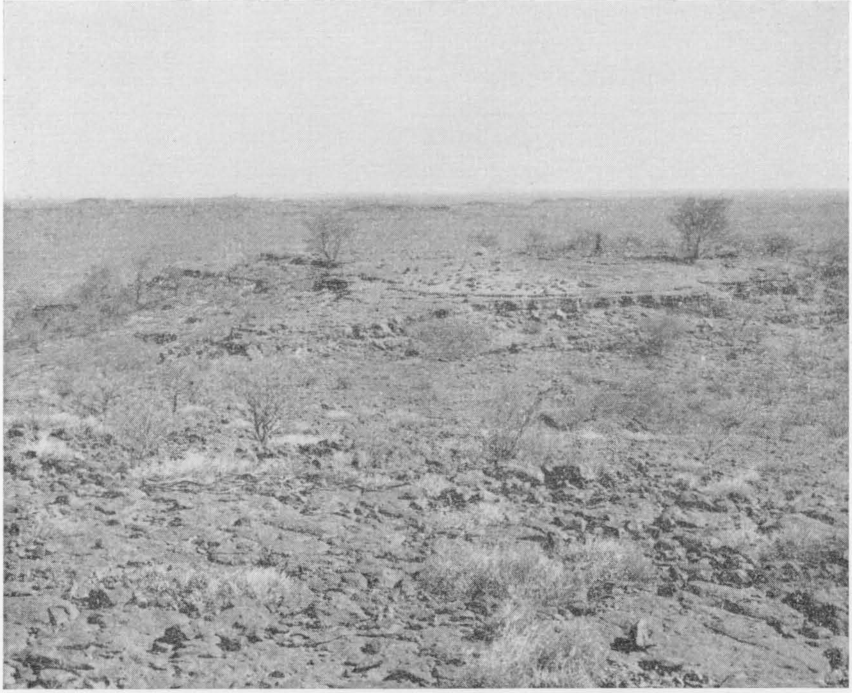


Fig. 87.—Kidson Beds near T6. Lake Auld on horizon.

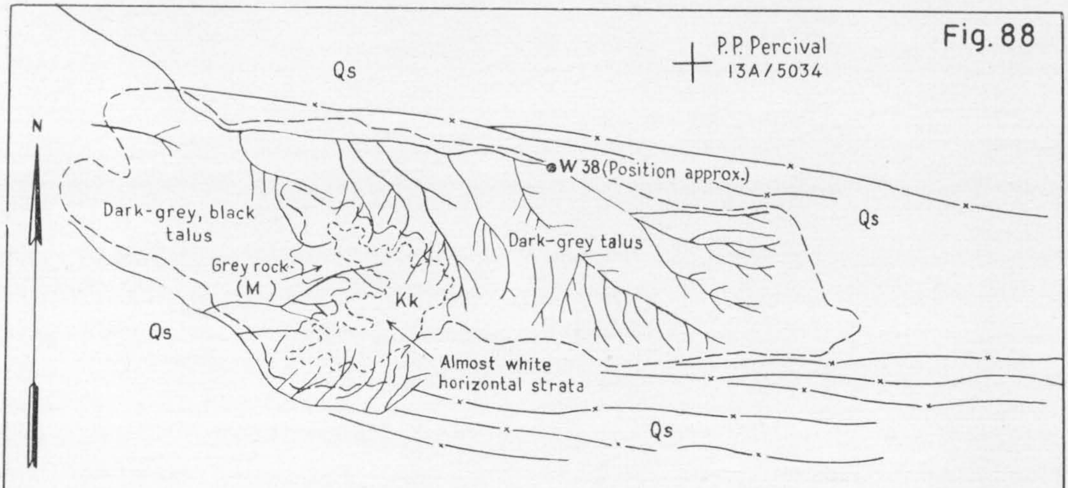


Fig. 88.—Kidson Beds (Kk) overlying undifferentiated Mesozoic rocks (M), Well 38 (Wardabunna Rock Hole), Canning Stock Route.

Barbwire Sandstone (Jb) (Guppy et al., p. 61)

The Barbwire, James, Mudjalla, and Millyit Sandstones are neither overlain nor underlain by other Mesozoic rocks. They are described under the heading of coarser-grained rocks at the bottom of the Mesozoic succession because they were probably continuous with these rocks. The Meda Formation, which overlies the Triassic Erskine Sandstone, is also described under this heading.

Guppy et al. introduced the name Barbwire Sandstone for the 71-foot-thick sandstone that unconformably overlies the Liveringa Formation in the Barbwire Range. The Barbwire Sandstone 'consists of fine to poorly sorted strongly cross-bedded to massive coarse sandstone, with some conglomerate and intercalated siltstone lenses; the siltstone is white, weathering to red-brown'. No fossils were found. Part of the type area, to which the Barbwire Sandstone is restricted, is shown in Figure 89, which is adapted from an unpublished Wapet map by R. M. Elliott and D. Roberts; the type section is M55. Guppy et al. report that 'south-east of the Barbwire Range the Barbwire Sandstone overlies the Liveringa Formation with a 5° unconformity'; this angular unconformity is well shown on the air photographs south and south-east of M56 (Fig. 89). The horizontal Barbwire Sandstone, identified on the air photographs by its light colour and the rough texture of fine jointing and drainage, fills the valleys between south-dipping cuestas of Liveringa Formation. The Barbwire Sandstone was probably not affected by the Fenton Fault, because the base of the formation lies at roughly the same level on either side of the fault. The fault coincides with part of the boundary between Barbwire Sandstone and Liveringa Formation, and the Barbwire Sandstone probably fills the valley formed by the underlying Liveringa Formation in the south, and the fault scarp in the north.

The outcrop of the Barbwire Sandstone, as seen in air photographs, resembles that of the boulder beds of the Callawa Formation at its type locality.

James Sandstone (Je) (Guppy et al., pp. 60, 108)

Guppy et al. introduced the term James Sandstone for

'all the coarse conglomeratic commonly ferruginous sandstone in the vicinity of the Fenton Fault and particularly at Mount James. . . . The James Sandstone disconformably overlies the Liveringa Formation, Noonkanbah Formation, and Poole Sandstone; the upper part of the James Sandstone is eroded.'

The formation is 107 feet thick at Mount James (Fig. 77, section MJ1).

'The formation includes quartz sandstone and fine conglomerate. The sandstone is well-bedded to thin-bedded, strongly cross-bedded, medium to coarse and porous. Beds of conglomerate may be six inches thick, but are characteristically in single layers. Individual beds and cross beds of sandstone are well-sorted, but the grain-size commonly varies largely from bed to bed, and the beds weather massively. The pebbles are rounded to subrounded, ranging from one-quarter to four inches in diameter, and consist of quartz, quartzite, and siliceous igneous rocks. In most places, the beds are very ferruginous. . . .

'No fossils have been observed in the sediments, but in lithology they resemble beds near the base of the Alexander Formation, where these are ferruginous. The Alexander beds are finer grained. The James Sandstone is regarded as being possibly equivalent to the Alexander Formation and therefore of Upper Jurassic age, and to represent a marginal Jurassic transgression.'

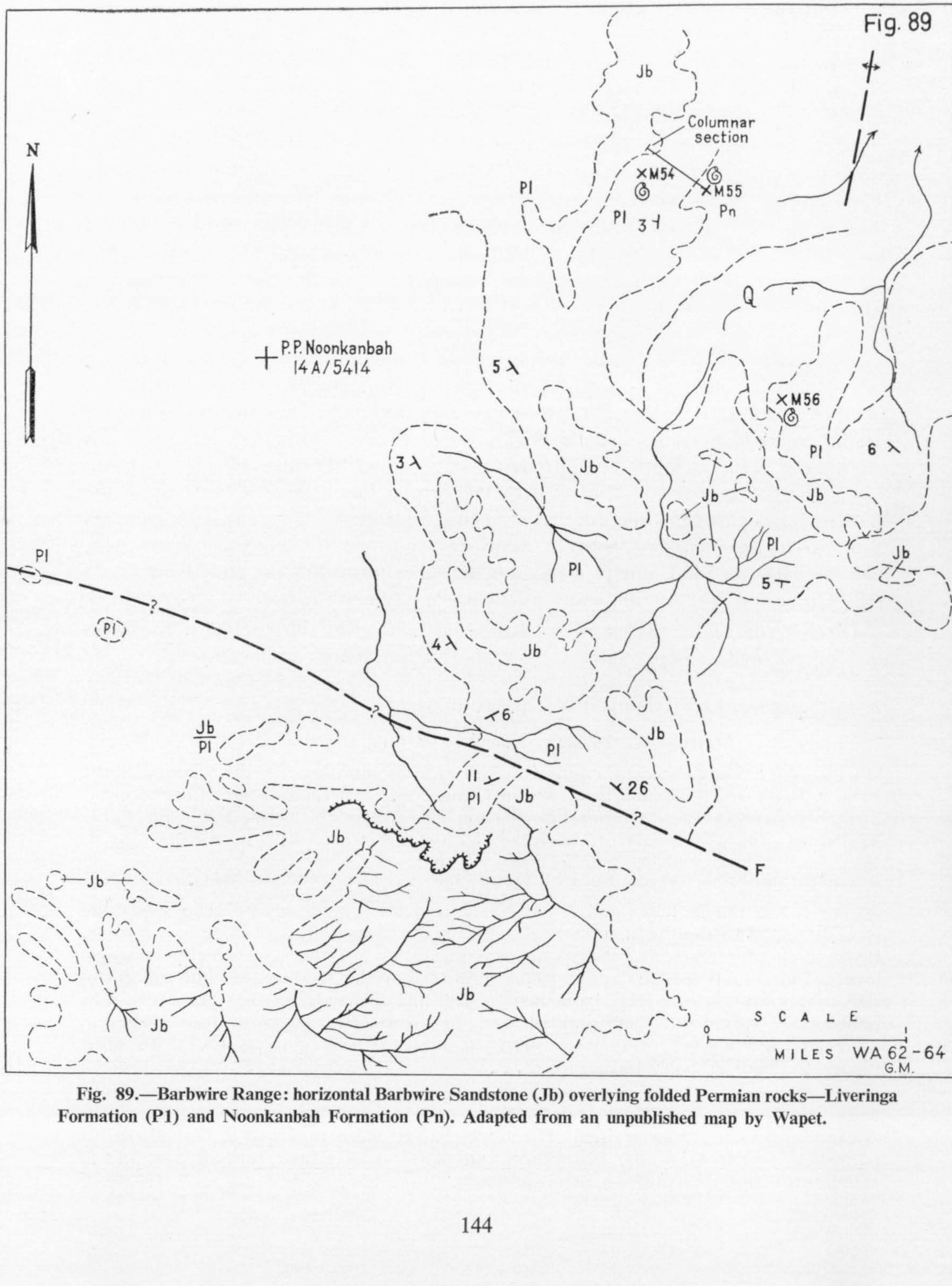


Fig. 89.—Barbwire Range: horizontal Barbwire Sandstone (Jb) overlying folded Permian rocks—Liveringa Formation (P1) and Noonkanbah Formation (Pn). Adapted from an unpublished map by Wapet.

Meda Formation (Jd) (Guppy et al., pp. 57-58; McWhae et al., pp. 103, 106)

Guppy et al. introduced the term Meda Formation 'for the conglomeratic sediments exposed on Meda and Kimberley Downs Stations and in the vicinity of Derby. . . . The greatest thickness observed is thirty feet at Trig H81' (17° 27′ S, 124° 17′ E; *see* Derby 4-mile geological map). According to Guppy et al., the Meda Formation unconformably overlies the Erskine Sandstone; McWhae et al. (p. 106) are more specific: 'the base rests on the Triassic Erskine Sandstone, probably with a low-angle unconformity'. According to McWhae et al., the type section is located at 17° 51′ S,* 124° 22′ E, in the Erskine Range. This is a regrettable choice of type section because the type section should be located in the type locality, which, for the Meda Formation, is obviously the Meda area.

The Erskine Sandstone is probably Lower Triassic, and the Meda Formation younger. 'It is thought to be either a marginal facies of one of the Upper Jurassic formations exposed elsewhere in the Fitzroy (Canning) Basin' (Casey, 1958(a), p. 7)—and from palaeogeographical considerations we are inclined to this view—'or a Cretaceous-Tertiary unit (which is its description in the [Derby] Sheet legend)'. For uniformity with the Fitzroy Basin maps, we too indicate the Meda Formation on the map as Cretaceous-Tertiary.

Millyit Sandstone (Jt) (McWhae et al., p. 90)

'The Millyit Sandstone is a sequence of crossbedded, grey to brown, micaceous, feldspathic, medium to coarse-grained sandstone with subordinate thicknesses of siltstone and conglomerate. It is named after the Millyit Range, where the type section, 47 feet thick, occurs at the head of Spring Creek (19° 12′ S., 125° 33′ 30″ E) [Fig. 77, M2]. The formation rests disconformably on the Liveringa Formation.'

The Millyit Sandstone is known from the type locality only, and it is preserved here probably because it occupies the trough of a broad syncline in the underlying Permian rocks.

'The James, Barbwire and Millyit Sandstones are similar isolated exposures of coarse-grained, cross-bedded sandstones and conglomerates which overlie Permian rocks. No fossils have been found in these units, but on lithological grounds they are placed tentatively in the Jurassic. None of them exceeds 100 feet in thickness.'

Mudjalla Sandstone (Guppy et al., pp. 58-59, 107; McWhae et al., p. 89)

Guppy et al. introduced the name Mudjalla Sandstone for the 'unsorted medium, coarse, and very coarse quartz sandstones, and lensing conglomerate beds, all strongly cross-bedded . . . that overlie the Liveringa Formation disconformably' in the area north-west of Mudjalla Yard and north-west along the south bank of the Fitzroy River. McWhae et al. state that the Mudjalla Sandstone 'overlies the Permian Liveringa Formation unconformably'. The top of the Mudjalla Sandstone is eroded. The thickest measured section of 135 feet is situated 5½ miles north-north-west of Mudjalla Yard (Fig. 77, section JM1). Rare plants, including conifers, are the only known fossils, and Guppy et al. believe that these indicate Jurassic. We regard the Mudjalla Sandstone as the equivalent of the Alexander Formation.

* This is misprinted in McWhae et al.

'*Broome* Buchia *Beds*' (Teichert, 1941, 1942; Reeves, 1951, p. 2491; McWhae et al., pp. 88-89)

'The Broome *Buchia* Beds' is the informal term for the 'shales with occasional intercalations of greensand and limestone, which lie at a depth of about 950 feet in the four artesian bores at Broome' (Teichert, 1941). These beds are 635 feet thick in No. 2 Bore, the only bore that penetrated the whole section. The informal term is retained because these beds are known only at Broome and Roebuck Bay; they probably occur also in a bore near Yeeda.

Broome No. 2 Bore (Fig. 68), the deepest of the four Broome bores, penetrated barren sandstone with thin pebble beds between the surface and 960 feet, fossiliferous glauconitic siltstone and sandy siltstone with thin medium to coarse sandstone beds in the lower half between 960 and 1555 feet, and 'white sand and boulders, sandy shale in last few feet' (driller's log) from 1555 to 1775 feet (total depth). The uppermost beds of the sandstone from the surface to 960 feet are part of the Broome Sandstone, the type section of which lies 4 miles westward, and because sandstone continues downward to 960 feet without a break, the whole section is identified as Broome Sandstone. The underlying glauconitic siltstone (960 to 1555 feet), the 'Broome *Buchia* Beds', contains *Buchia subpallasi* and *Belemnopsis* cf. *alfurica*. Teichert (1941) also records *Buchia subspitiensis* and *Belemnopsis* cf. *incisa* from similar levels in the same beds in Broome No. 3 Bore. According to Teichert, this fauna indicates Oxfordian or Kimmeridgian. Balme (1957, pp. 41-42) records his Microflora IIa from 1504 to 1543 feet in No. 2 Bore and from 1300 to 1357 feet and 1405 to 1427 feet in No. 3 Bore. Balme (p. 44) also found spores from 1001 to 1042 feet and from 1200 to 1211 feet in No. 3 Bore, but these were inadequate for dating. Cookson & Eisenack (1958, p. 69) found microplankton in the interval 1405 to 1427 feet in No. 3 Bore, and determined them as probably Oxfordian.

The Roebuck Bay No. 1 Bore (Crespin & Condon, 1956, unpubl.) penetrated unfossiliferous pebbly sandstone and thin beds of siltstone between 30 and 500 feet, glauconitic sandy siltstone with thin beds of glauconitic sandstone and greywacke between 500 and 1240 feet, and pebbly sandstone and thin beds of claystone between 1240 and 1570 feet. Permian and older rocks were penetrated below 1570 feet. Crespin & Condon record abundant foraminifera and radiolaria from cores in the interval of siltstone between 560 and 1240 feet. One of the foraminifera, *Lenticulina* cf. *audax*, also occurs in the Broome No. 2 Bore.

Following Reeves (1951, p. 2491), McWhae et al. correlate and identify the 'Broome *Buchia* Beds' of the Broome artesian bores with the Jarlemai Siltstone. Brunnschweiler (1954, p. 49) denied Reeves' identification because the '*Buchia* Beds' include limestone and glauconite, which are lacking in the type Jarlemai Siltstone, and the correlation because the type Jarlemai Siltstone is probably middle Tithonian. Glauconite and pyrite are found in practically all subsurface occurrences of Mesozoic finer-grained rocks, and their absence in outcrops is almost certainly attributable to removal by weathering. This removes Brunnschweiler's objection to Reeves' identification. Brunnschweiler (1954, p. 50) regarded the 'Broome *Buchia* Beds' as middle to upper Tithonian because he considered them to be the lower part of the glauconitic Langey

Beds (uppermost Tithonian). Both the Langey Beds and the 'Broome *Buchia* Beds' contain glauconite, but this does not confute the fossil evidence, which proves that the 'Broome *Buchia* Beds' (Oxfordian or Kimmeridgian) are older than the Langey Beds.

McWhae et al. (p. 88) follow Reeves further in regarding the lowermost exposed rocks in the Fraser River area as Jurassic. 'It also appears now that the siltstones exposed in the central part of the Fraser River Anticline can be correlated with the Jarlemai Siltstone.' This correlation is refuted by the Lower Cretaceous foraminifera determined by Crespin from the underlying section. If McWhae et al. mean to identify instead of correlate the Jarlemai Formation with the siltstone at Fraser River, we would agree, because both formations are probably parts of the continuous body of finer-grained rocks that occupy the middle of the Mesozoic succession.

Teichert (1942, pp. 33-34) tentatively determined *Buchia subpallasi* and *Belemnopsis* cf. *alfurica*, forms already determined in the Broome Bores, from 300 to 400 feet in a bore at Yeeda Station (according to Reeves, 1951, pp. 2491, 2494, and Casey, 1958(a), p. 5, probably Cockatoo Bore), and concluded 'that the strata . . . can be correlated with those which occur at Broome at a depth of 1,200 to 1,350 feet below sea-level'. The position of Cockatoo Bore is uncertain, but it is shown (Casey, 1958(a)) one mile south of outcropping Langey Beds.

Jarlemai Siltstone (Jr) (Brunnschweiler, 1954)

Brunnschweiler introduced the name Jarlemai Siltstone for the siltstone in the Edgar Range that conformably overlies the Alexander Formation, and is overlain, in places conformably, in others disconformably, by the Mowla Sandstone. The

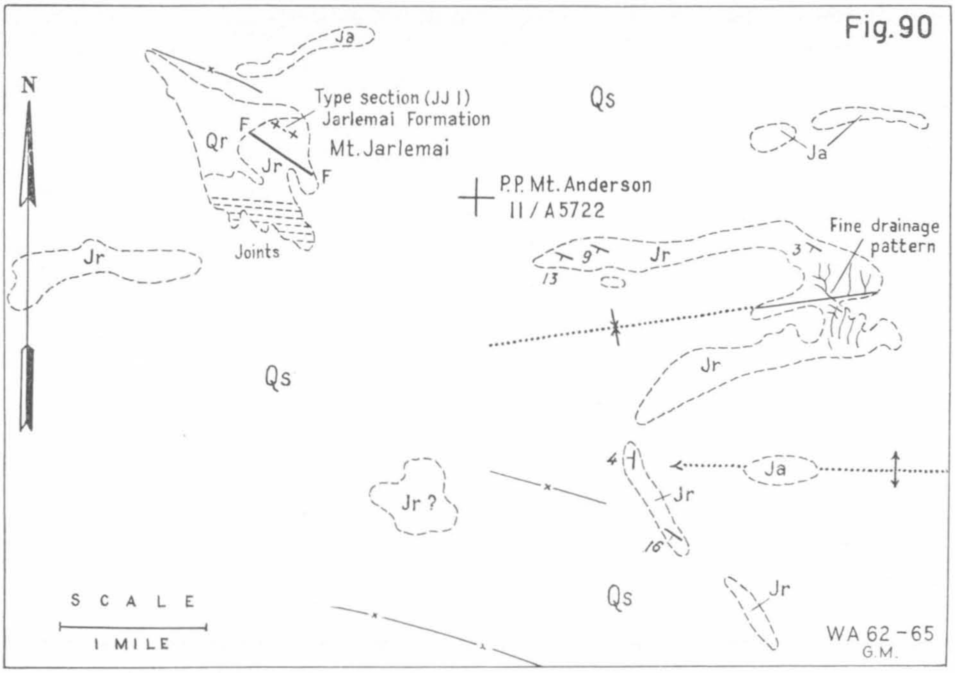


Fig. 90.—Mowla Sandstone (Jo), Jarlemai Siltstone (Jr), Alexander Formation (Ja), residual soil (Qr), and sand (Qs), at Mount Jarlemai, Edgar Range. Adapted from Mount Anderson 4-mile geological map.

Jarlemai Siltstone consists of poorly bedded pink, purple or white saccharoidal (or sandy) siltstone, silty sandstone, and, in places, interbedded ochreous claystone. The siltstone contains rare pebbles up to four inches long. These rocks weather buff or brick-red. The type section is Mount Jarlemai (Fig. 77, section JJ1; Fig. 90). In the Edgar Range, the Jarlemai Siltstone is about 300 feet thick. The only fossils so far found in the type locality are rather rare pelecypods, which, according to Brunnschweiler, indicate middle Tithonian.

The Jarlemai Siltstone is carved into a sheer and rugged cuesta in the western half of the Edgar Range, and numerous mesas in the eastern half. The bold weathering forms of the Jarlemai Siltstone, and their light-grey tone on air photographs, contrast with the smooth forms and darker tones of the Alexander Formation. At Mount Jarlemai (Fig. 90), the siltstone is exposed in imposing mesas, the surfaces of which are finely jointed or finely etched by drainage. Four miles north-north-west of Goorda Tower (Fig. 91), most of the Jarlemai Silstone has been eroded away, and only small residuals, some of which have a perfectly flat top, remain. The smaller residuals (less than 300 yards long) are almost white on air photographs, and resemble the white rocks that cap darker rocks in the eastern part of the McLarty Hills Sheet area (*see* Fig. 94).

The Jarlemai Siltstone identified in Frome Rocks No. 1 Bore (40 to 307 feet), 40 miles north-north-west of the type section, contains a little glauconite and much pyrite, and consists mainly of clay and claystone. Balme (*in* Elliott, 1960) found microplankton, pollen, and spores in a sample from the nearby water-well (145 to 165 feet) and reported that the microplankton suite appears distinct from that of the 'Broome *Buchia* Beds'. A species of spore possibly indicates uppermost Jurassic or Lower Cretaceous. This supports Brunnschweiler's determination of the Jarlemai Siltstone in the type area (in which Frome Rocks can broadly be included) as mid-Tithonian.

None of the many attempts at precisely identifying the Jarlemai Siltstone outside the type locality (Edgar Range/Frome Rocks) has been satisfactory. First, Brunnschweiler suggested, on lithological evidence alone, that Mount Phire consists of Jarlemai Siltstone. Later evidence shows that Mount Phire is better regarded as Parda Formation. Nevertheless, in the broad sense, the rocks at Mount Phire may be regarded as Jarlemai Siltstone, because the siltstone and the Parda Formation are parts of the body of finer-grained rocks that form the middle of the Mesozoic succession. McWhae et al.'s correlation and identification of the Jarlemai Siltstone with the 'Broome *Buchia* Beds' and with siltstones in the Fraser River area have already been discussed.

Alexander Formation (Ja) (Brunnschweiler, 1954, pp. 47-49)

Brunnschweiler introduced the name Alexander Formation for the brick-red to buff and brown fine to coarse quartz sandstone interbedded with white to pink siltstone and silty shale that disconformably overlies the Jurgurra Sandstone in the Edgar Range. Many beds are cross-bedded and ripple-marked. The type section is Mount Alexander. According to McWhae et al. (p. 88), the complete formation in the type locality is 150 to 230 feet thick. Ammonoids, pelecypods, and ophiuroids occur

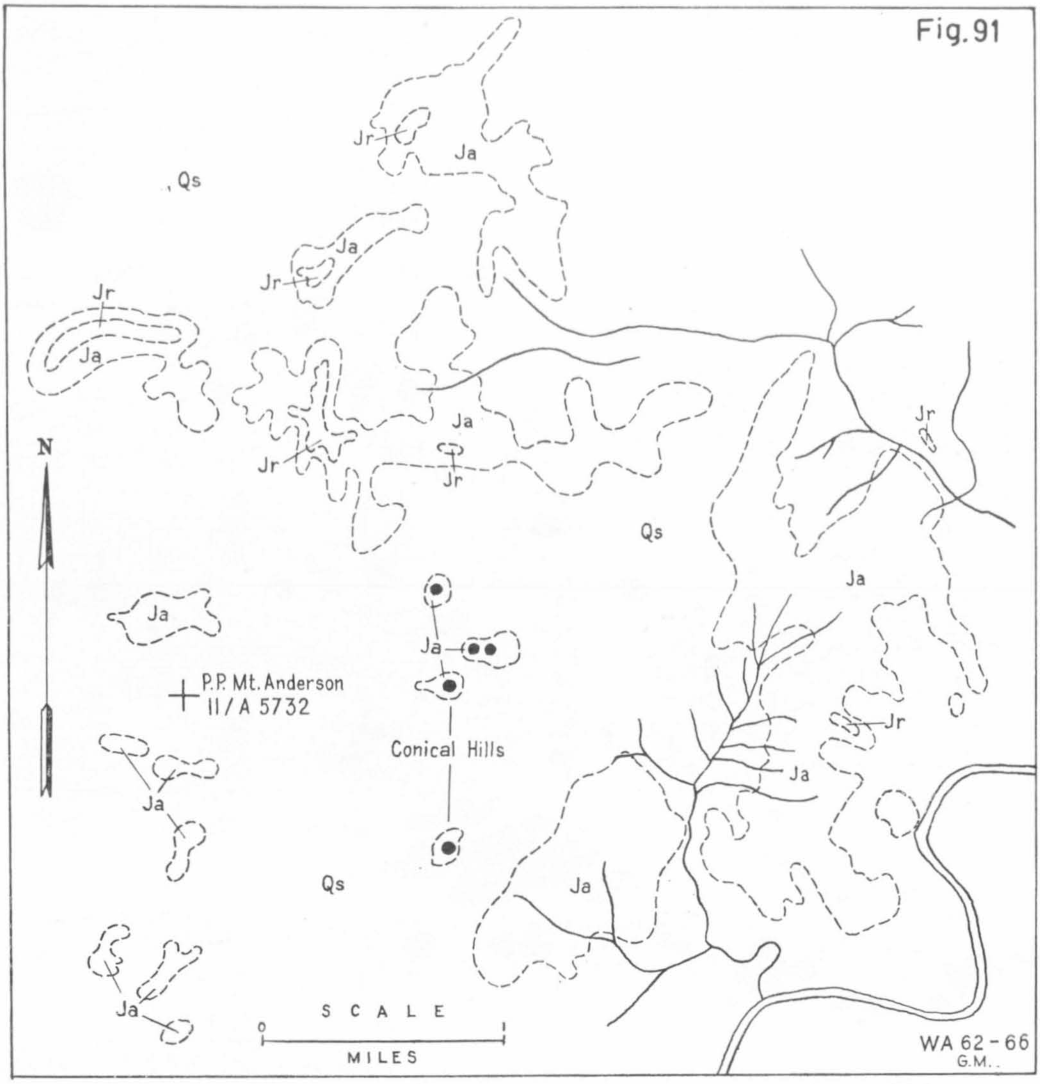


Fig. 91.—Jarlemai Siltstone (Jr) overlying Alexander Formation (Ja) in the Edgar Range, 4 miles north of Goorda Tower. Adapted from Mount Anderson geological map.

abundantly in the outcropping Alexander Formation, and, according to Brunnschweiler, indicate Kimmeridgian to early Tithonian. The Alexander Formation identified in Frome Rocks No. 1 Bore from 307 to 547 feet contains microplankton and spores, which Evans (*in* Elliott, 1960) determined as Middle or Upper Jurassic. From 390 to 411 feet in the nearby water-well, Balme recovered microplankton and spores, which he determined as probably Upper Jurassic.

In the type locality (Figs. 90, 91), the Alexander Formation is exposed in smooth dissected mesas and buttes that are dark-grey to black on the air photographs. Bedding is visible in only a few mesas. A short distance from the mesas, small black

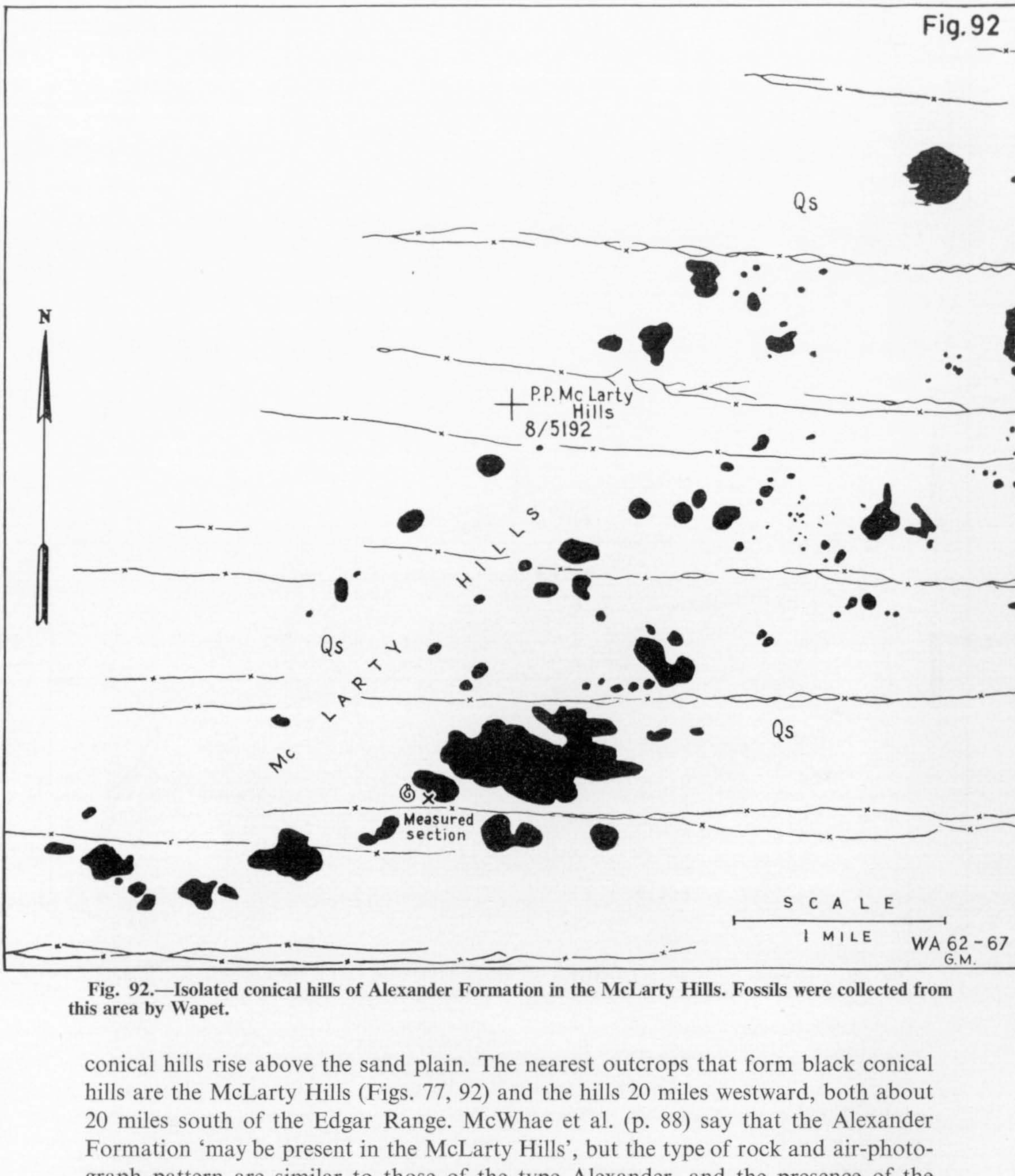


Fig. 92.—Isolated conical hills of Alexander Formation in the McLarty Hills. Fossils were collected from this area by Wapet.

conical hills rise above the sand plain. The nearest outcrops that form black conical hills are the McLarty Hills (Figs. 77, 92) and the hills 20 miles westward, both about 20 miles south of the Edgar Range. McWhae et al. (p. 88) say that the Alexander Formation 'may be present in the McLarty Hills', but the type of rock and air-photograph pattern are similar to those of the type Alexander, and the presence of the pelecypod *Meleagrinella maccoyelloides* (*in* Dickins, Appendix 4) in the Edgar Range, McLarty Hills, and 20 miles westward leaves no doubt that McLarty Hills consist of Alexander Formation. The same air-photograph pattern reappears at Battlement Rocks, but the strongly cross-bedded grits and sandstones here cannot be identified as Alexander Formation. One hundred miles westward, at Colorado Outcrop, the air-photograph pattern probably indicates either Callawa Formation or Alexander Formation.

Langey Beds (Jl) (Guppy et al. 1952, p. 112; Brunnschweiler, 1954, 1957, 1960)

'On the left bank of the lower Fitzroy River, at Langey Crossing (Lat. 17° 40′ S; Long. 123° 33′ E), a small and isolated outcrop has been quarried for road material. The exposed rock consists of nodular, greenish to white, sandy and glauconitic, siliceous siltstone interbedded with thin bands of white fine sandy micaceous shale. Thin sections show the siltstone to be composed of a very fine-grained argillaceous groundmass (50% to 70%) in which numerous globular glauconite grains and angular quartz fragments are embedded. The average diameter of the glauconite grains is about 0.2 mm. (maximum 0.5 mm.). The quartz particles are about equal in number and size to the glauconite grains. The siltstone is partly an organic deposit because it contains numerous more or less well-preserved tests of radiolaria and infusoria.' (Brunnschweiler, 1957, p. 5.)

The marine fossils of the Langey Beds indicate late Tithonian. Water bores near Langey Crossing probably penetrated at least 100 feet of Langey Beds.

Limestone in the Fraser River (Jf) (Guppy et al., 1952, p. 112; Brunnschweiler, 1957, p. 6)

Small outcrops of unfossiliferous nodular limestone have been found on the lower Fraser River. The limestone underlies the nearby exposed Jowlaenga Formation. Because the Jowlaenga Formation continues some hundreds of feet below the surface in this area (Fig. 68), the limestone probably forms part of this formation. Brunnschweiler pointed out the possibility that the limestone is continuous with the 'hard bands' and thin beds of nodular limestone encountered in the 'Broome *Buchia* Beds' between 960 and 1150 feet in the Broome Bores; these bands lie above the actual beds that contain *Buchia* and *Belemnopsis*.

Jowlaenga Formation (Kj) (Brunnschweiler, 1957, p. 7, 1960; McWhae et al., p. 106)

Brunnschweiler introduced the name Jowlaenga Sandstone for the lowermost Cretaceous formation exposed in the Fraser River area and in sections on the east coast of Dampier Peninsula. McWhae et al. amended the name to Jowlaenga Formation because siltstone is a major constituent. According to Brunnschweiler,

'In the type area the Jowlaenga Sandstone consists of marine quartz sandstone, fine to medium-grained, and commonly ferruginous. Thin sections show that in general the quartz grains are angular; the sediment is not well sorted. Detrital feldspar and mica flakes are present, but common only in the fine-grained sandstone. The formation is generally wellbedded but contains a few cross-bedded strata which occur irregularly at several levels in the sequence. The provenance of the Jowlaenga Sandstone is essentially that of a near-shore deposit. Grain-size generally decreases towards the north: the sequence at North Cliffs, Valentine Island, and in the section along the east coast consists almost exclusively of fine-grained sandstone and sandy siltstone.'

The maximum exposed thickness is about 250 feet in the Fraser River area; 420 feet were penetrated in Fraser River No. 1 Bore, and, because the bore spudded into rocks about 100 feet stratigraphically below the base of the nearest exposure, the total thickness in round figures is 750 feet (*see* Fig. 68). Brunnschweiler says that 'its thickness probably increases towards the west, where it may attain 500-700 feet in the Broome Bores'. Brunnschweiler is referring here to the possible lateral equivalent of the Jowlaenga Formation, the Broome Sandstone, and not to the Jowlaenga Formation itself.

The Melligo Quartzite caps the Jowlaenga Formation in both areas of outcrop (Fig. 93). The Melligo Quartzite weathers into mesas bounded by steep, almost vertical, cliffs; on the air photographs it is white, probably because it is sparsely vegetated compared with the surrounding pindan country. Near Reeves Hill, the Melligo Quartzite is crossed by widely spaced east-trending joints. The underlying Jowlaenga Formation is exposed in low rises or cliffs and is crossed by widely spaced east-trending joints, weaker than those in Melligo Quartzite; it is medium to dark-grey in air photographs, and is covered by dense vegetation.

The relationship between the Jowlaenga Formation and the Melligo Quartzite is not clear. According to Brunnschweiler, 'the absence of the formation [Melligo] in the western portion of the Peninsula is believed to be due to non-deposition. This is in accordance with the observed erosional unconformity at the base of the Quartzite in the eastern and central portion of the Peninsula.' Opposed to this, McWhae et al. (p. 107) claim that 'a disconformable junction between these formations [Jowlaenga and Melligo] has been observed only near Swan Point at the extreme north end of Dampier Land'. Swan Point is 2½ miles north-west of Apex Island, where the Melligo Quartzite overlies Precambrian rocks, and a disconformity at Swan Point could be expected because the shore-line during deposition of the Melligo Quartzite was close by.

Brunnschweiler found belemnites, pelecypods, ammonites, and worm (?) tracks in exposures of the Jowlaenga Formation in the type locality, and these indicate Neocomian or uppermost Jurassic. According to White (Appendix 6), plants indicate Jurassic or Lower Cretaceous.

Fraser River No. 1 Bore and Fraser River No. 1 Corehole spudded into rocks about 100 feet stratigraphically below nearby outcrops of Jowlaenga Formation (Fig. 68). Fraser River No. 1 Bore penetrated sandy siltstone and silty, sparsely glauconitic sandstone between the surface and 420 feet, sandstone with thin beds of siltstone and claystone between 420 and 720 feet, and Permian and Carboniferous sedimentary rocks below 720 feet. Crespin (1956(a), unpubl.) found abundant Lower Cretaceous foraminifera between 40 and 204 feet, and Balme (pers. comm.) determined spores from 195 to 204 feet (probably Lower Cretaceous) and from 400 to 409 feet (probably Upper Jurassic). The Mesozoic section in Fraser River No. 1 Corehole, as indicated by cuttings between 438 and 677 feet, differs only from that in Fraser River No. 1 Bore in its higher content of glauconite, which is present in grains and in replacement of tests of radiolaria and some foraminifera (Crespin, 1955, unpubl.).

The silty sandstone and sandy siltstone almost certainly continue upwards into the exposed Jowlaenga Formation, and because the fossils in the bore and the nearby outcrops both indicate the same age, at least the uppermost fossiliferous 204 feet of the bore are part of the Jowlaenga Formation. The absence of glauconite and

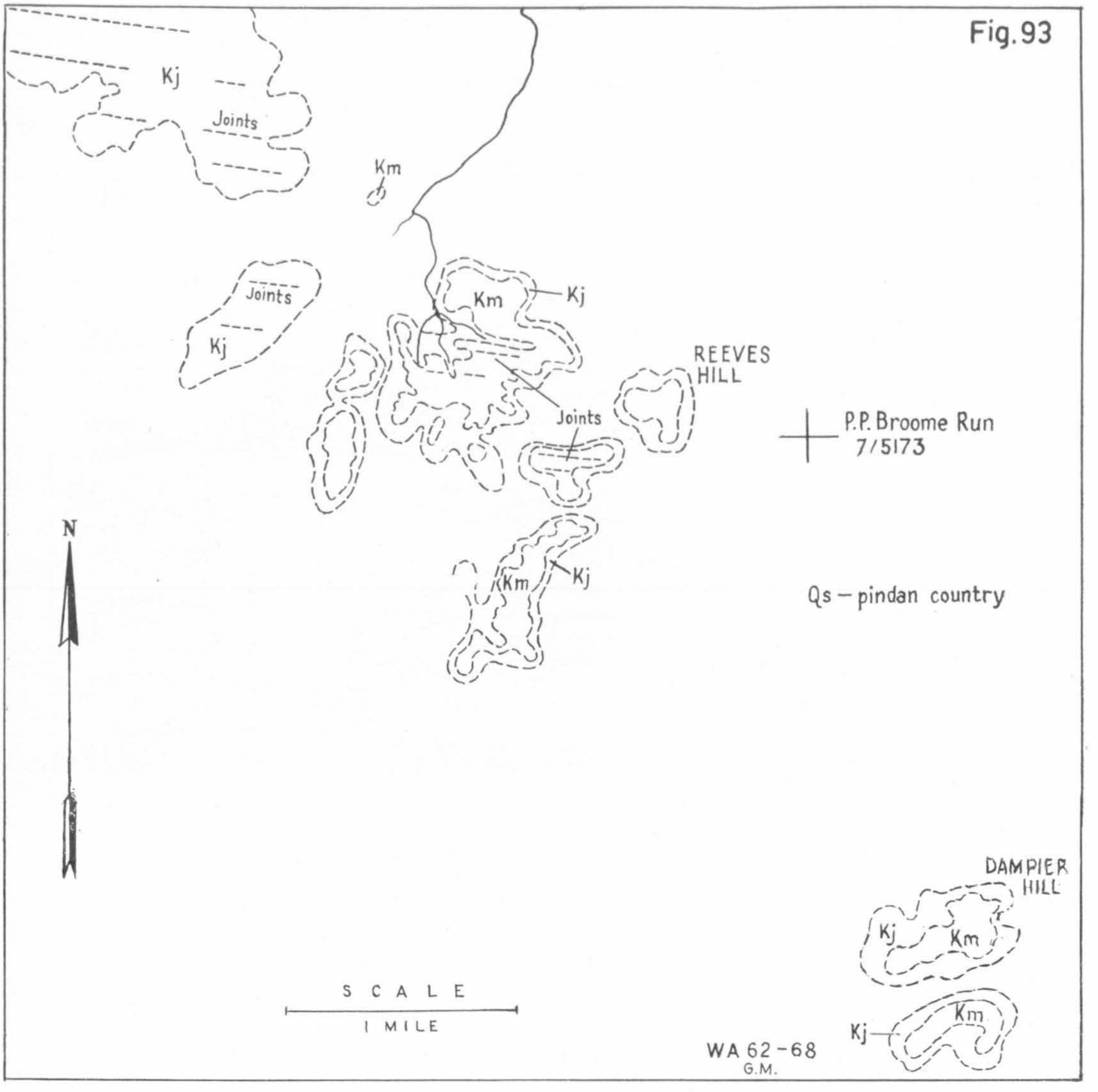


Fig. 93.—Melligo Quartzite (Km) overlying Jowlaenga Formation (Kj) in the Fraser River area.

pyrite in the outcropping Jowlaenga Formation is attributed to deep weathering. The rocks between 204 and 420 feet are little known; they may be continuous with the rocks above, and hence be part of the Jowlaenga Formation. The glauconite indicates neritic deposition and the poor sorting and angular quartz grains deposition without re-working; taken together, these features indicate deposition on a sinking floor.

McWhae et al.'s correlation of the siltstones exposed in the central part of Fraser River Anticline with the Jarlemai Siltstone is discussed on p. 147. The evidence provided by molluscs, foraminifera, and spores indicates that the Jowlaenga Formation is Neocomian, and possibly ranges into the uppermost Jurassic.

The foraminifera in Fraser River No. 1 Bore are *in situ*: cores were taken at 100-foot intervals downwards from a depth of 195 feet in the Mesozoic section, and the only core which contains foraminifera is Core 1 (195-204 feet). Cuttings containing foraminifera all come from higher in the bore.

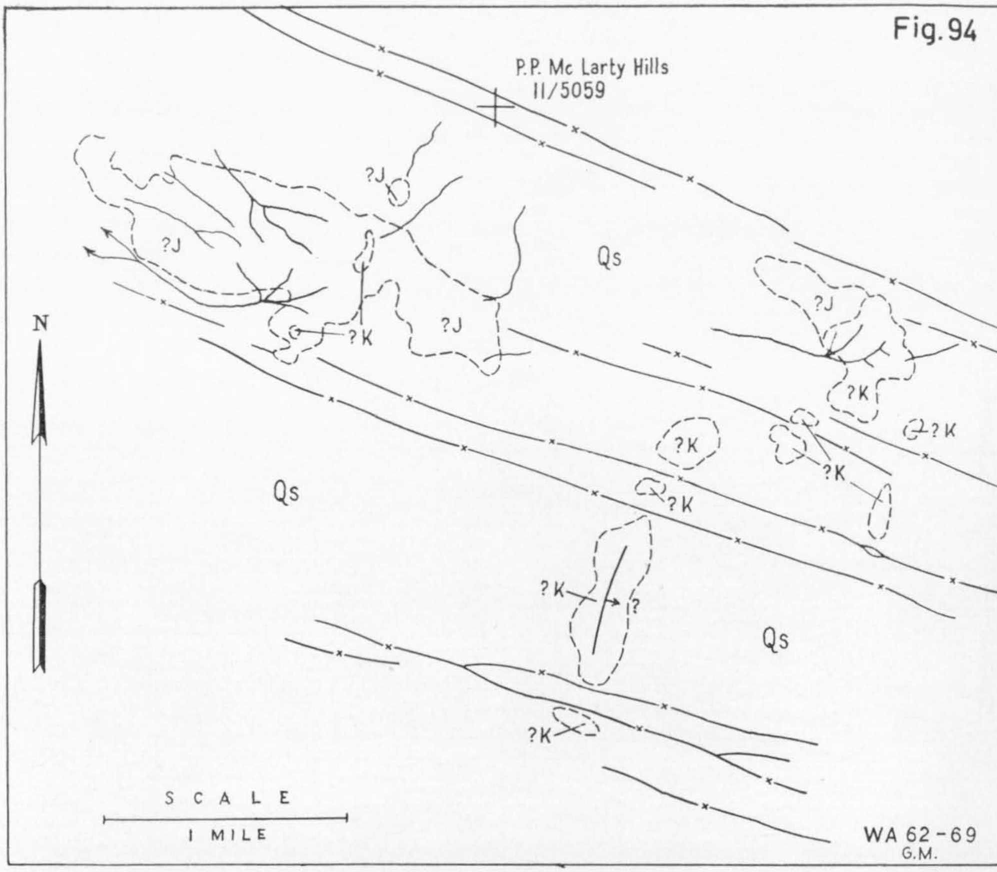


Fig. 94.—Cretaceous (K) rocks overlying Jurassic (J) rocks 35 miles east-south-east of McLarty Hills.

Probable Cretaceous Rocks in the eastern half of the McLarty Hills Sheet Area (K)

Four small isolated exposures of suspected Cretaceous rocks are found in the McLarty Hills Sheet area. Three exposures probably show Cretaceous overlying Jurassic rocks, and the fourth Cretaceous alone. The air-photograph interpretation of the exposure 35 miles east-south-east of McLarty Hills is given in Figure 94. The western outcrop and part of the eastern outcrop form low dark hills, and break into low dark rubble—they are either Jurassic (Alexander Formation) or, less likely, Permian; two small conspicuously white hills, 100 yards across, cap the dark rock, and are probably Cretaceous (Anketell or Parda Formation) or Jurassic (Jarlemai Siltstone). Most of the eastern outcrop has an air-photograph pattern like that of the type Parda Formation, and dissimilar to that of the type Jarlemai Siltstone. The

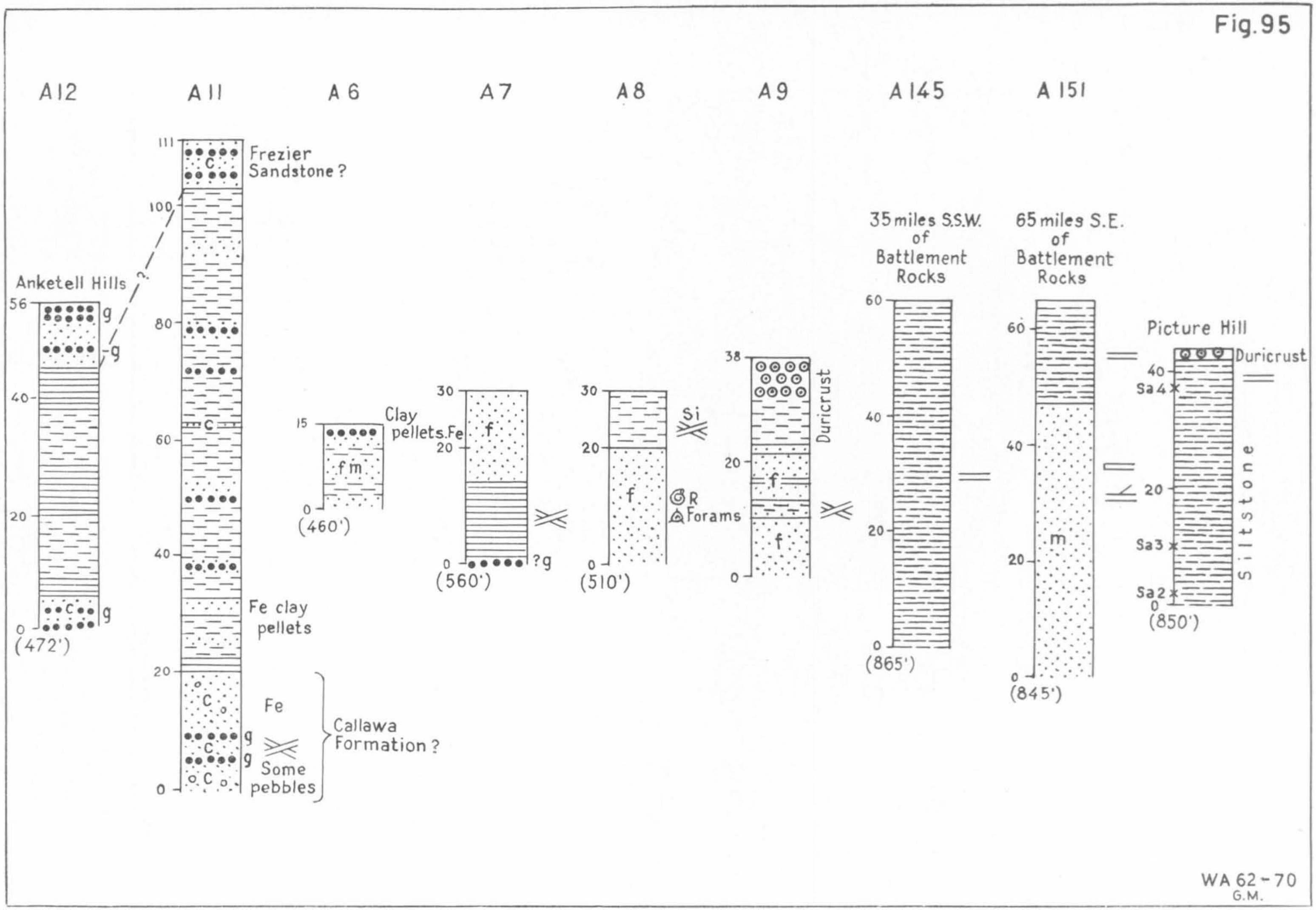


Fig. 95.—Sections of Anketell Formation. See Anketell geological map for localities of A6-9, 11, 12.

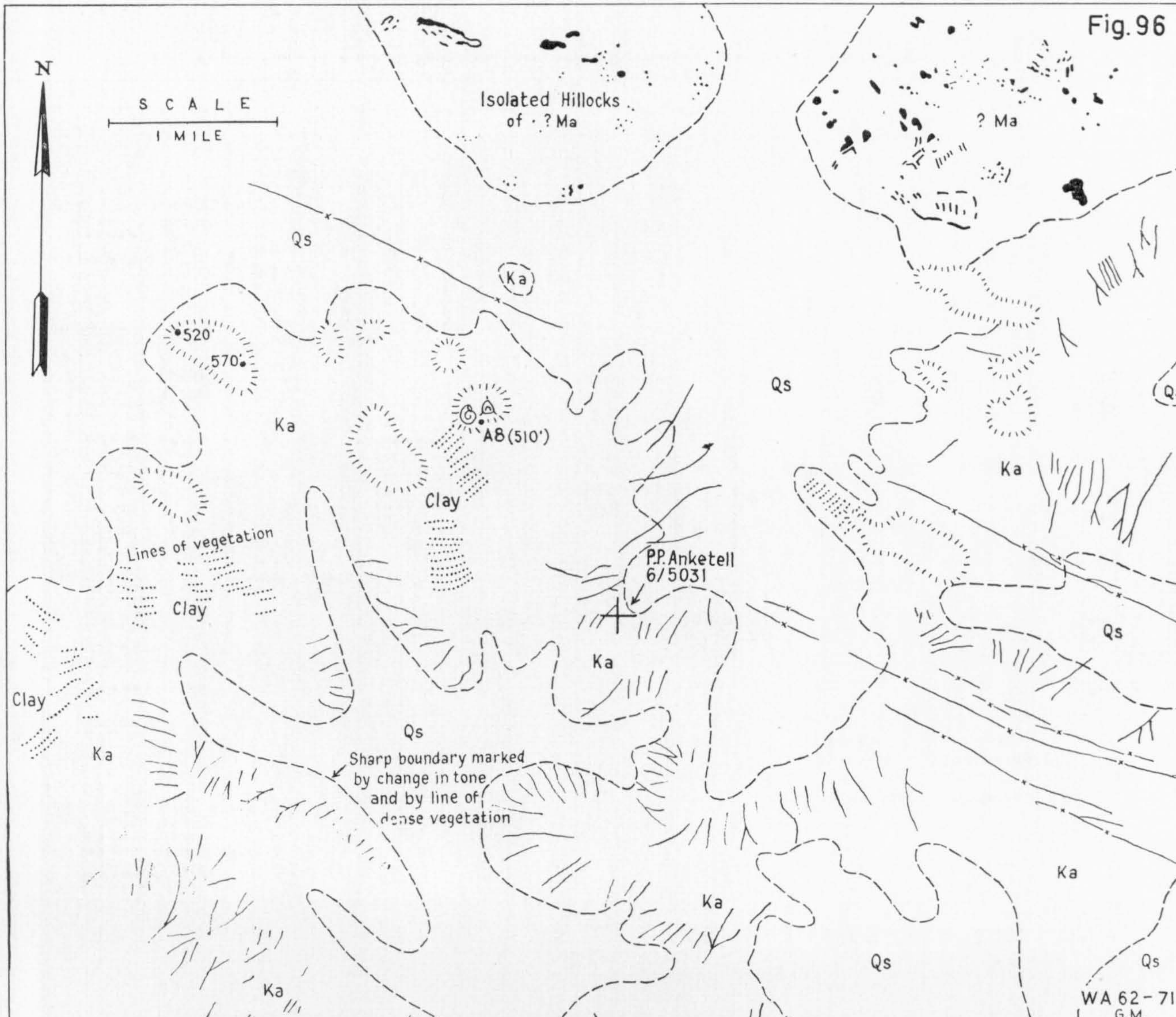


Fig. 96.—Anketell Formation (Ka) and probable Callawa Formation (Ma), 10 miles west of Anketell Hills.

rocks of the eastern outcrop probably dip gently eastward, and the probable Jurassic rocks are only exposed at the area shown in Figure 94 because they occupy the core of a broad anticline.

Anketell Formation (Ka) (Traves et al., pp. 28-30, amended)

Traves et al. introduced the name Anketell Sandstone for a formation that 'consists of sandstone and shale, with several small beds or lenses of fine conglomerate. The name is derived from the Anketell Four Mile Sheet.' As type section they chose a hill, T7, that lies 100 miles south-east of the boundary of the Anketell 4-mile Sheet area. A re-examination of the Anketell Sandstone shows that the rocks in the type locality, the Anketell 4-mile Sheet area, are not identifiable with those in the type section (T7). The following revision is therefore proposed. The Anketell Formation consists of claystone, shale, siltstone and sandstone, with thin beds of grit. The thickest known exposure of 83 feet is at A11 (Fig. 95) in the Anketell 4-mile Sheet area, and because all the lithologies of the formation are represented, A11 (20° 26′ 30″ S, 122° 32′ 30″ E) is selected as type section. A11 replaces T7, which forms part of the Kidson Beds, described above.

Outcrops of the Anketell Formation overlie several formations: undifferentiated Jurassic (either Alexander or Callawa Formation) in the Munro Sheet area, the Callawa Formation in the Yarrie, Anketell, and Port Hedland Sheet areas, undifferentiated Mesozoic sandstone in the Anketell, Joanna, and Sahara Sheet areas, undifferentiated Permian rocks and undifferentiated Mesozoic sandstone in the Paterson Range Sheet area. The base of the Anketell Formation has been seen only in the Anketell and Yarrie Sheet areas, and here it overlies the Callawa Formation with apparent conformity. The exposed top of the Anketell Formation is eroded, except possibly at A11, where it appears to be conformably overlain by probable Frezier Sandstone.

The Anketell Formation varies in composition considerably from one outcrop to another (Fig. 95). Two-thirds of the type section consists of claystone and shale, and the remainder of interbedded medium-grained sandstone and pebbly grit; the section at A12 consists mainly of claystone and shale, and that at Picture Hill (Figs. 98, 99) and A145 of siltstone (*see* Appendix 2, Jo10). A7 and A8 contain nearly equal amounts of shale or claystone and sandstone, and A151 twice as much sandstone as siltstone. The Anketell Formation is thus characterized by an alternation of finer-grained rocks (claystone, shale, siltstone) and sandstone. This unity in diversity is reflected in a characteristic air-photograph pattern, which allows isolated outcrops to be identified. The area shown in Figure 96, 10 miles west-north-west of A11, and linked to it by almost continuous outcrop (*see* Anketell 4-mile geological map), includes isolated 40-foot hills and low mesas of well-bedded Anketell Formation rising above sand or low rubbly outcrop and clay-soil crossed by parallel lines of vegetation. The rubbly outcrop is incised by dry watercourses. Isolated hillocks of probable Callawa Formation to the north contrast in air-photograph pattern with the softer pattern of the Anketell Formation.

Forty miles east-south-east of the area shown in Figure 96, in the south-western part of the Joanna Sheet area (Fig. 97), relief is even lower. The southern slope (near A146) of a low mesa, capped by lightly dissected duricrusted Anketell Formation, is

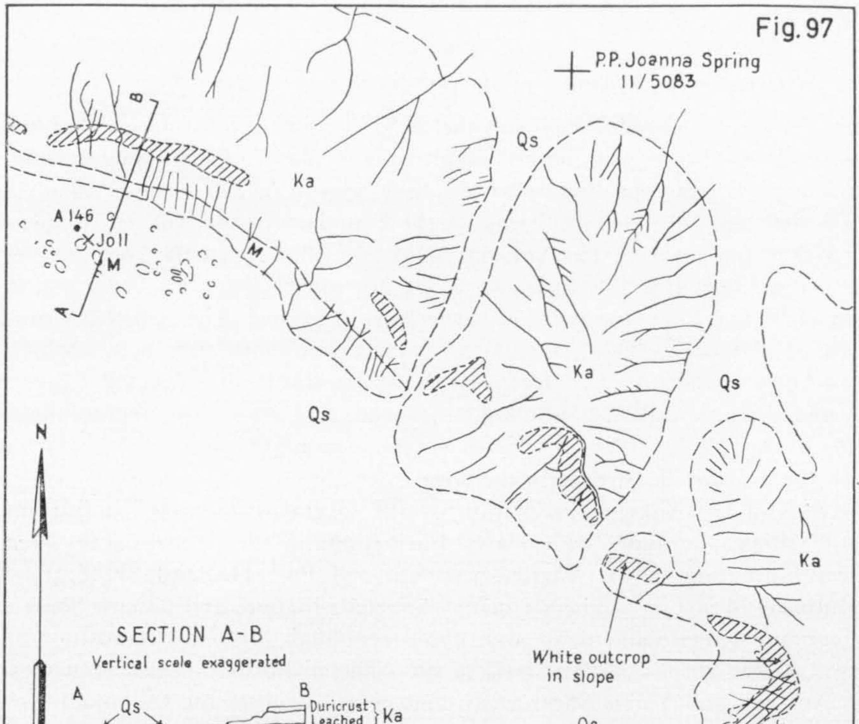


Fig. 97.—Anketell Formation (Ka) overlying undifferentiated Mesozoic rocks (M), 35 miles south-east of Anketell Hills.

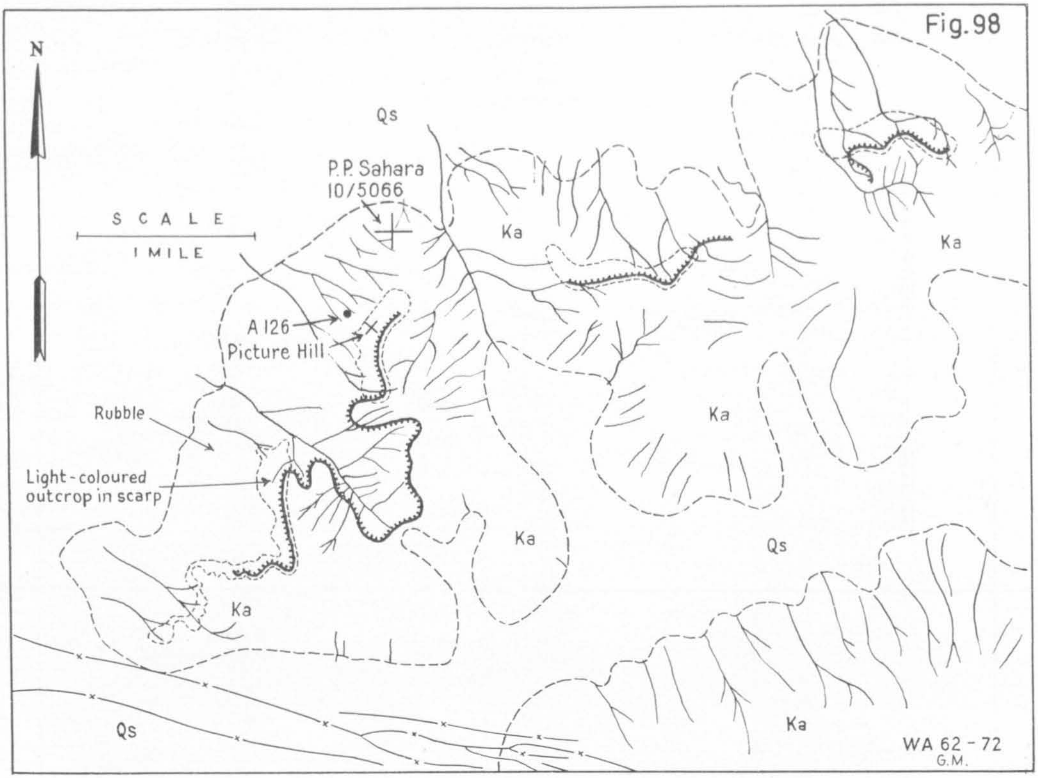


Fig. 98.—Anketell Formation (Ka) at Picture Hill.

Fig. 99.—Picture Hill. The caves are decorated with aboriginal paintings.

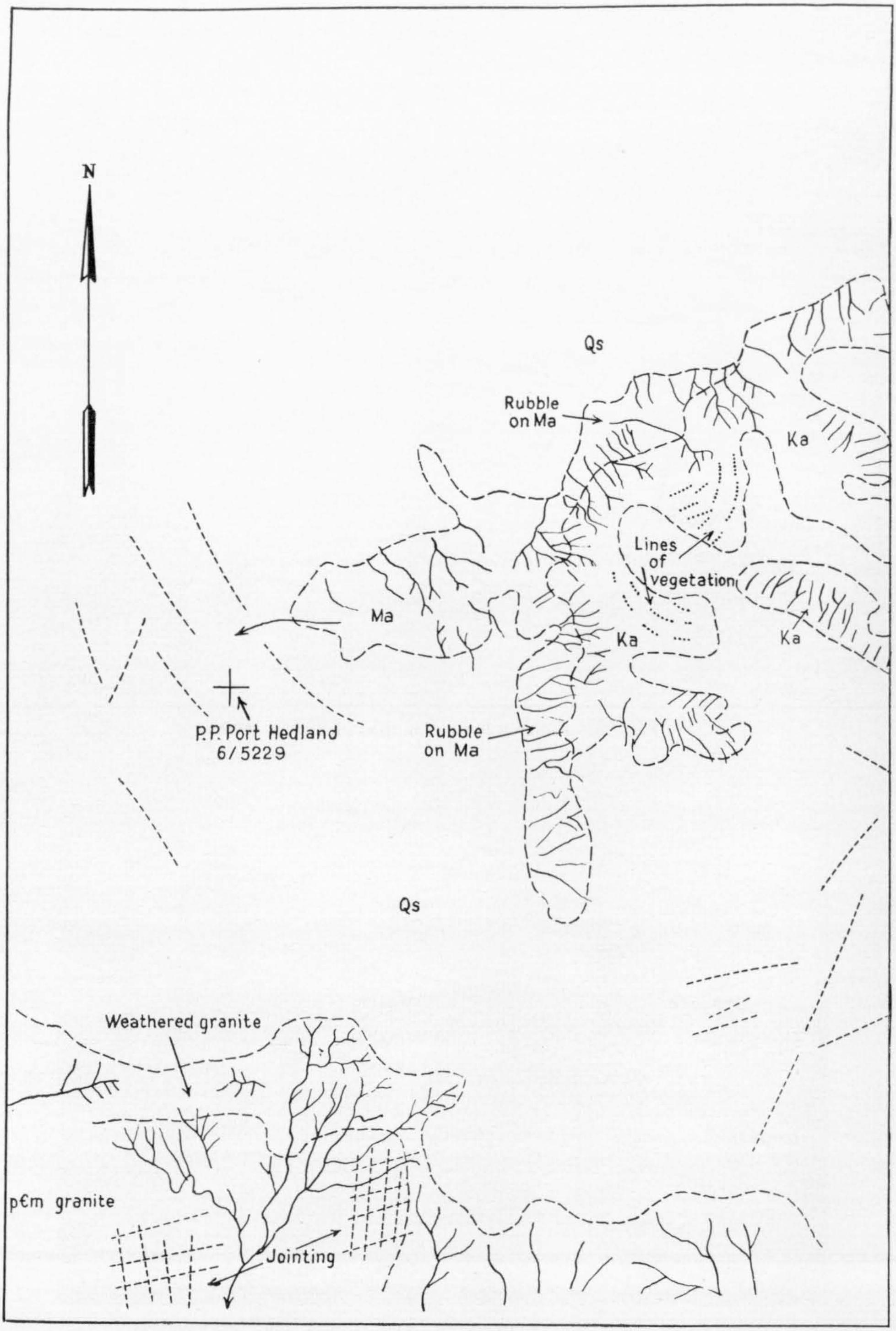
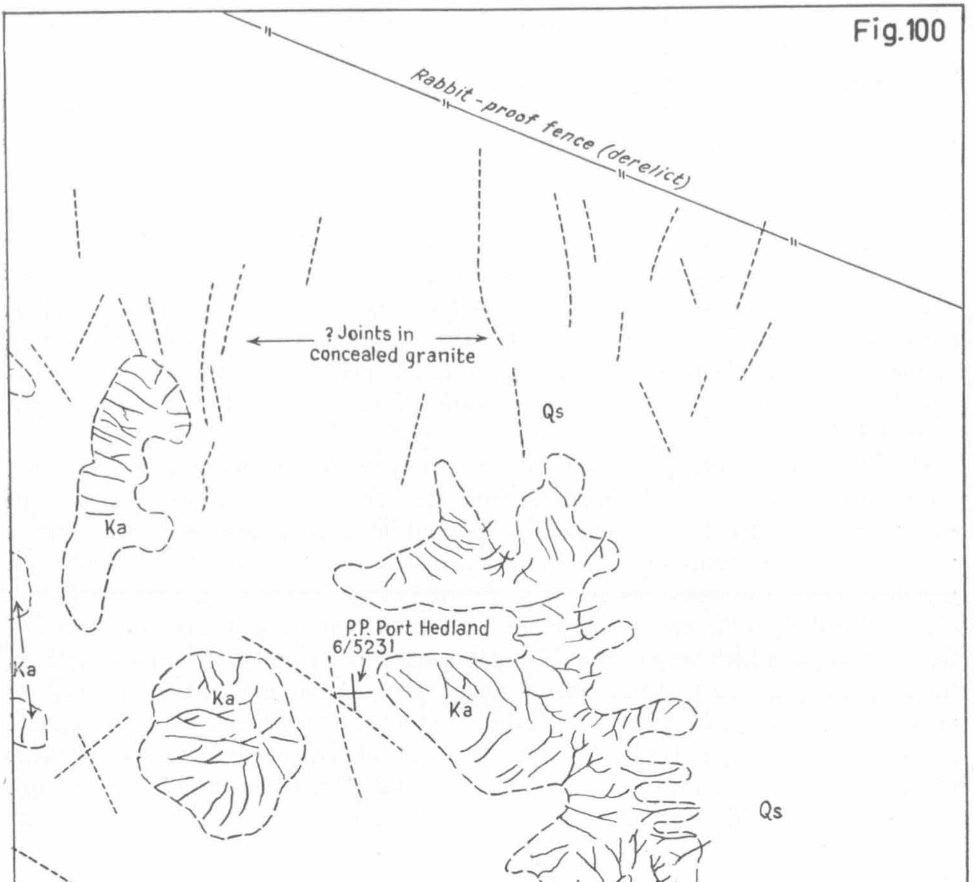


Fig. 100.—Anketell Formation (Ka), Callawa Formation (Ma), Precambrian (pCm)



basement rocks, north-eastern corner of the Port Hedland Sheet area.

F

indicated on the air photographs by a discontinuous white strip of fresh Anketell Formation, which overlies a dark strip of undifferentiated Mesozoic sandstone. A short distance south of the mesa, the Mesozoic rocks form characteristic groups of low isolated conical hills isolated by sand. South-eastward, the Mesozoic sandstone is jointed, and, in one place, possibly faulted. A similar pattern is found at Picture Hill (Fig. 98), except that no Mesozoic sandstone is exposed, and the Anketell Formation forms a long scarp.

The higher relief in the north-eastern corner of the Port Hedland Sheet area (Fig. 100) accentuates the different air-photograph pattern of the Anketell Formation and Callawa Formation. Here the Anketell Formation is finely dissected, and in places is covered by parallel lines of vegetation. On the air photographs, the texture of the Anketell Formation is velvety, and the tone grey. The Callawa Formation is knobby, it is crossed by only a few dry watercourses, and, on the air photograph, its tone is jet black.

Near Colorado Outcrop, in the southern part of the Munro Sheet area (Fig. 101), the Callawa or Alexander Formation forms black conical hills, some with a rough surface, others with a duricrusted cap. Larger outcrops are capped by what is identified as Anketell Formation, and the junction on the air photographs is indicated by a grey line. Thirty-five miles west-north-westward, in Woods Hills (Fig. 102), low lightly dissected rubbly outcrops of Anketell Formation surround lighter outcrops of fresher rock, in which very narrow joints in a rectangular pattern are just visible on the air photographs. An identical set of joints appears again in the Parda Formation at Mount Phire (Fig. 103), and will be discussed below. Identifiable fossils have been found in one outcrop only, A8. These are the worm burrows *Rhizocorallium* (Traves et al., p. 29; Veevers, 1961) and arenaceous foraminifera (Crespin *in* Traves et al.). Elsewhere only unidentifiable worm tracks have been found. These fossils indicate Neocomian; *Rhizocorallium* is found in some other formations in the basin, and is therefore useful in correlation. Fossils in probable subsurface Anketell or Parda Formation are discussed under the Parda Formation.

Parda Formation (Kp) (McWhae et al., pp. 107-108)

McWhae et al. briefly describe the Parda Formation as follows: 'The Parda Formation is named after Parda Hill (18° 53′ S, 121° 59′ E), where the type section is located. This section is 90 feet thick, and consists of siltstones interbedded with fine-grained sandstones.' No fossils are known from the exposed formation, but McWhae et al. identify the rocks exposed at Gourdon Bay as Parda Formation lying between Frezier Sandstone above and Broome Sandstone below, and hence the Parda Formation here is Lower Cretaceous. Evidence provided by air-photograph interpretation confirms this dating.

Parda Hill lies in the middle of an elongate, low, almost continuous outcrop, 60 miles long, of Parda Formation. The air-photograph pattern of the part of this outcrop immediately east of Mount Phire is shown in Figure 103. Low scarps facing north-west provide the only relief in this area of low outcrop and sandy clay. Throughout this area are very thin joints, particularly well shown in the fresher rock exposed in the scarp. These joints are identical in appearance with those seen in the Anketell Formation at Woods Hills (Fig. 102), 20 miles southward. Two and a half miles

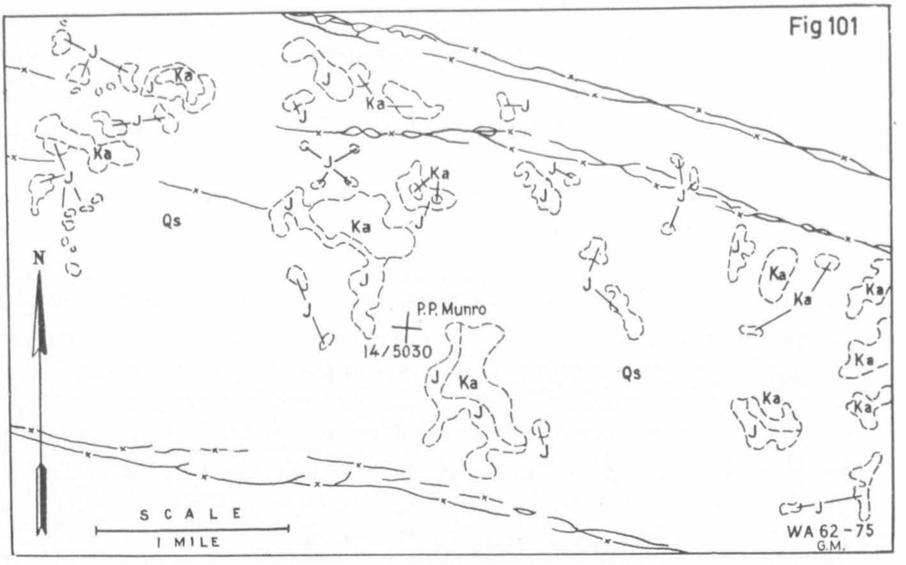


Fig. 101.—Anketell Formation (Ka) overlying undifferentiated Jurassic rocks (J) at Colorado Outcrop.

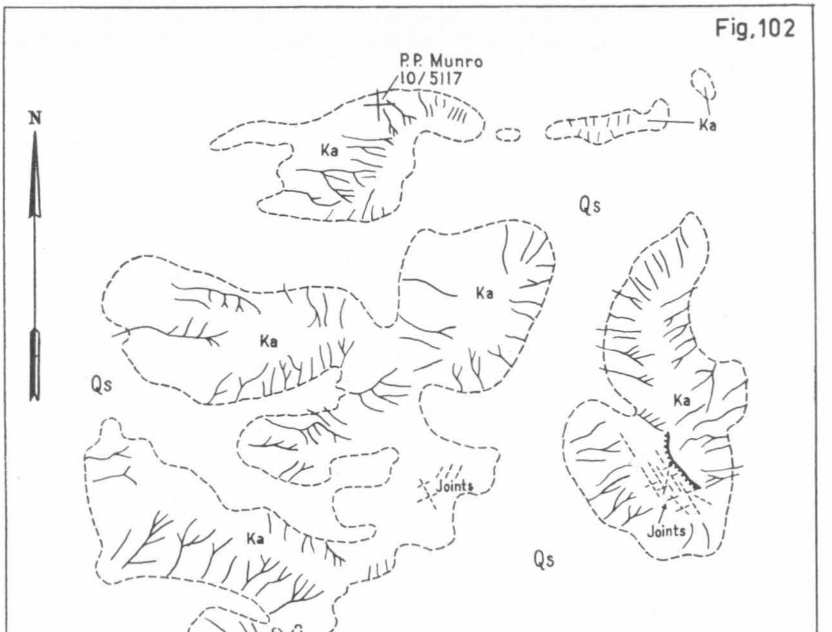


Fig. 102.—Joints in Anketell Formation (Ka) at Woods Hills.

westward, near Mount Phire (Fig. 103), narrow joints are even more abundant. We consider that the occurrence of the same type of joints in the Parda and Anketell Formations probably indicates continuity between these formations. The argument is:

(a) The Parda Formation (interbedded siltstone and fine sandstone) is similar to but nevertheless distinct from the Anketell Formation (claystone and shale with thin beds of sandstone and grit).

(b) The nearest extensive outcrops of these formations (Mount Phire and Woods Hills) lie only 20 miles apart, and are distinguishable from one another by different air-photograph patterns.

(c) In both areas, each formation contains an apparently identical type of jointing.

(d) This type of jointing, not seen elsewhere in the Canning Basin, probably indicates an identical group of minor properties. These properties, which possibly include type of cement, and diagenesis, could influence the particular type of response, in the form of joints, to minor periodic stress (earth tides) or to relief of load by erosion.

(e) Taken together, these points probably indicate that the Parda and Anketell Formations interfinger in the area between Woods Hills and Mount Phire. Continuity, and not necessarily contemporaneity, is indicated.

The intervals 560 to 1200 feet in Samphire Marsh No. 1 Bore and 346 to 1400 feet in BMR 4, 4A Wallal (Fig. 68) are probably part of the interfingering belt between the Parda and Anketell Formations. These intervals consist of sandy siltstone, quartz sandstone, and quartz greywacke, all with glauconite and pyrite. Glauconite and pyrite have not been found in outcrops of the Parda or Anketell Formations, but had they been originally in these rocks, they would have been destroyed by deep weathering. Crespin (*in* Johnstone, 1960) determined Cretaceous foraminifera and radiolaria from cuttings in the Anketell-Parda interval in Samphire Marsh No. 1. Two microfaunal assemblages, both associated with indeterminable belemnites, are distinguishable: an upper assemblage, comprising Lower Cretaceous arenaceous foraminifera and radiolaria, which probably indicates a correlation with the lower Gearle Siltstone or Windalia Radiolarite of the Carnarvon Basin (Aptian-Albian, according to Brunnschweiler, 1959); and a lower assemblage of foraminifera, *Ammobaculites fisheri* Crespin, *A. minimus* Crespin, and *Haplophragmoides chapmani* Crespin. Dr Crespin examined arenaceous foraminifera from BMR 4 Wallal (Core 6, 600-610 feet, Core 9, 888-898 feet) and found that they are distinct from known Australian Mesozoic foraminifera. The specimens were sent to Drs A. R. Loeblich and Helen Tappan, who reported that they indicate Upper Jurassic or Lower Cretaceous. From studies of microplankton, Evans (Appendix 5) regards the interval 399 to 1515 feet in BMR 4, 4A as Upper Jurassic or possibly Lower Cretaceous.

Crespin (1955, and 1956(a), both unpublished, and *in* Traves et al., p. 55) records *A. fisheri* from A8 in the Anketell Formation (Fig. 83) and from the Jowlaenga Formation in the Fraser River No. 1 Corehole and Fraser River No. 1 Bore, and therefore the lower assemblage probably indicates Neocomian. Only cuttings were available in the Samphire Marsh No. 1 Bore. The first appearance of the upper assemblage is at 790 to 800 feet, and of the lower assemblage, 1140 to 1150 feet. Cuttings from lower in the bore, in the Callawa Formation, contain the lower assemblage, probably derived from 1140 to 1150 feet. In this bore, the Anketell-Parda

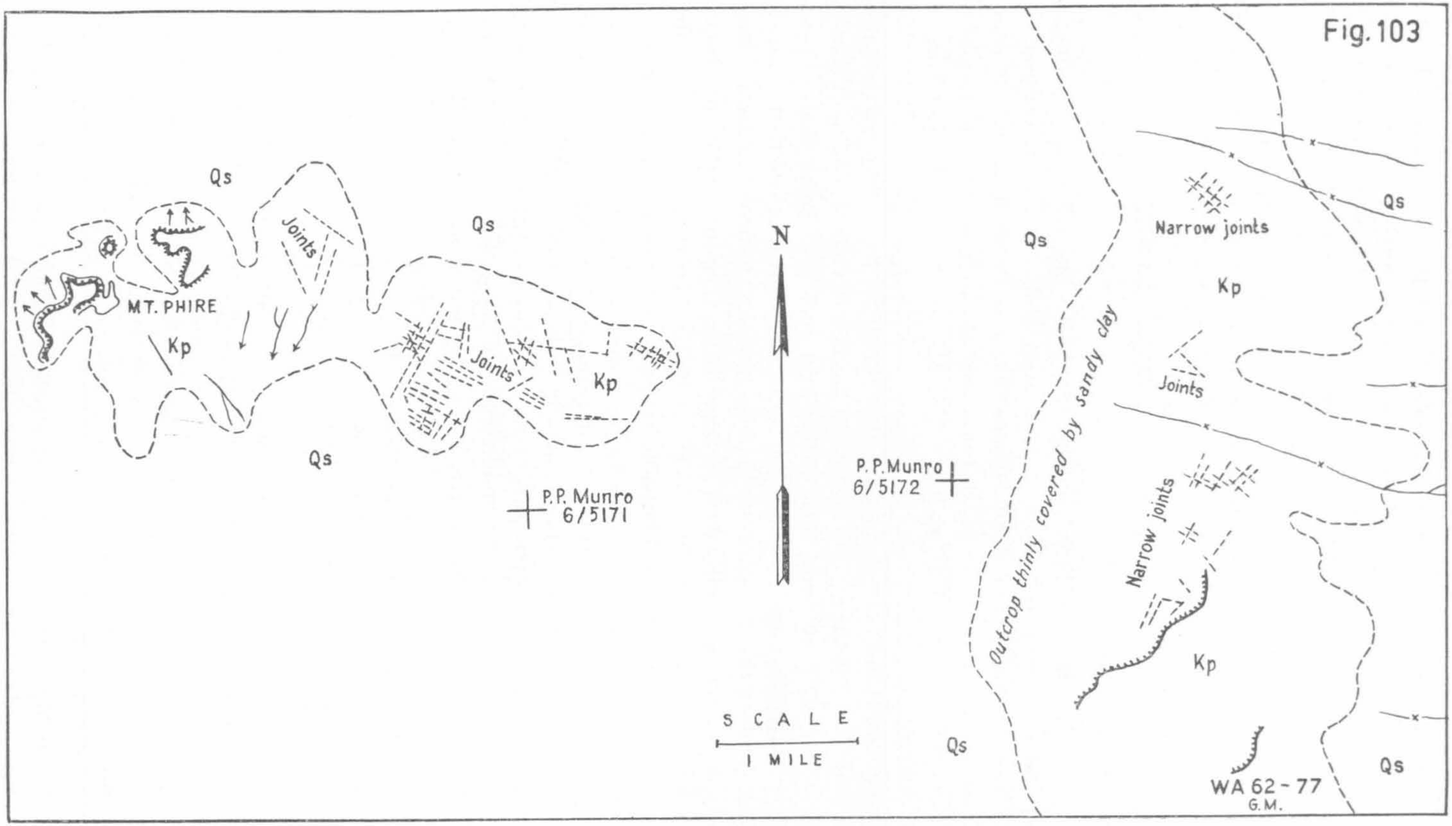


Fig. 103.—Joints in Parda Formation in the Mt. Phire area.

Formation accordingly ranges from Neocomian to Aptian-Albian. As already noted, the occurrence of glauconite above and below the top of the Callawa Formation in BMR 4, 4A Wallal indicates that this boundary is transitional, and hence that in this area the Anketell-Parda Formation succeeded the Callawa Formation without a break. Balme determined Oxfordian-Kimmeridgian spores from 1260-1270 feet in the Callawa Formation of Samphire Marsh No. 1. In this bore, the interval 1150 to 1260 feet therefore probably spans the Tithonian, and perhaps part of the Kimmeridgian as well. Glauconite does not cross the boundary between the Anketell-Parda Formation and Callawa Formation in the Samphire Marsh Bore, and part of the Tithonian could be represented by a hiatus.

Bejah Beds (Ke) (new name)

The name Bejah Beds is introduced for the hard white siliceous claystone (porcellanite) and shale with thin medium to coarse sandstone that is exposed in the Runton, Morris, Warri, and Ryan Sheet areas. The Bejah Beds extend probably some distance south of latitude 24° S. Forty feet of claystone and five feet of interbedded sandstone are exposed at Bejah Hill (23° 46′ S, 124° 09′ E). This is the thickest observed exposure.

At Woolnough Hills (Veevers & Wells, 1959, 1960) the Bejah Beds overlie probable Permian sandstone; on the ground no contact has been seen here, and undifferentiated Mesozoic rocks may intervene between Permian rock and Bejah Beds. From air-photograph interpretation, the Permian rocks appear to be overlain directly by Bejah Beds, and on this evidence, the undifferentiated Mesozoic sandstone seems to be missing at Woolnough Hills. West of Bejah Hills, again no contact has been seen between the Bejah Beds and older rocks; probable Mesozoic sandstone crops out ten miles south of Bejah Hill, and possibly lies between the Bejah Beds and the nearby outcrops of probable Permian sandstone but is not exposed. We have indicated this possibility on the 20-mile map (Pl. 1) by drawing, west of Bejah Hill a strip of undifferentiated Mesozoic rocks, which connects with outcrops south-west and north-east of Bejah Hill. In the eastern part of their outcrop, in the Ryan Sheet area, the Bejah Beds apparently overlie the undifferentiated Mesozoic sandstone of Dowling Hills. At M17 (Fig. 107), in the Morris Sheet area and in the Nipper Pinnacle area (Figs. 104-106) fine to coarse sandstone, possibly Kidson Beds, underlies the claystone (*see* Appendix 2, M17) of the Bejah Beds. The top of the Bejah Beds is eroded except at M1 and M13 (Fig. 104), where the claystone is capped by coarse sandstone.

At Bejah Hill, Rn37, and M1 (Fig. 104), the claystone contains a bed, five feet thick at Bejah Hill, one foot thick at M1, of medium-grained sandstone with claystone fragments. This distinctive bed probably occurs also at M2, M11 and M12, and M14. The section at M13 (Fig. 104) was measured in a scarp, and M14 lower down the slope.

As already mentioned, the Bejah Beds overlie a fine to coarse-grained sandstone with grit bands at M17 and in the Nipper Pinnacle area (M22-24). As the Bejah Beds are probably Aptian-Albian, the underlying sandstone is pre-Aptian. Among the pre-Aptian formations in the southern part of the Canning Basin, the Kidson Beds, undifferentiated Mesozoic rocks, and part of the Permian rocks resemble this sandstone. In the northern part of the Morris Sheet area, the air-photograph pattern

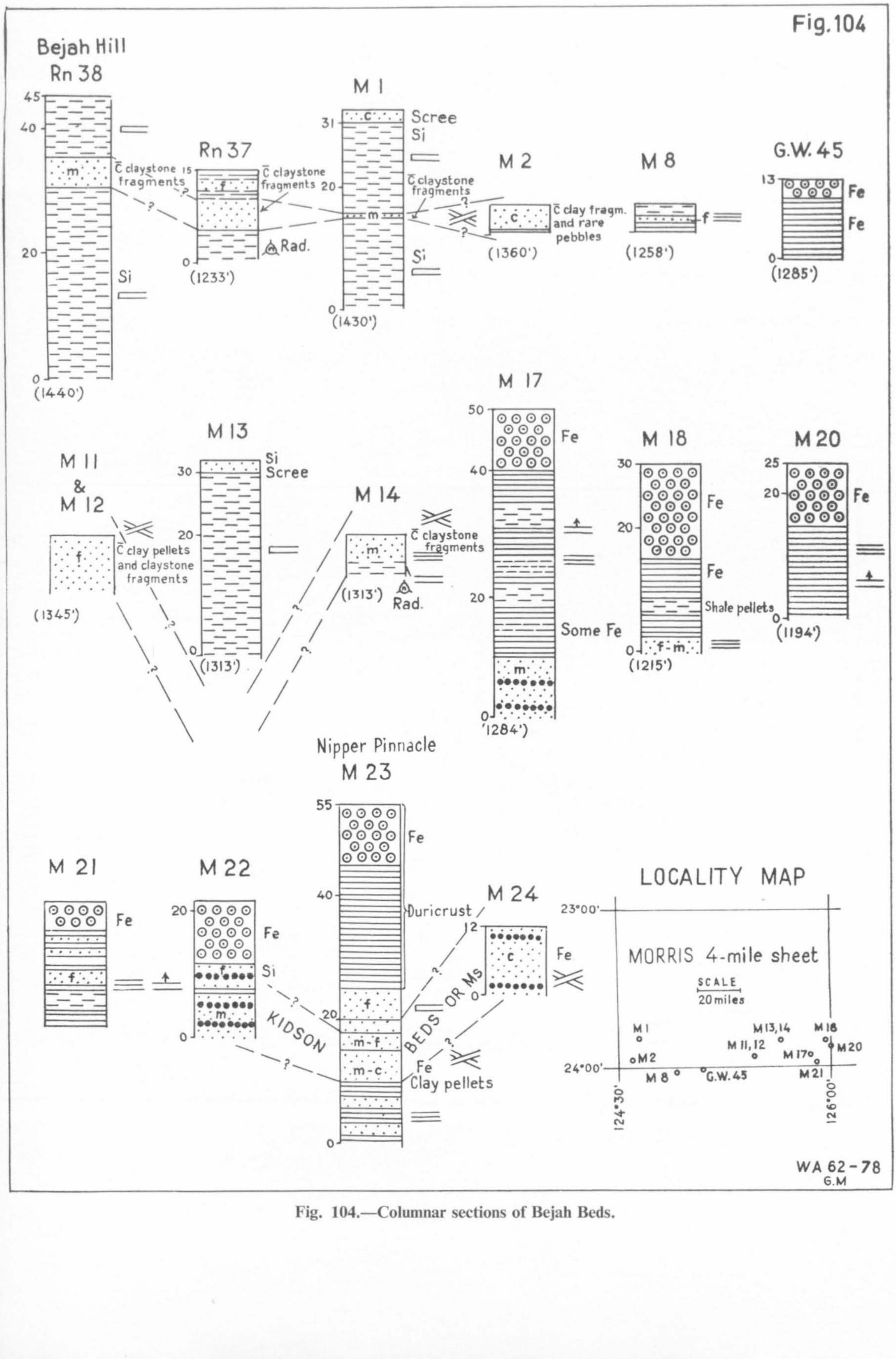


Fig. 104.—Columnar sections of Bejah Beds.

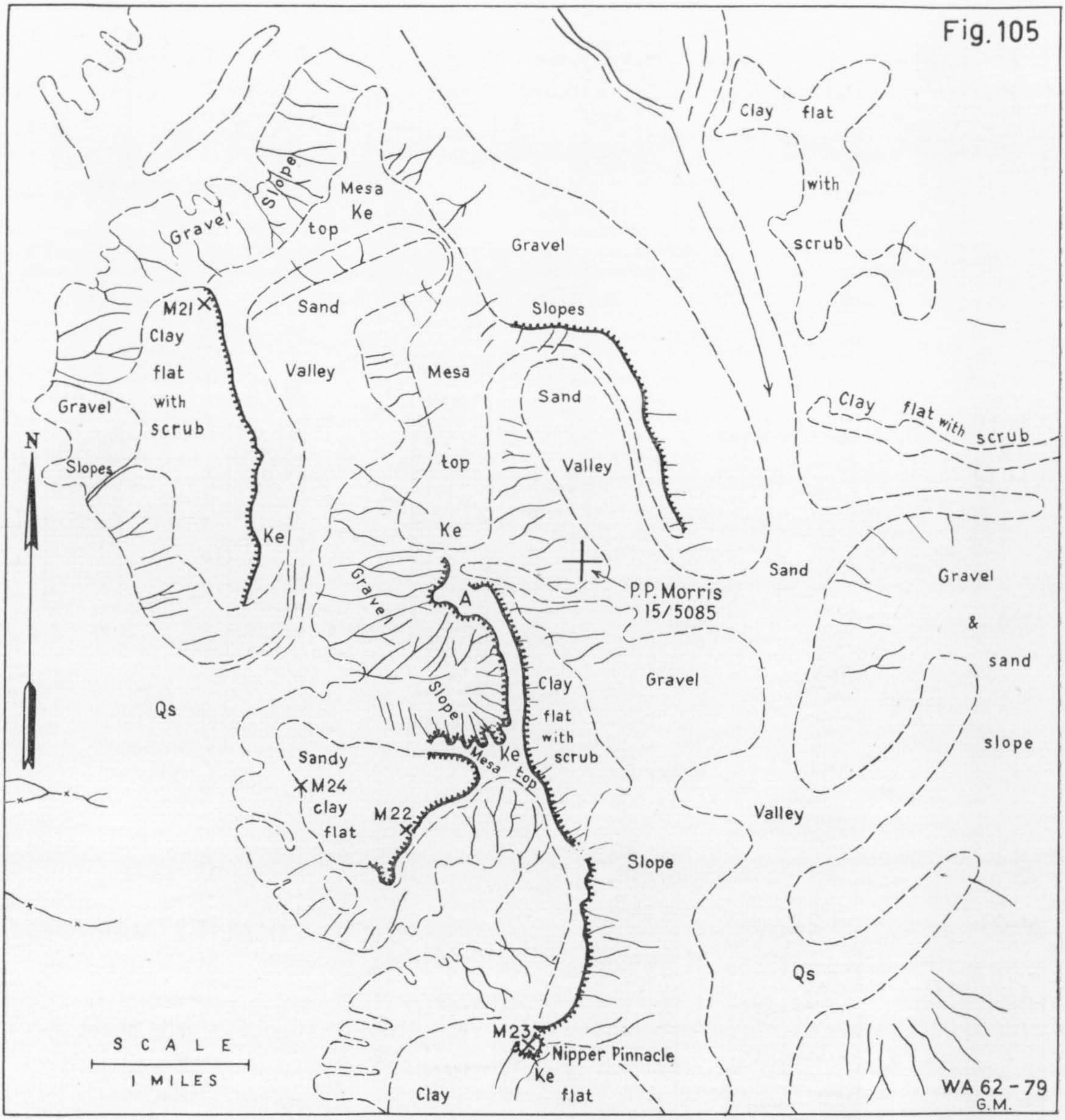


Fig. 105.—Bejah Beds (Ke) in the Nipper Pinnacle area.

of the Kidson Beds grades imperceptibly into that of the Bejah Beds, which, because they occupy higher land, probably overlie the Kidson Beds. The sandstone at the above-mentioned localities apparently conformably underlies the Bejah Beds, and is therefore probably Neocomian. For these reasons, this sandstone is identified, very tentatively only, with the Kidson Beds.

The only known fossils in the Bejah Beds are radiolaria. Dr Irene Crespin has determined *Lithocyclia exilis* Hinde from Rn37, and *Cenosphaera* sp. from M14. 'These radiolaria-bearing rocks are regarded as representing the topmost part of the Lower Cretaceous and probably equivalent of the Albian Stage' (pers. comm.).

The coarse sandstone that caps the claystone at M1 and M13 is probably the youngest preserved deposit of the regressive late Aptian-Albian sea.

The Bejah Beds are horizontal except at Woolnough Hills (Veevers & Wells, 1959, 1960), where they form the low-dipping flanks (5° to 6°) of a probable salt dome.

Aptian-Albian siliceous claystones and shales represented in the Canning Basin by the Bejah Beds, are widespread throughout Australia. Brunnschweiler (1959, p. 9) briefly described them as follows:

'Rocks similar to the well-bedded, although poorly fissile, Windalia Radiolarite are very characteristic of much of the Australian Middle Cretaceous. Not only in Western Australia but also in the Darwin area and in the Great Artesian Basin of Eastern Australia varicoloured lightweight radiolarites and siltstones make up considerable portions of the Aptian and Albian sequences. In some areas there are almost pure kaolinites, in others the rock consists of as much as 95 per cent silica (partly bound in kaolinite). These rocks, which are macroscopically quite alike, grade laterally and vertically into each other over immense areas. They are, incidentally, reponsible for the most prominent among the "duricrust" beds in the arid and semi-arid regions of Australia, and in them occur also the most important opal fields.

'On the whole the peculiar conditions producing this lithology seem to have been limited to the Aptian and Albian epochs. But there are occasional beds of that type in the Upper Jurassic of the Canning Basin (Brunnschweiler, 1954) and the lithology seems to persist for a time also into the earliest period of the Upper Cretaceous (Winton Formation of Western Queensland). The type of environment indicated by it is still a matter for speculation.'

Only the shales of the Bejah Beds show good bedding. The commonest component, called siliceous claystone, at first glance seems to be massive, but under careful examination specimens show barely discernible fine bedding. Specimens are not fissile; they have a subconchoidal fracture. Most of these rocks contain about 90% silica, as shown by analyses of representative samples.

	M17E	M1A	M13	Rn37
SiO_2	6.64	92.68	86.06	89.36
SO_3	34.03	..	..	..
Fe_2O_3	0.73	0.16	0.29	0.13
Al_2O_3	30.71	0.24	2.75	0.43
Na_2O	1.06	0.13	0.10	0.10
K_2O	7.73	0.16	0.12	0.11
P_2O_5	2.10	..	..	..
H_2O (105)	0.8	0.70	0.65	0.50
H_2O (1000)	Remainder	5.12	9.92	9.42

Analyst: S. Baker.

The composition of M17E is anomalous, and will be discussed below. Two other specimens were analysed by Mr Baker for silica only: they are M1B (91.40%) and Rn38 (90.74%). Apart from water, the impurities in these silica rocks total 0.69% in M1A, 0.77% in Rn37, and 3.26% in M13. M1A (*see* Appendix 2) is a reconstituted radiolarite which consists almost entirely of opal. M13, which contains 6.62% less silica than M1A, is a reconstituted silty radiolarite, and, from thin section examination, is estimated to contain about 5% quartz grains with average diameter 0.06 mm. Rn37 is similar to M13. All the specimens at M17 are argillaceous siltstones, except M17E (*see* analysis, and Appendix 2), which is mainly alunite, a hydrous sulphate of aluminium and potassium. W. B. Dallwitz suggests that the alunite was possibly derived from the weathering of a pyritic shale.

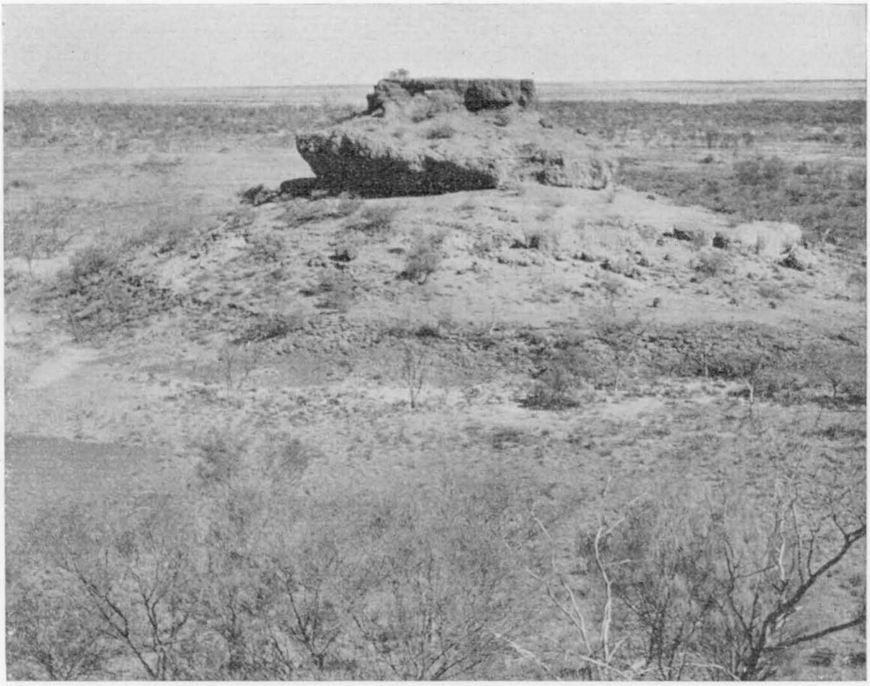


Fig. 106.—Bejah Beds at Nipper Pinnacle (M23)—looking south.

The features of the distinctive air-photograph pattern of the Bejah Beds are shown in the map of the Nipper Pinnacle area (Fig. 105). From the highest ground to the lowest, four divisions may be mapped:

1. *Mesa top*, consisting of pisolitic ferruginous duricrust, bounded on one or more sides by scarps, 20 feet high at M21 and M22, and 55 feet high near Nipper Pinnacle (Fig. 107). The scarp is the only part of the outcrop that yields fairly fresh rock. Scarps face onto either

2. *Clay and sand flats*, which have a smudgy air-photograph pattern, thick vegetation, and no lines of drainage; or

3. *Gravel slopes*, which also border clay and sand flats. On the air photographs, the boundary between the gravel slope and the mesa top is diffuse, that between gravel slope (dark-grey) and clay and sand flat or sand valley (both light-grey) sharp. South-west of M21, the gravel slope is breached by 100-yard wide valleys filled with clay, and crowded with vegetation. These valleys, and all other drainage channels longer than a quarter of a mile, are restricted to the gravel slope, and run at right angles to the boundaries of the gravel slope. This distinctive drainage pattern is visible on almost every air photograph of the Bejah Beds. The final division is the

4. *Sand valley*, covered by spinifex which is uniform in density except where the surface trace of a sand-choked stream is indicated by thicker growth. Rare dunes form in sand valleys.

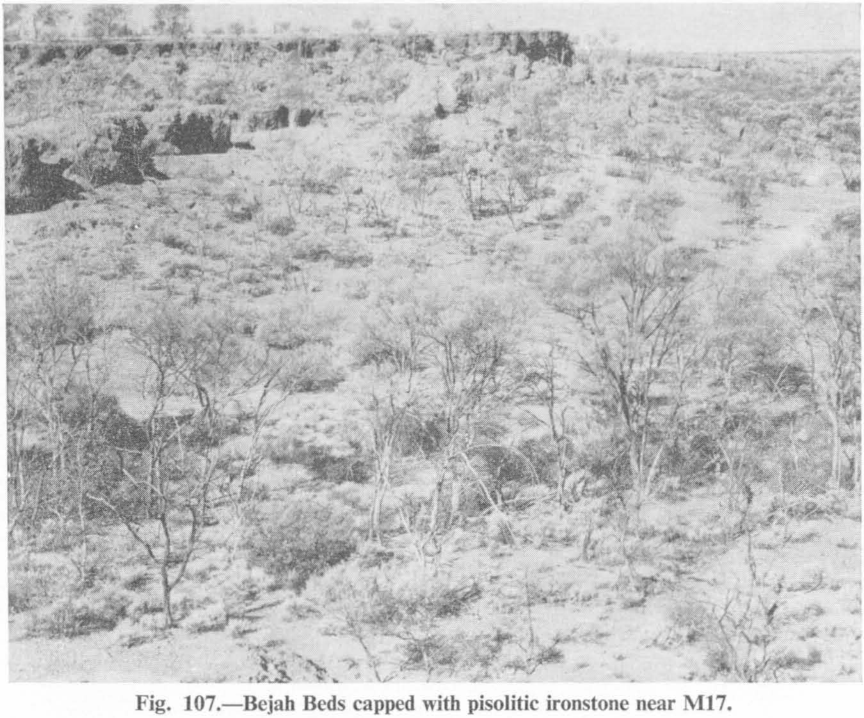


Fig. 107.—Bejah Beds capped with pisolitic ironstone near M17.

A few additional features are shown in Figure 108. Relief in this area is about 30 feet. The dissected mesa and, in the north-west corner of the area, a butte are bounded by a gravel slope, one-fifth to two-fifths of a mile wide, to which almost all watercourses are confined. These watercourses are evenly spaced, and run at right angles to the mesa edge. The mesa edge is further indicated by the dense vegetation at the heads of watercourses, where low scarps are cut into the mesa. On the duricrusted mesa top, lines of vegetation, generally parallel to the mesa edge, probably indicate open joints in the duricrust. These joints are probably caused by rainwater that percolates through the duricrust to the underlying impermeable claystone, flows outwards into watercourses rising at the mesa edge, and, in so doing, undermines the duricrust.

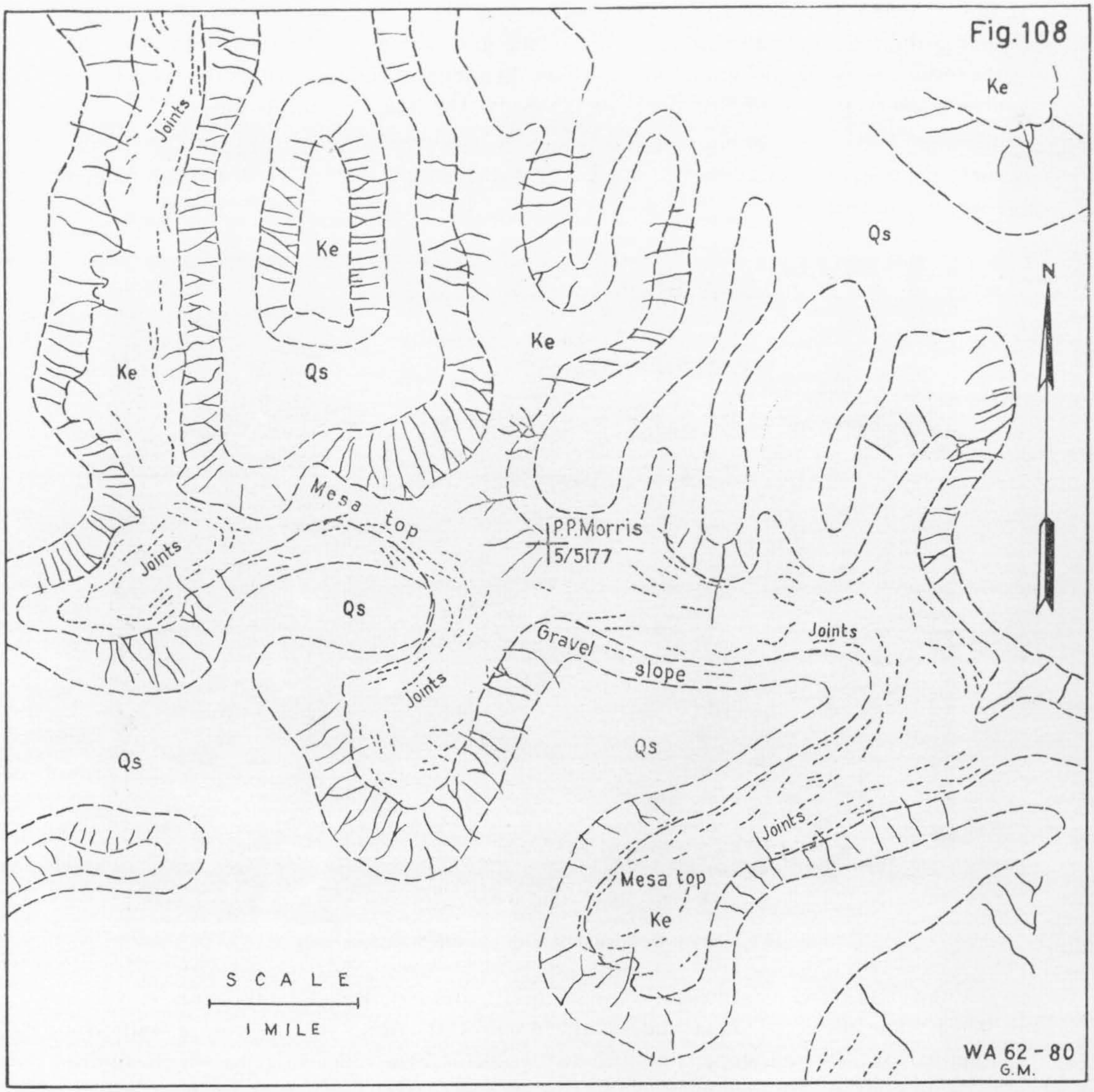


Fig. 108.—Bejah Beds (Ke) 70 miles north-east of Bejah Hill.

The sand that fills the valleys in the claystone in the southern two-thirds of the Morris 4-mile Sheet area probably lies too far downwind to be derived from source areas outside the area of claystone. This leads to the belief that the sand was locally derived from a sandstone that capped the Bejah Beds. Sandstone that overlies the Bejah Beds at M1 and M13 is probably a remnant of an extensive sandstone bed.

Mixed Rocks

Godfrey Beds (Kg) (McWhae et al., p. 109; Casey & Wells)

Elliott, Casey & Wells (*in* McWhae et al.) introduced the name Godfrey Beds for the 300-foot-thick fine to medium quartz sandstone (*see* Appendix 2, C2a and C58), with minor shale, siltstone, and grit, that forms the imposing breakaway range in the Godfrey Tank area. The base of the Godfrey Beds is not exposed and the top is eroded.

According to R. M. Elliott (pers. comm.), the 179-foot section at C3a consists of laminated to thinly bedded and cross-bedded fine sandstone with thin beds of siltstone in the middle of the section, a six-foot bed of coarse sandstone 38 feet above the base, and a one-foot bed of coarse sandstone containing pebbles of quartzite four inches long at the top. Worm burrows, identified in the field as *Rhizocorallium*, were found in the middle of the section. Other measured sections in the Godfrey area (Fig. 110) are similar, but in addition contain mica, ripple marks, and clay pellets. Abundant mica in some fine-grained sandstones makes them as fissile as a shale.

The only fossils collected from the Godfrey Beds are the worm burrow *Rhizocorallium* (Veevers, 1961) from several localities and pelecypods from the Catspaw Hills (C2a), identified by J. M. Dickins (Appendix 4) as *Etea* (?) sp. *Etea* occurs in the Cretaceous rocks of North America; *Rhizocorallium* is widespread in the Cretaceous rocks of the Canning Basin, and probably indicates Neocomian.

Outside the Godfrey area, the Godfrey Beds are tentatively identified 14 miles north of Well 48 at C59 (*see* Cornish 4-mile geological map), at Mount Cornish, at Mount Elgin, in the Minnie Range, and at C23. The sections at Mount Cornish and Mount Elgin are similar to that at C3a, but the others require further comment.

At C59 (Casey & Wells), 20 feet of sandstone, probably the Condren Sandstone Member (Permian), are disconformably overlain by 40 feet of conglomerate with boulders up to two feet across, probably derived from the underlying Condren Sandstone. Two isolated outcrops in the Minnie Range have been tentatively identified as Godfrey Beds by their air-photograph pattern. At C23 (Fig. 112), about 35 miles south-east of the Minnie Range, 80 feet of massive and laminated sandstone with (?) *Rhizocorallium* is tentatively identified as Godfrey Beds. This sandstone overlies 90 feet of interbedded fine micaceous sandstone and shale, possibly Blina Shale, which in turn overlies undifferentiated Noonkanbah Formation and Balgo Member (both Permian).

Before 1955, when fossils were first found in the Godfrey Beds, these beds were regarded as Permian. The Godfrey Beds are similar, except in fossil content, to nearby outcrops of Permian rocks, particularly the Condren Sandstone Member. The Condren Sandstone was probably the youngest part of the local Permian succession, and so was probably the main source of sediment for the Godfrey Beds.

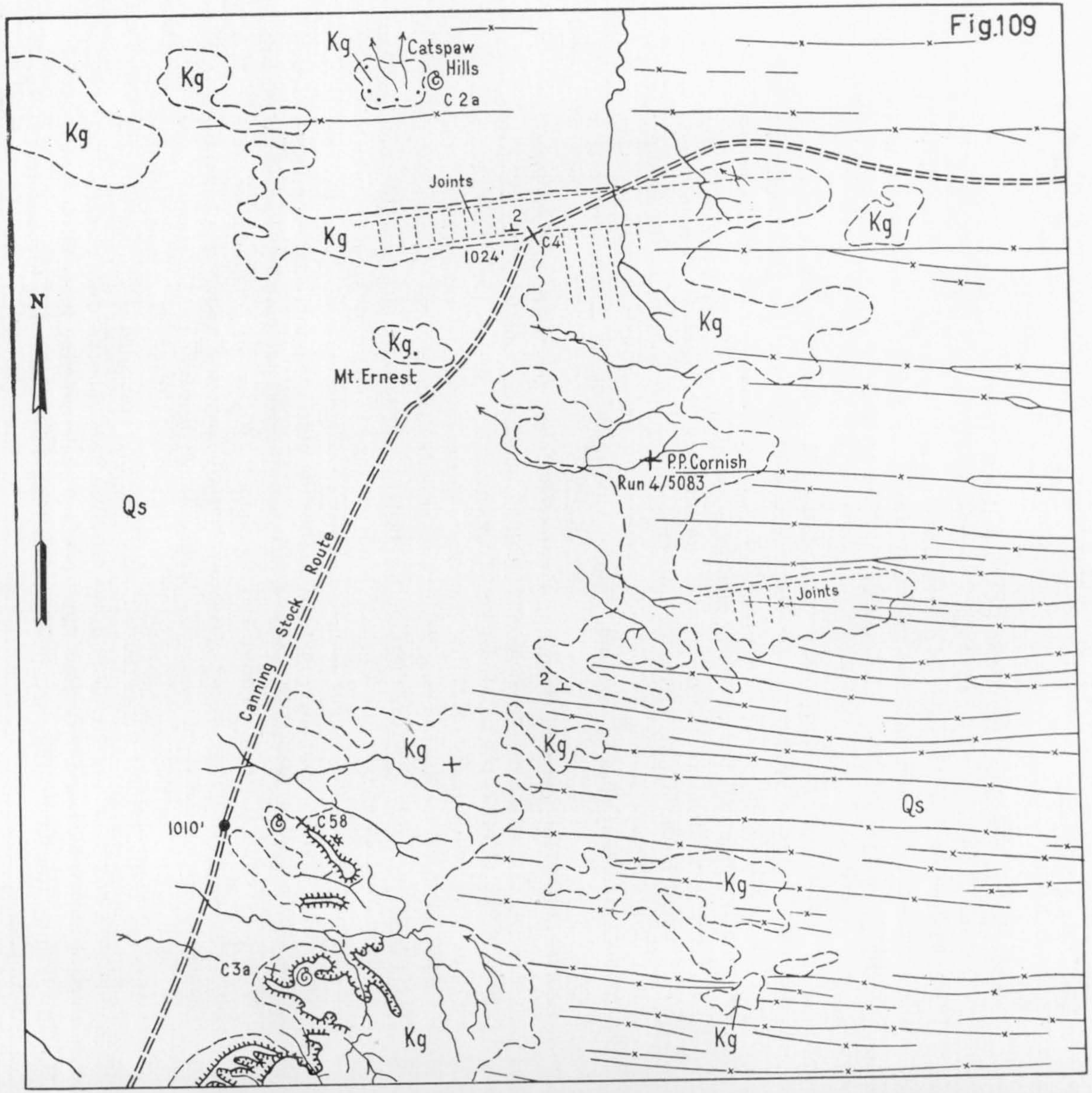

Kg
Catspaw
Hills
C 2a
Kg
Kg
Joints
2
Kg
1024'
C4
Kg
Kg
N
Kg.
Mt.Ernest
P.P.Cornish
Run 4/5083
Qs
Canning Stock Route
Joints
2
Kg
Kg
Qs
1010'
C58
Kg
C3a
Kg
Kg

Fig.109

Fig. 109.—Godfrey Beds (Kg). For explanation of symbols, see Cornish geological map.

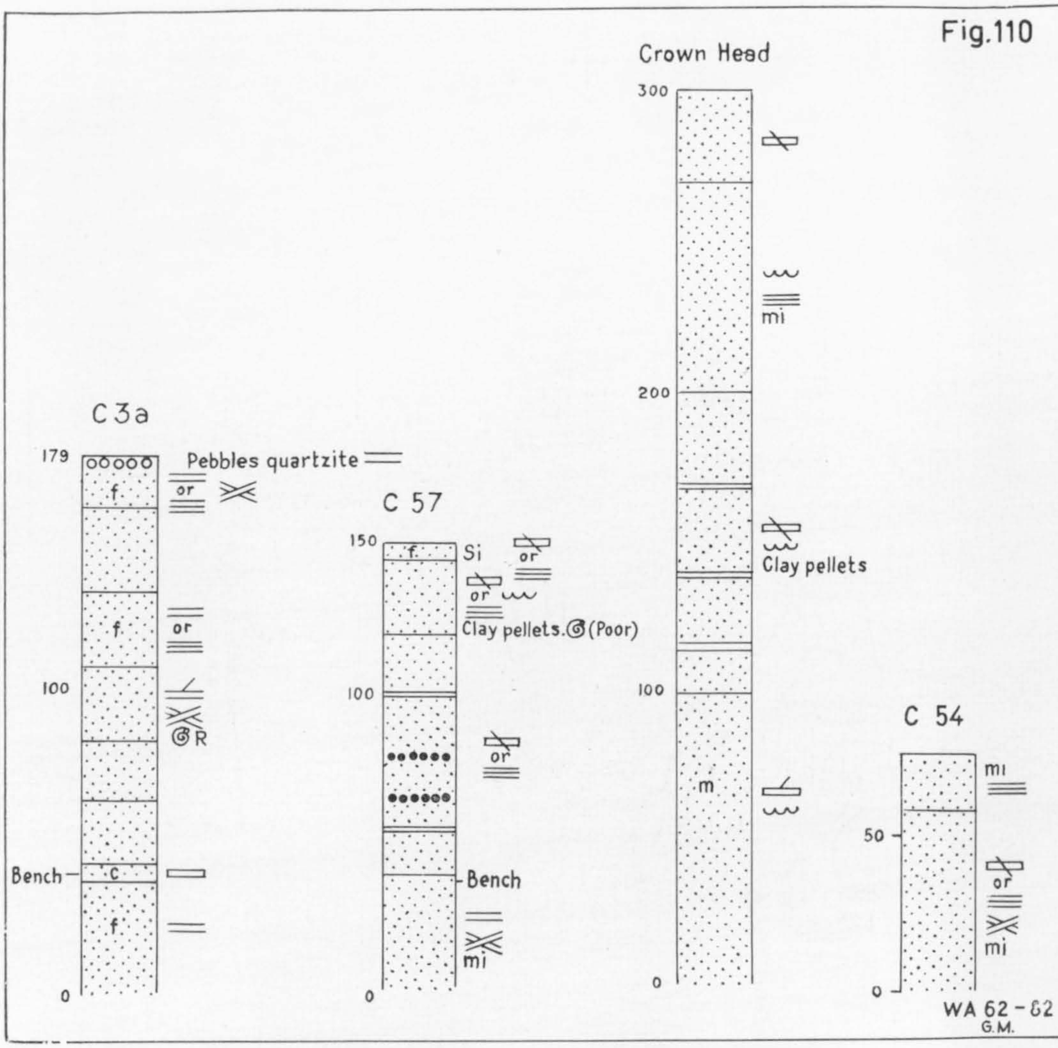


Fig. 110.—Godfrey Beds. See Cornish geological map for localities.

Fig. 111.—Godfrey Beds near Breadens Pool (Fig. 110).

Hazlett Beds (Kh) (new name)

The name Hazlett Beds is introduced for the thin beds of claystone, siltstone, and sandstone exposed in the Lake Hazlett/Lake Wills area (21° 30′ S, 128° 30′ E). Twenty-five feet of claystone and billy crop out at S60 (Figs. 113, 114). This is the only outcrop that was visited; other outcrops have been interpreted from air photographs; the northernmost of these lies 30 miles from S60, which is the southernmost outcrop. The Hazlett Beds unconformably overlie Precambrian sandstone, dolomite, and fine conglomerate. The top of the Hazlett Beds is eroded.

At S60 (Fig. 114), in the scarp of a mesa, 15 feet of white radiolaria-bearing claystone with rare quartz grains are capped with ten feet of billy. One mile south of S60, at S81, 15 feet of fine massive white and yellow siltstone are overlain by 20 feet of billy. The butte at S81 is surmounted by a cairn, probably erected by M. Terry in 1933. One mile north-east of S60, at S61, well-bedded white quartz sandstone is draped on the western side of a north-trending ridge of Precambrian rocks, and dips 25° to 35° westward.

On the air photographs, the Hazlett Beds at S60 are soft dark grey to black with white edges. Strike ridges of the underlying Gardiner Beds are indicated on the photographs by lines in the dissected parts of the mesa. Northward, outcrops with this type of pattern have been tentatively mapped as Hazlett Beds.

The radiolaria at S60 are identified by Dr Crespin (pers. comm.) as cf. *Cenosphaera*. On this basis, the Hazlett Beds are tentatively correlated with the Bejah Beds.

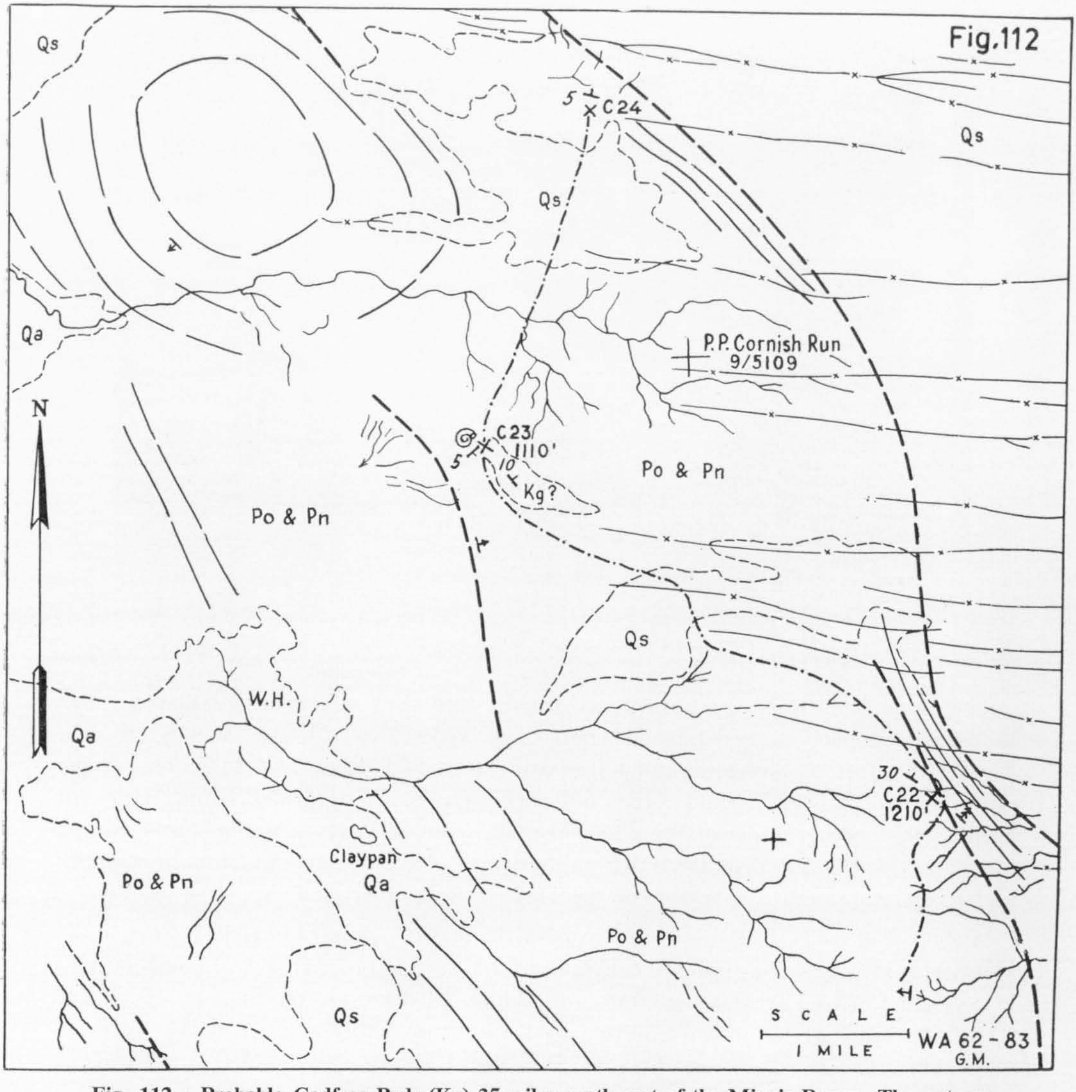


Fig. 112.—Probable Godfrey Beds (Kg) 35 miles south-east of the Minnie Range. The outcrop of possible Blina Shale at C23 is too narrow to be shown on the map. Pn—Noonkanbah Formation; Po—Balgo Member.

Coarser-grained Rocks at the Top of the Jurassic-Cretaceous Succession

Broome Sandstone (Kb) (Reeves, 1951, p. 2491; Brunnschweiler, 1957, p. 8; McWhae et al., pp. 106-107)

Brunnschweiler amended Reeves' 'Broome Beds' to Broome Sandstone, and redefined it as follows:

'The Broome Sandstone . . . consists of fine to coarse-grained commonly friable, micaceous quartz sandstone with interbedded light-coloured micaceous sandy siltstone. This siltstone is scarce or absent in the section west of Broome, but is common or even dominant in the coastal cliffs between Carnot Bay and Cape Leveque. At Cape Borda sandy siltstone is exposed. The Broome Sandstone differs from the Jowlaenga Sandstone by the apparent absence of marine fossils (other than numerous small worm-tracks), by more pronounced cross-bedding, and by comparatively high mica-content of both siltstone and sandstone.'

According to Brunnschweiler, some of the siltstones appear to be tuffaceous, but this material cannot be related to the plugs of Fitzroy Lamproite, 100 miles southward and south-eastward, because the biotite is unlike the particular biotite in the volcanics.

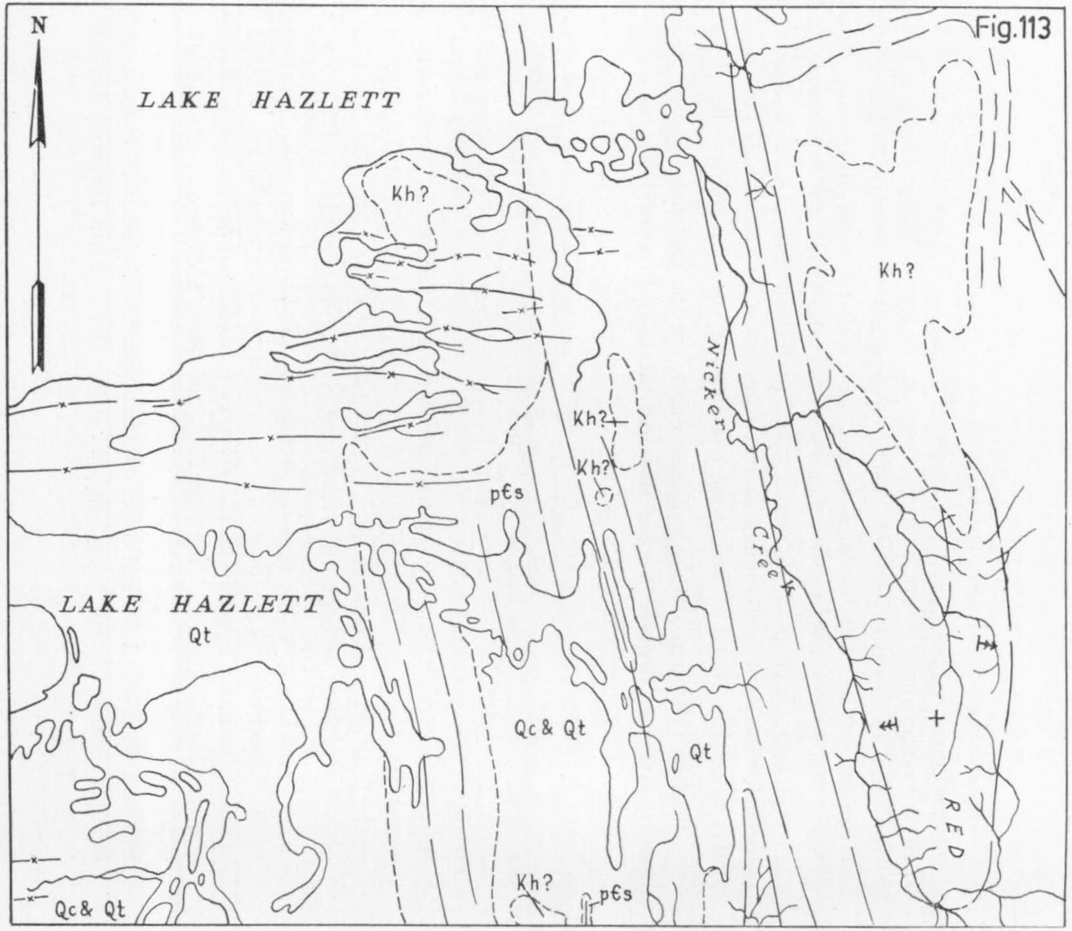
The Broome Sandstone is discontinuously exposed from Cape Gourdon northward along the west coast of Dampier Peninsula to Cape Leveque. McWhae et al. chose Gantheaume Point, near Broome, as the type locality. The Broome Sandstone continues downward from the surface to a depth of about 950 feet in the Broome area, and to 500 feet in the Roebuck Bay area (Broome Bores and Roebuck Bay No. 1 Bore—Fig. 68). These subsurface intervals, which are many times thicker than the thickest outcrop of 40 feet, consist of barren fine to coarse quartz sandstone with thin beds of conglomerate, and some siltstone. In the Broome and Roebuck Bay areas the Broome Sandstone overlies the 'Broome *Buchia* Beds'.

Teichert (1941, p. 104) records the depths of the junction between Broome Sandstone and the 'Broome *Buchia* Beds' in the four Broome bores as:

963	feet	in	bore	No. 1.
920	,,		,,	No. 2.
960	,,		,,	No. 3.
935	,,		,,	No. 4.

Bores Nos. 1 and 3 are 360 feet apart, and the difference in depth to the junction is negligible. No. 4 is 2760 feet south-west of Nos. 1 and 3, and the difference in depth to the junction is 30 feet, giving a gradient of 1 in 92 or $0^\circ 40'$. No. 2 is 1720 feet north of Nos. 1 and 3, and the difference of 45 feet gives a gradient of 1 in 38 or $1^\circ 30'$.

At Cape Leveque, the Broome Sandstone grades upward into the Leveque Sandstone. Along the rest of the west coast of Dampier Peninsula, the Broome Sandstone is disconformably overlain by the Tertiary Emeriau Sandstone, or by Recent deposits. Farther south along the coast, at Gourdon Bay, McWhae et al. identify the lowermost exposed strata as Broome Sandstone overlain by strata identified as Parda Formation. This identification of the Broome Sandstone is supported by the identification of this unit in bores situated between Gourdon Bay and Broome.



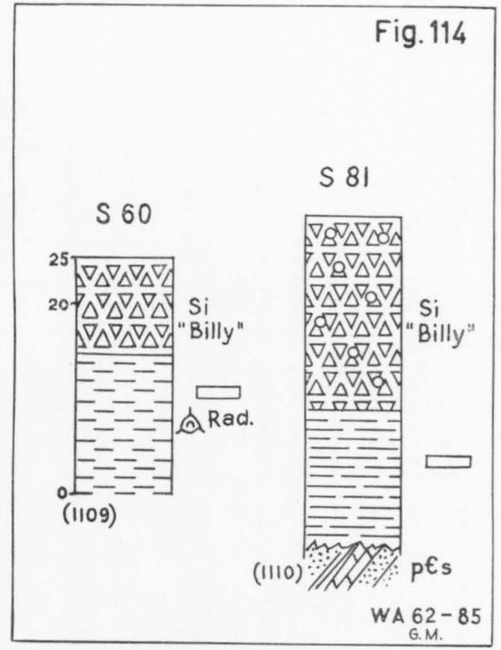


Fig. 114.—Sections of the Hazlett Beds. Localities shown in Figure 113.

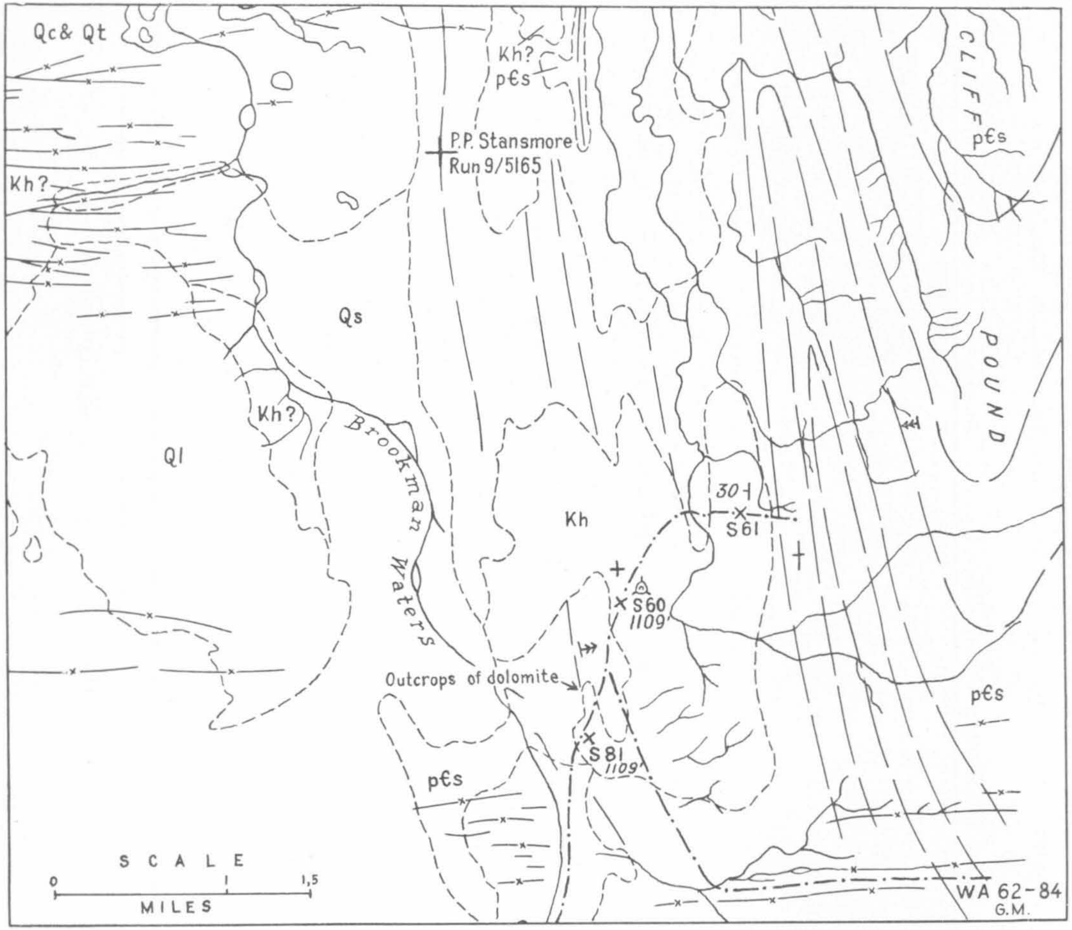


Fig. 113.—Hazlett Beds (Kh) overlying Precambrian sediments (pCs).

Plants, indicating Upper Jurassic or Lower Cretaceous (Brunnschweiler, 1960; White, Appendix 6), worm tracks, and a footprint of a three-toed iguanodont reptile have been found at the type locality. McWhae et al. believe that the Broome Sandstone is 'in the main, a continental deposit'. We prefer to regard at least the exposed part of the formation as paralic because of the association of such undoubted fresh- or brackish-water fossils as the reptile, and possibly also the plants, with probably marine worm tracks. Furthermore, at Cape Leveque, the Broome Sandstone grades upwards into the marine Leveque Sandstone.

Leveque Sandstone (Kl) (Brunnschweiler, 1957, p. 9)

The Leveque Sandstone is known from a single exposure at the top of the high cliffs at Cape Leveque. 'The formation consists of light red-brown rather coarse sandstone, which is hard and well-bedded and contains little or no mica. The maximum thickness of this sandstone is about thirty feet. . . . It is overlain by Quaternary fresh-water limestone, red soils and dunes. Its lower limit cannot be clearly defined, because there are passage beds, five to ten feet thick, which grade into the underlying Broome Sandstone.'

The Leveque Sandstone contains three forms of *Inoceramus*, which, according to Brunnschweiler (1960), indicate Neocomian, *Rhizocorallium*, which, according to Veevers (1961) indicates Lower Cretaceous, probably Neocomian, and plants, which, according to White (Appendix 6), indicate Upper Jurassic or Lower Cretaceous.

Mowla Sandstone (Jo) (Brunnschweiler, 1954, pp. 50-51; Guppy et al., p. 61; McWhae et al., p. 108)

Brunnschweiler introduced the name Mowla Conglomerate for the intermittent outcrops of strongly cross-bedded conglomeratic sandstone, passing into interbedded sandstone and siltstone near the top that overlie the Jarlemai Siltstone in parts of the Edgar Range. Guppy et al. changed the name to Mowla Sandstone. The thickest measured section is 60 feet. No fossils have been found, and its top is eroded. According to Brunnschweiler, 'fairly well-defined erosional disconformities alternate laterally with vague transitions at the contact with the underlying Jarlemai Siltstone. . . . It seems that the increasing shedding of quartz grit and small pebbles into the youngest beds of the Jarlemai Siltstone foreshadows the lithology of the Mowla Conglomerate, which may therefore be only slightly younger than the youngest beds of the Jarlemai Siltstone.' McWhae et al. disregarded Brunnschweiler's field evidence of local transitions between the Mowla Sandstone and the Jarlemai Siltstone, and seeing only the disconformity, argue that a Lower Cretaceous age is more likely than Upper Jurassic. In the correlation chart (Fig. 78), the age of the Mowla Sandstone is given as uppermost Tithonian to lowermost Neocomian.

Melligo Quartzite (Km) (Brunnschweiler, 1957, p. 9; McWhae et al., p. 107)

Brunnschweiler introduced the name Melligo Quartzite for the youngest Cretaceous formation found in Dampier Peninsula. Like the Jowlaenga Formation, it is exposed on the east coast of Dampier Peninsula, and in the Fraser River area. McWhae et al. called it the Melligo Sandstone because it consists of 'white to light grey, medium- to coarse-grained quartz sandstone, which is partly silicified and locally contains conglomerate beds. It is poorly bedded to cross-bedded. . . . It is only silicified superficially.' Brunnschweiler argued that the silicification 'is due to some primary, intrinsic quality of the formation, not, or only to a minor degree, to subsequent lateritization'. Until the details for McWhae et al.'s amendment are published, we use Brunnschweiler's term.

The Melligo Quartzite ranges from 40 to 70 feet in thickness. It forms an erosion surface on the top of mesas and buttes in the Fraser River area (Fig. 93), and is overlain by Quaternary deposits on the east coast. Wherever its base is exposed, the Melligo Quartzite overlies the Jowlaenga Formation, except on Apex Island, where it overlies Precambrian quartzite. The junction between the Melligo Quartzite and the Jowlaenga Formation is described on p. 152.

Pelecypods and belemnites have been found in the Melligo Quartzite, and, according to Brunnschweiler (1957, 1960), these probably indicate Aptian.

Frezier Sandstone (Kf) (McWhae et al., p. 108)

'The Frezier Sandstone is known in the area south of Broome on Frazier [*sic*] Downs, Anna Plains and Thangoo Stations. It is named after Cape Frezier (18° 53′ S, 121° 37′ E), where the type section is located. In this section twenty feet of cross-bedded sandstone, conglomeratic sandstone and rare siltstone are exposed on a cliff face. At Cape Gourdon the unit is 55 feet thick.

'The Frezier Sandstone contains rare marine fossils which suggest a Lower Cretaceous age. It disconformably overlies the Parda Formation and is overlain disconformably by Quaternary deposits.'

Dickins (Appendix 4) identified *Pseudavicula papyracea* Eth. Jnr 1907 from the Frezier Sandstone, two and a half miles south of La Grange Telegraph Station. This species indicates Lower Cretaceous, probably Aptian.

The intervals 134 to 559 feet in Samphire Marsh No. 1 and 100 to 346 feet in BMR 4, 4A Wallal (Fig. 68) are identified as Frezier Sandstone. These rocks are barren, but they overlie the Anketell-Parda Formation, the upper part of which in these bores is Aptian, and hence the Frezier Sandstone here is Aptian or younger.

Correlation

Figure 78 shows the correlations between Jurassic-Cretaceous formations in the Canning Basin, and Figure 79 the methods employed in dating, and hence correlating, these rocks. Figure 78 is but one of many such charts that could be drawn on the basis of present-day knowledge. The chief variable relates to those parts of sections, indicated by broken lines in Figure 78, that contain either a hidden hiatus or strata not yet dated. Before a firmly-based palaeogeography can be described, the hiatuses must be more closely estimated than they are at present.

The chart is nevertheless accurate enough to indicate that nearly all the Jurassic and Cretaceous formations that extend from one area to another are diachronous, and hence that similar lithology alone is invalid as a means of extended correlation. In fact, a glance at the chart shows that the reverse—that dissimilar lithology suggests correlation—is true of most of these rocks.

The smallest divisions of geological time that are applicable in the Jurassic and Cretaceous of the Canning Basin are indicated in Figures 78 and 79. These undifferentiated divisions are: Middle Jurassic, Oxfordian, lower and upper Kimmeridgian, lower, middle and upper Tithonian, lower and upper Neocomian, lower and upper Aptian.

PALAEOGEOGRAPHY

In the Canning Basin, two types of rock were deposited during the Jurassic and Cretaceous. Coarse to conglomeratic sandstone and conglomerate with thin beds of siltstone, all of which contain abundant, generally poorly preserved plants; and claystone, shale, and sandy siltstone—the siltstone is glauconitic, except in deeply weathered outcrops, and is interbedded with fine quartz sandstone. The first type, the conglomeratic sandstone, is interpreted as a shallow-water (littoral) deposit, the second type, the siltstone and claystone, as a deeper-water (neritic) deposit. This may seem an unnecessarily over-simplified interpretation, but the theory based on it is self-consistent, and, moreover, accounts for nearly all the relevant observed facts.

Here we must point out that many parts of the theory described below were foreshadowed by Brunnschweiler (1954, 1957, most of it written in 1952). This is remarkable in view of the fact that Brunnschweiler had seen the Mesozoic of Dampier Peninsula and the Edgar Range only, and that when he wrote his report in 1952, the greater area of Mesozoic rocks of the basin was unexplored, and Wapet's drilling campaign had not started.

The oldest known Jurassic deposits in the Canning Basin, except some Triassic-Jurassic rocks, are the conglomerate sandstone that underlies the Oxfordian-Kimmeridgian glauconitic siltstone at Broome and Roebuck Bay, and the conglomeratic sandstone and siltstone which Balme dates as Middle Jurassic or lowermost Upper Jurassic in BMR 4A Wallal and as pre-Oxfordian (Bajocian-Bathonian) in Samphire Marsh No. 1. Middle Jurassic rocks are probably present at the base of the type Callawa Formation, and also at the base of the type Jurgurra Sandstone. Figure 115A is drawn on the basis of this dating. The minimum extent of the transgressive sea is shown by the broken line in Figure 115A. The eastward limit of the Middle Jurassic deposits is concealed by younger rocks; the 'embayment' in the Edgar Range area (Fig. 115A) is probably due to the deep dissection of this area, and the consequent exposure of Middle Jurassic rocks; south-westward, Middle Jurassic rocks are detectable only by the drill, at least until the south-western part of the basin is reached. The sea probably extended farther eastward to the limit indicated on Figure 115A by the solid line.

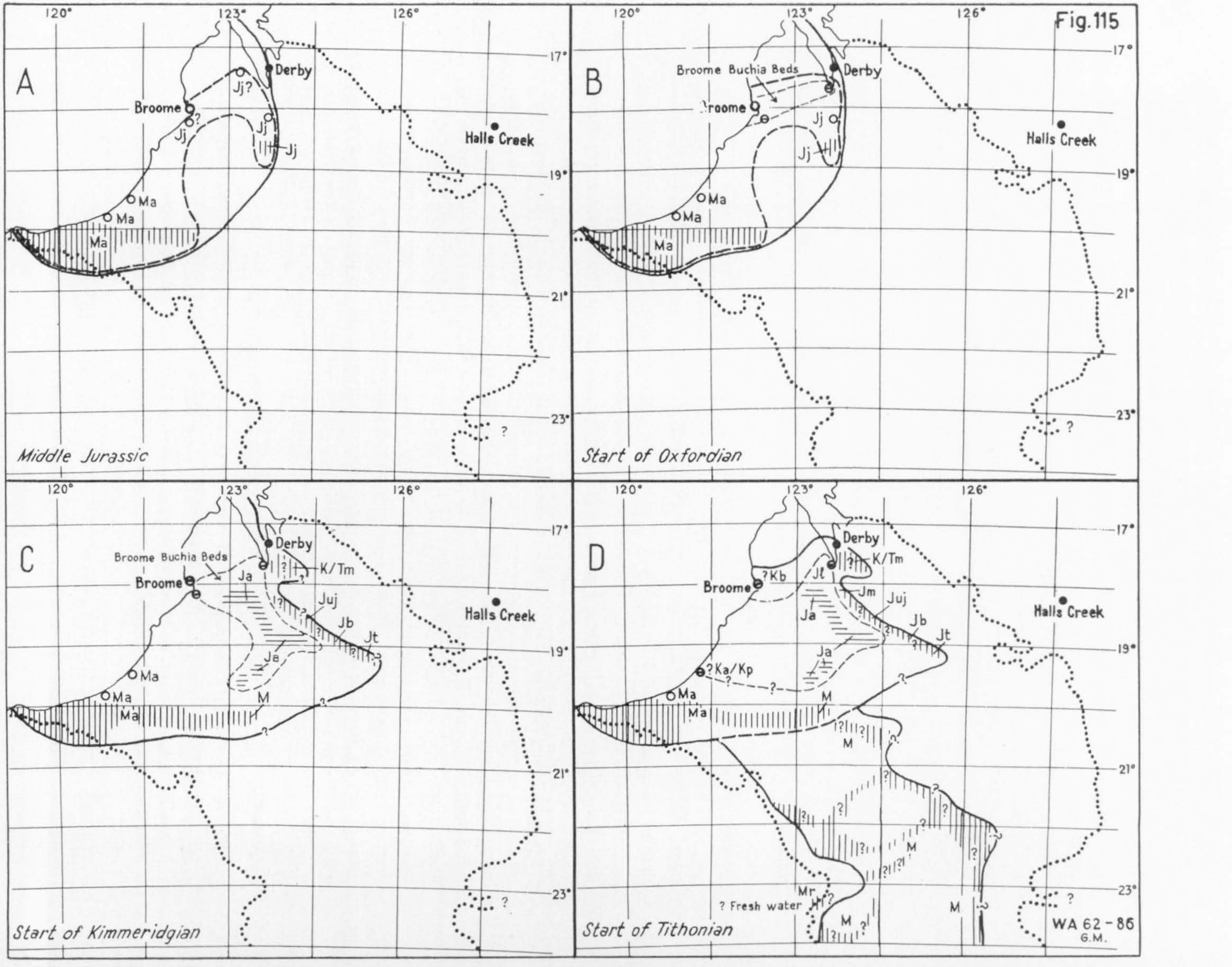
The extent of the sea at the beginning of the Oxfordian (Fig. 115B) was probably much the same as that of the preceding Middle Jurassic. The new element in the Oxfordian was the area of glauconite deposition—new in that, whereas glauconite was probably deposited earlier farther westward, in the area of the present-day Rowley Shelf, the glauconite on Dampier Peninsula was the first laid down on the area of present-day land. Oxfordian glauconitic siltstone is known from bores at Broome, Roebuck Bay, and Yeeda. The southern limit of deposition of glauconite lies somewhere between these bores and the Edgar Range, where coarse sandstone or a hiatus represents the Oxfordian.

The sea advanced eastward during the Oxfordian until by the start of the Kimmeridgian it occupied the area shown in Figure 115C. Glauconite deposition probably continued in the Broome/Roebuck Bay/Yeeda area; south-eastward, in the Edgar Range/McLarty Hills area (Alexander Formation), conditions were sufficiently different to inhibit the formation of glauconite. In the Kimmeridgian, the fine-grained rocks were probably flanked to the north by coarser-grained rocks (the Meda Formation, Mudjalla, James, Barbwire, and Millyit Sandstones), which were deposited along a coast formed by ranges of folded and faulted Permian rocks. Part of the Callawa Formation and part of the grit at Battlement Rocks formed the southern flank. Clear evidence of a former shore-line is provided by the boulder beds in the type locality of the Callawa Formation.

At least two changes took place between the start of the Kimmeridgian and the start of the Tithonian (Fig. 115D). First, the coastline in the north-western part of the basin moved a short distance southward, so that where glauconite was formerly deposited, there was now either conglomeratic sandstone or no deposition. In the Langey Crossing/Yeeda area, lowermost Tithonian rocks with glauconite are not directly known, but Oxfordian-Kimmeridgian and uppermost Tithonian glauconitic siltstones are known in the area, and glauconite was probably deposited also during the rest of the Tithonian. At Samphire Marsh, the oldest dated glauconitic rock is Neocomian; the upper part of the underlying conglomeratic sandstone is Oxfordian-Kimmeridgian; these formations are probably conformable (they are certainly so in BMR 4A Wallal), so the boundary must lie somewhere within the Tithonian. For the purpose of drawing Figure 115D, we have assumed that the finer-grained rocks were first deposited at Samphire Marsh during the Tithonian, and at Wallal during the Neocomian (Fig. 115E). Probably simultaneously with the southern shift of the glauconite-depositing area, the littoral area shifted southward, and conglomeratic sandstone was deposited. The oldest dated part of the upper conglomeratic sandstone (Broome Sandstone) in the Broome area is Neocomian, at the top of the formation. The youngest dated part of the underlying glauconitic beds is probably Kimmeridgian. The greater part (about 900 feet) of the Broome Sandstone lies between the fossiliferous beds that indicate Kimmeridgian and Neocomian. The four bores at Broome indicate that the junction between the 'Broome *Buchia* Beds' and the Broome Sandstone is fairly flat (*see* p. 179); if this junction is conformable, the Broome Sandstone ranges through the Tithonian (as indicated in Figs. 78 and 115D).

Secondly, the sea probably transgressed south-eastward at least as far as 24° S, and deposited quartz sandstone, of which the Cronin Sandstone may have formed part, though it was more probably deposited in a lagoon as indicated in Figure 115D. The Callawa Formation and the Mesozoic sandstone underlie the Neocomian Anketell Formation and the Kidson Beds with apparent conformity, and hence are probably Tithonian.

The sea transgressed eastward to $127\frac{1}{2}$° E and probably had its widest extent at the beginning of the Neocomian (Fig. 115E). The southern part of the basin became the main area of deposition of fine-grained rocks, and only a small area in the north (Jowlaenga Formation) remained. Littoral deposits (the Broome Sandstone westward, Mowla Sandstone southward) border part of the Jowlaenga Formation, and may



A
Middle Jurassic
B
Start of Oxfordian
C
Start of Kimmeridgian
D
Start of Tithonian
120°
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
Broome Buchia Beds
Jj
Jj?
Ma
K/Tm
Ja
Juj
Jb
Jt
Jm
M
?Kb
?Ka/Kp
Mr
? Fresh water
WA 62-86
G.M.

Fig. 115

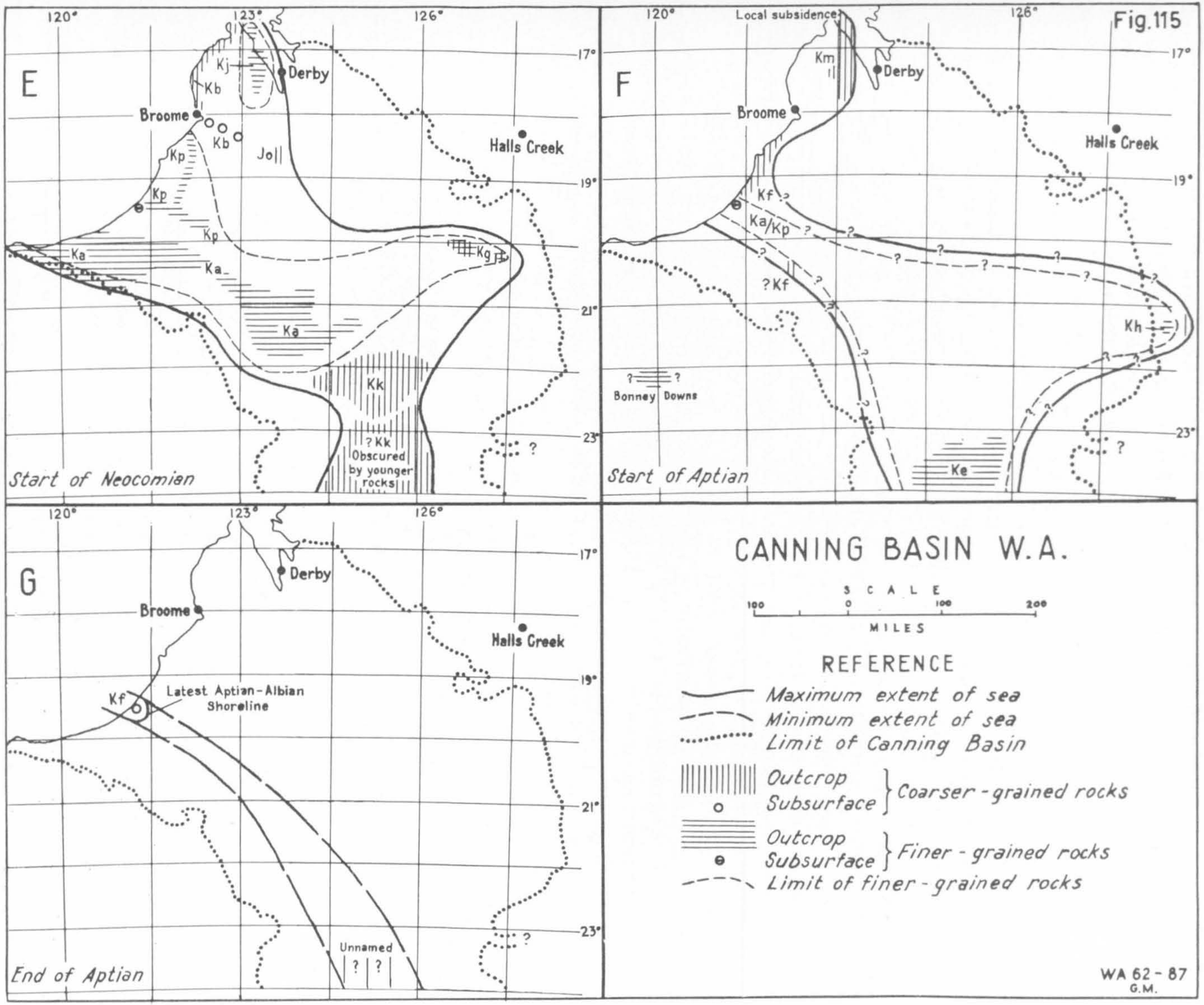


Fig. 115.—Palaeogeographical maps Middle Jurassic to Lower Cretaceous.

actually have isolated the Jowlaenga Formation from other finer-grained rocks southward. Wapet bores between the Edgar Range and Roebuck Bay penetrated near the surface a coarse sandstone, which overlies the Jarlemai Siltstone. The Mowla Sandstone locally grades down into, locally disconformably overlies, the Jarlemai Siltstone. At the oldest, the Mowla is therefore just younger than mid-Tithonian, and probably ranges into the lowermost Neocomian. The Godfrey Beds, which are probably Neocomian, were laid down near the boundary of the two depositional areas (littoral and neritic) and thus contain both finer- and coarser-grained rocks. The Anketell and Parda Formations are fine-grained rocks (the Anketell Formation locally contains thin beds of grit), and in the only bores (Samphire Marsh and BMR 4, 4A Wallal) which penetrate the Anketell-Parda Formation, it contains glauconite. Shallower-water deposits are represented by the coarser-grained Kidson Beds and by the sandstone farther south (probably Kidson Beds) that underlies the Bejah Beds. Coarser-grained equivalents of the Anketell Formation are not known in the south-western part of the basin. Either these equivalents are unidentified in the undifferentiated Mesozoic sandstone, or they have been removed by erosion.

The record of Aptian deposition is fragmentary. Coarser-grained Aptian rocks are known in Dampier Peninsula (Melligo Quartzite) and southwest-ward on the coast (Frezier Sandstone). The regression of the sea during the deposition of the Melligo Quartzite was reversed for a short time at Apex Island,where the Melligo Quartzite directly overlies Precambrian rocks. The bed of sandstone that overlies the Anketell Formation at A11 (Fig. 95; *see* Traves et al., p. 29) is slightly younger than Neocomian, probably Aptian. The finer-grained rocks are represented by the Bejah Beds, most of the Hazlett Beds, which also contain some coarser rocks, and rocks penetrated by Samphire Marsh No. 1 Bore; all these contain radiolaria like those of the Windalia Radiolarite of the Carnarvon Basin. In the Bejah and Hazlett Beds, siliceous claystone and shale are dominant, and are unlike any older Mesozoic sediments in the basin except perhaps the silty shales of the Alexander Formation. The coarser rocks in the Hazlett Beds lie in the easternmost part of the outcrop (Fig. 113), and are probably shore-line deposits. Claystone from Bonney Downs contains radiolaria which Dr Crespin (pers. comm.) finds similar to forms in the Bejah and Hazlett Beds; the claystone was probably deposited in an arm of the sea that flooded the Fortescue River area, but probably did not link up with the Canning Basin.

The narrow opening of the epicontinental Aptian sea possibly explains in part why claystone with radiolaria, rather than interbedded siltstone and fine sandstone with foraminifera, is the dominant sediment.

The youngest known Mesozoic rocks in the Canning Basin are the coarser-grained rocks that overlie the claystone of the Bejah Beds and that overlie the radiolaria-bearing sediments in Samphire Marsh No. 1 Bore (Fig. 115G). These rocks are interpreted as the final regressive shore-line deposits of the Mesozoic sea.

The theory outlined above accounts for most of the observed facts. A more complex theory, involving a double cycle of marine transgression and regression, is supported by the occurrence of a ferruginous and siliceous cap on the Anketell-Parda Formation in BMR 4, 4A Wallal Bores (Fig. 68). If this cap is interpreted as a Mesozoic duricrust, it indicates the regression of the sea early in the Lower Cretaceous, and exposure of the Anketell-Parda Formation, before the deposition of the Frezier Sandstone. Whether this postulated early Cretaceous regression was general in the Canning Basin remains to be studied further.

POONDANO FORMATION (Jp) (McWhae et al., p. 124)

Lindner & Drew (*in* McWhae et al.) briefly described the Poondano Formation as follows:

'The Poondano Formation caps mesas in the area between Poondano Well (20° 26′ S, 118° 48′ E) and Wallaringa Peak, twenty miles south-east of Port Hedland. It consists of pisolitic ironstone containing fossil wood, and unsorted silty kaolinitic quartz sandstone. The formation overlies Precambrian crystalline rocks and perhaps also the Lower Cretaceous [*sic*] Callawa Formation. It is believed to be of lacustrine origin, and the character of its occurrence suggests that it may be homochronous with the development of the Oakover Beds.'

In 1955 and 1956, J. N. Casey and A. T. Wells briefly visited the type locality of the Poondano Formation, and mentioned it in Traves et al. (p. 31). These notes are based on this field work and on air-photograph interpretation. Traves et al. describe a locality of the Poondano Formation (loc. A on Fig. 116) as follows:

'A hill 20 miles east [actually 25 miles east-south-east] of Port Hedland is capped with 20 feet of pisolitic ironstone which resembles a ferruginous zone of a laterite; but it contains fossil wood and probably has a lacustrine origin. Chemical analysis of this deposit shows:

Loss on ignition at 100°C*	13.80%
SiO_2	1.89%
Fe_2O_3	77.50%
Al_2O_3	8.75%.'

Analyses by S. Baker (May, 1959) of other specimens of ironstone from this locality are:

	P.H. 1a	*P.H. 1b*
Fe_2O_3	74.90%	78.20%
SiO_2	7.23	4.35
Al_2O_3	2.80	1.70
Loss on ignition ...	12.94	15.50

The above results refer to the samples dried to constant weight at 105°C.

The ironstone is underlain by ten feet of sandstone which in turn overlie Precambrian Rocks.

The Precambrian rocks of the Port Hedland Sheet area may be grouped into three parts:

(a) deformed metamorphic rocks (greenstone, jasper, marble, slate), intruded by

(b) granite, which forms a plain covered by sparse spinifex and alluvial sand. On the air photographs, the granite plain is uniformly light-coloured, with a few platforms and hillocks of exposed granite. Linear structures in the exposed rock continue

* This should probably be 1000°C. Analysis by I. Reynolds, November 1954.

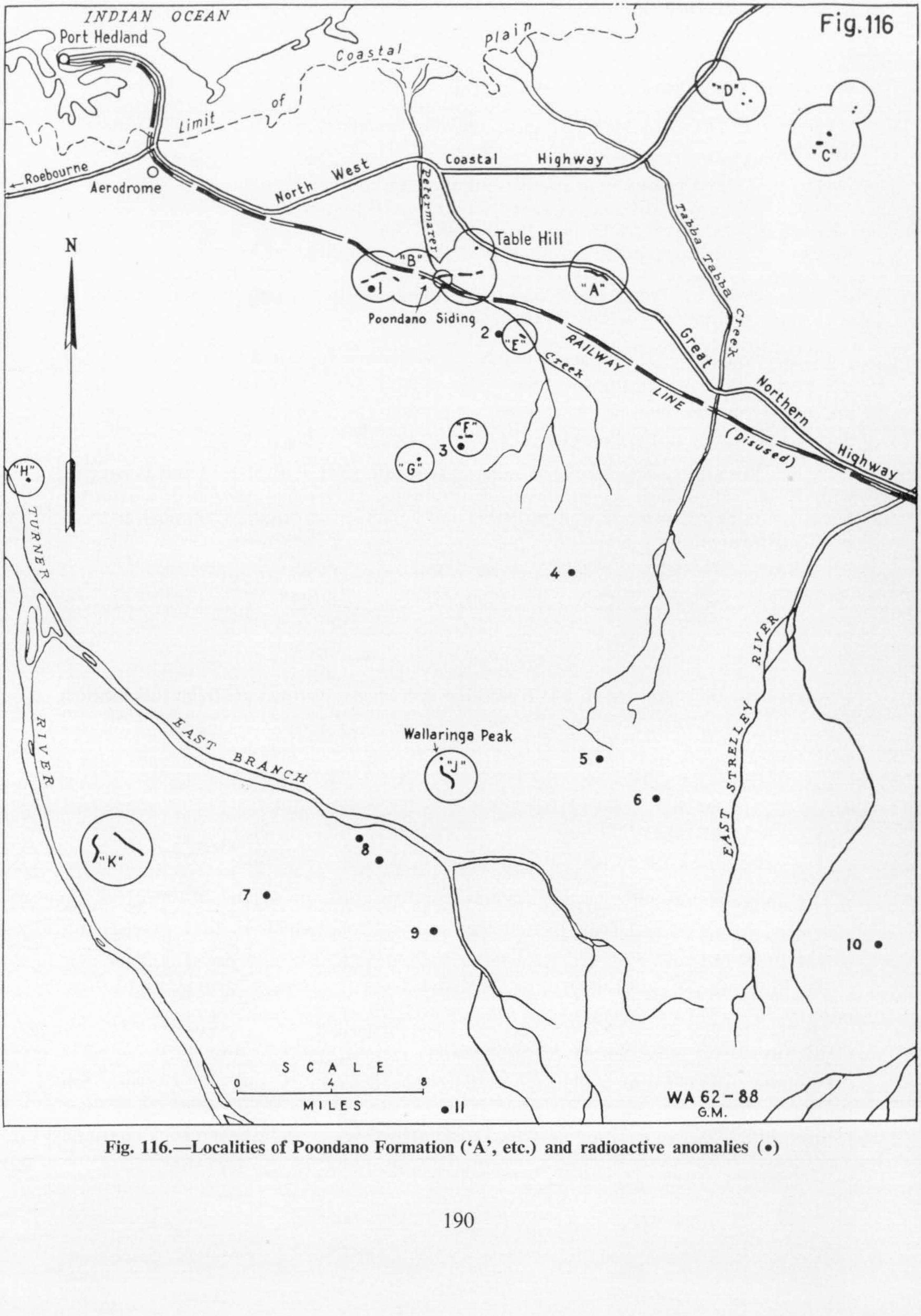


Fig. 116.—Localities of Poondano Formation ('A', etc.) and radioactive anomalies (•)

under the sand, and are indicated by lines of vegetation. In places, the granite is crossed by dykes of dolerite up to 250 yards across.

(a) and (b) are overlain unconformably by

(c) gently folded sandstone, dolomite, and volcanic rocks.

The only other rocks in this area are the flat-lying deposits of Poondano Formation, which, except for two deposits ('J' and 'K') which overlie Precambrian metamorphic rocks, overlie the Precambrian granite.

Deposit A is a 20-foot-thick ironstone cap on a granite butte 70 feet high, one mile from east to west, and, on the average, 250 feet wide at the top, and 1500 feet at the base. The contact between granite and sandstone is obscured by ironstone talus, except at the eastern and western ends of the butte, where patches of white on the air photographs probably indicate granite. The ironstone talus has straight or evenly curved contacts with the Quaternary sand. This is one of the main criteria for recognizing ironstone deposits on air photographs of this area, because the talus from Precambrian rocks in the area is crossed by 'fingers' of sand, and nowhere makes a straight or evenly curved contact with it. The contact between the sandstone and the ironstone lies at the base of the prominent 20-foot scarp. Sparse vegetation grows on the talus, none on the ironstone. The ironstone cap lacks drainage, and is dark brown, almost black, and horizontal.

W. B. Dallwitz described the two specimens from Deposit A:

'*Specimen PH 1a* (slides 4539 and 4540) is a rather coarsely pisolitic ironstone containing fragments of fossil wood measuring up to 2.5 cm. by 1 cm. Pore-spaces commonly remain near contiguous pisolites, and are also found in other positions throughout the rock. The largest pisolite is about 1 cm. across. Some soft whitish patches of probable argillaceous material are scattered through the rock.

'In thin section the rock is seen to consist of ironstone pisolites and fragments of wood replaced by ironstone, set in a matrix of ironstone containing angular grains of quartz. Concentric banding of various degrees of perfection is developed in the pisolites.

'Cores of the pisolites consist of: fragments of wood replaced by ironstone (Fig. 117); unbanded or faintly banded ironstone; fragments of sandy ferruginous argillite; and pieces of broken, banded pisolites.

'The pisolites are held together by structureless ironstone rather porous in places, which contains very unevenly distributed angular quartz grains, pieces of broken, banded pisolites, and large to small fragments of sandy ferruginous argillite which are not surrounded by banded ironstone.

'Kaolin or other clay mineral occurs in small pockets (these are the whitish patches noted in the hand specimen). Some cavities are partly lined by a layer of opal up to 0.08 mm. thick. In one place thin alternating layers of clay mineral and opal line a cavity.

'*Specimen PH 1b* (slide 4541) is a pisolitic ironstone in which the average size of the pisolites is notably less than that seen in specimen PH 1a. Fragments of fossilized wood are much rarer than in specimen PH 1a. Figure 118 shows pieces of broken pisolites in this rock, with new material built up around them.

'The cores of the pisolites consist of materials similar to those described for specimen PH 1a.'

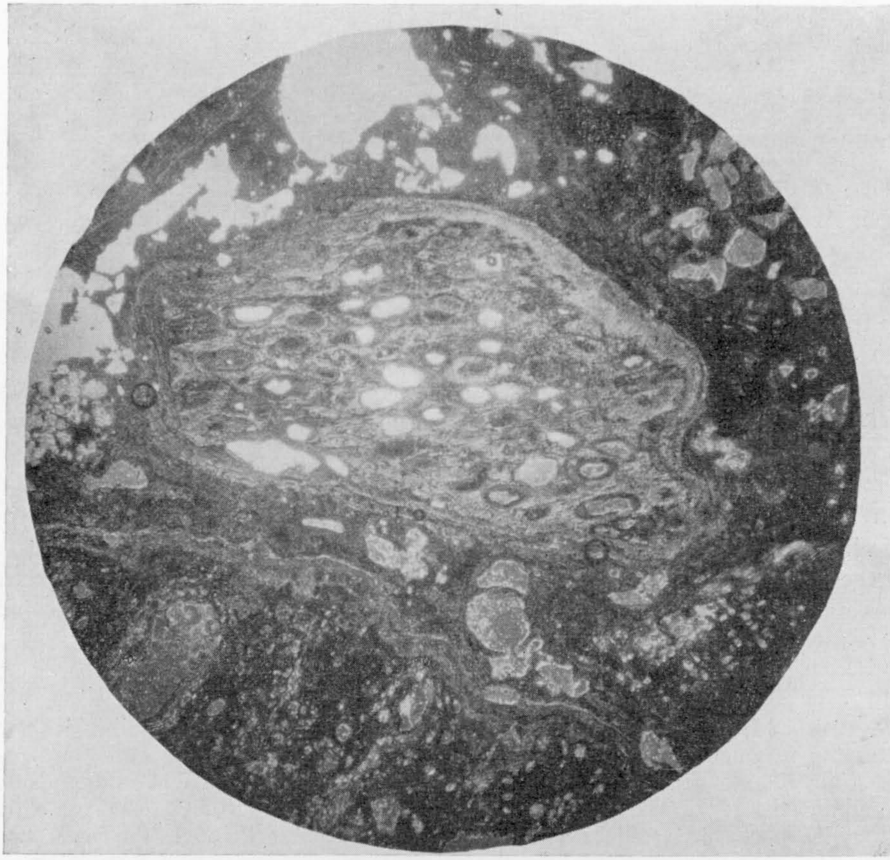


Fig. 117.—Specimen PH 1a, slide 4539. Ferruginized wood in porous ironstone containing angular quartz grains. ×34.5. Photo by J. Zawartko.

Deposit B—four miles west of Deposit A—is a west-trending discontinuous chain of buttes; Table Hill lies one mile northward. The buttes are thinly capped with pisolitic ironstone, and rise abruptly above talus-covered granite. The chain is cut by the north-flowing Petermarer Creek. The buttes east of Petermarer Creek form an almost continuous chain two miles long, about 220 yards wide at base of talus, and about 50 yards wide at the ironstone cap. The five ironstone-capped buttes on the western side of the creek form a less continuous chain; three are surrounded by a continuous sheet of ironstone talus which is $3\frac{1}{2}$ miles long, and from 100 to 900 yards wide. These three buttes are only about 30 feet high. Nearer the creek are two isolated buttes; one is elongated east-west, in the same direction as those east of the creek; the other is almost conical.

Deposits A and B are the only ones that were visited by Bureau geologists. Air-photograph interpretation indicates the probable occurrence of other ironstone deposits in the Port Hedland Sheet area, e.g., Wallaringa Peak, and McWhae et al. confirm this interpretation. These deposits (C—H, J, K), are shown in Figure 116.

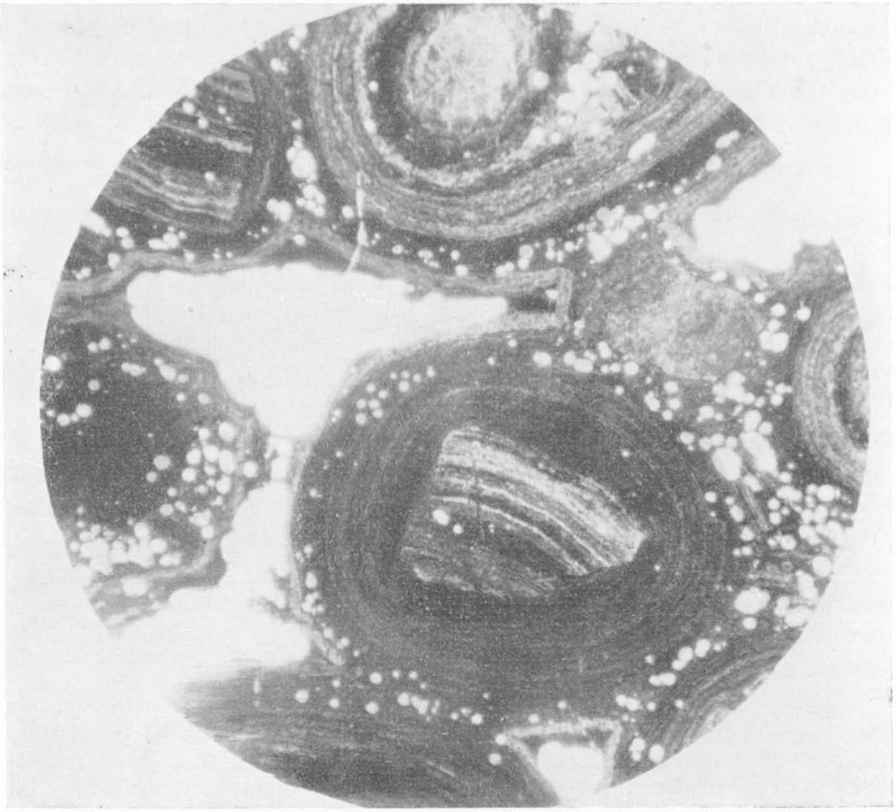


Fig. 118.—Specimen PH 1b, slide 4541. Fragment of pisolite as the nucleus of a subsequently formed pisolite. ×19.5. Photo by J. Zawartko.

Origin and Age of the Pisolitic Ironstone

The abundance of replaced wood in the pisolitic ironstone of Deposit A suggests that it is similar to the bog limonites being deposited at the present day in Sweden, Finland, and Canada. Bog limonites commonly consist of concretionary limonite. 'Precipitation appears to take place most vigorously in extremely shallow water, and many lakes with extensive bog-iron deposits in the marginal marshes appear to deposit sediments containing much smaller proportions of iron materials in their deeper parts.' (Hatch, Rastall, & Black, 1950, pp. 146-147.)

Traves et al. (p. 31) considered the ironstone to be lacustrine, but pointed out that it could be easily confused with laterite, presumably because it protects the underlying rock from erosion, and is itself eroded by scarp retreat only. It differs from the ferruginous zone of a laterite profile by the high content of iron oxide, which replaces wood, and the low content of silica.

The nearest wood-bearing sediments are the outcrops of Callawa Formation along the margin of the Canning Basin, 25 miles to the north-east. These rocks are Mesozoic, probably Jurassic, and are shore-line deposits of siltstone, sandstone, and conglomerate, and contain abundant plant remains. The best estimate of the age of the ironstone deposits (and the underlying conformable sandstone) is therefore Mesozoic, probably Jurassic. Traves et al. (p. 30) consider that the ironstone is possibly Tertiary, because the laterite present earlier in the Tertiary could have provided a source of iron oxide. A palaeobotanical examination of the wood may indicate the age.

Radioactive Anomalies

The map of radioactive anomalies in the western part (Sheet 1) of the Pilbara Region of Western Australia shows radioactive anomalies detected by airborne scintillograph (*see* Fig. 116). The aircraft was flown at a height of 500 feet along lines a mile apart, so only 10% of the area was covered. Deposits C and D lie immediately outside the surveyed area.

Three radioactive anomalies occur over granite close to ironstone deposits. Anomaly 1 is at the edge of the talus slope of Deposit B, 200 yards from the ironstone cap; Anomaly 2 is a mile west of Deposit E; and Anomaly 3 is on the edge of the talus slope of Deposit F, 200 yards from the (?) ironstone cap. Radioactive anomalies may occur near the other deposits of ironstone in the area, but none were detected in the reconnaissance. The two specimens of ironstone from Deposit A show no radioactivity.

A similar association of radioactive anomalies near the contact of granite and sediments containing plant remains is reported from Russia by Nekrasova (1958, p. 29):

> 'The Jurassic beds are up to 700 m. thick, and are composed of deltaic-fluviatile, lacustrine, and paludal sediments. . . . The ore zones are narrow belts in the Jurassic rocks, near the (faulted) contact of these rocks with Proterozoic granites and metamorphic rocks. Coal-bearing beds occurring away from the granites do not contain economic concentrations of uranium.'

The main differences between the Russian and the Port Hedland sediments are (1) the greater thickness of the Russian sediments; (2) the faulted contact between the Russian sediments and the granite; and (3) the absence of ironstone in the Russian sediments. But the high content of organic matter in the original sediments, the contact with granite, and the radioactive anomalies at or near the contact of granite with the sediments, are features common to both areas.

CAINOZOIC

In the Cainozoic, the coastal fringe of the Canning Basin was intermittently submerged, and the rest of the basin was land. The land was deeply weathered to form a siliceous and ferruginous duricrust up to 50 feet thick, and locally up to 300 feet thick. Thin alluvium, lake sediments, and evaporites were locally deposited on the land, and later, probably in Recent time, a layer of sand, locally 200 feet thick, was spread over almost the whole area.

The greatest variety of Cainozoic sediments is found along the coast, and these are the only Cainozoic sediments in the basin that at the moment can be dated in any detail. Brunnschweiler (1957) studied them in the Dampier Peninsula, and correlated them, in particular the Quaternary sediments, with the European stages. This correlation was based on the interpretation of past climate and eustatic changes in sea level found in the sediments, and, in our opinion, is tentative only.

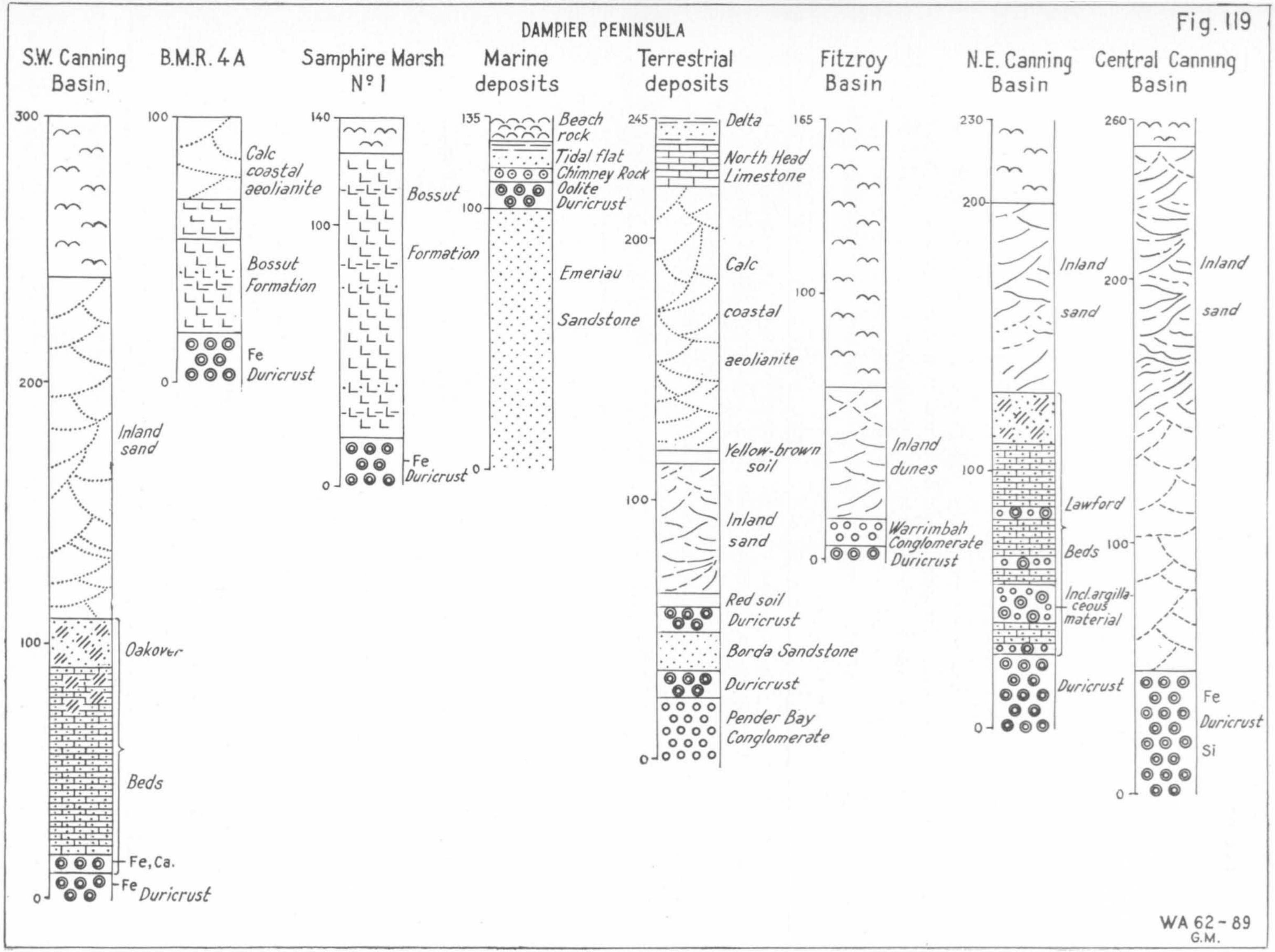


Fig. 119.—Graphic sections of Cainozoic deposits.

The Cainozoic sediments fall into the following categories (in approximate order of decreasing age):

Coastal fluviatile deposits;
Duricrust;
Inland fluviatile deposits;
Lake deposits;
Coastal calcareous rocks;
Sand;
Alluvium, soil, evaporites, and travertine.

Coastal fluviatile deposits

The *Emeriau Sandstone* and the *Pender Bay Conglomerate* (both Brunnschweiler, 1957) are scour-and-fill fluviatile sediments deposited on an erosion surface of Broome Sandstone and Jowlaenga Formation. The ferruginous duricrust on the Pender Bay Conglomerate is disconformably overlain by 15 feet of finer-grained quartz sandstone, the *Borda Sandstone* (Brunnschweiler, 1957), which in turn is overlain by loose pisolitic limonite and red soil.

The Emeriau Sandstone crops out at Carnot Peak and Kings Peak, where it is 100 feet thick, and along the west coast of Dampier Peninsula, principally south of Pender Bay. At Emeriau Point, it is 12 feet thick. It consists of black medium ferriginous sandstone with rounded and angular quartz grains. The sandstone contains no diagnostic fossils; from general considerations, Brunnschweiler regards it as early Tertiary.

The Pender Bay Conglomerate contains pebbles of quartz sandstone and vein quartz, the largest of which are at the base; the matrix is medium quartz sand. The Conglomerate crops out between Cape Boileau and Cape Borda, and in this area does not exceed 12 feet. 25 feet of conglomeratic sandstone with pebbles of vein quartz and chert overlies the Jowlaenga Sandstone on Valentine Island, and Brunnschweiler tentatively identifies it as Pender Bay Conglomerate. The conglomerate contains no fossils, and is regarded as the same age as the Emeriau Sandstone.

The Borda Sandstone crops out at Cape Borda, and is 15 feet thick. It is mainly a soft fine sandstone, and contains reworked Emeriau Sandstone and Pender Bay Conglomerate. According to Brunnschweiler, the Borda Sandstone is older than Pleistocene, and younger than the Emeriau Sandstone and Pender Bay Conglomerate.

Duricrust

The coastal fluviatile deposits and nearly all the outcropping Mesozoic and older rocks in the Canning Basin have been deeply weathered to form a duricrust. This duricrust consists of a layer of pisolitic ironstone (Fig. 120) that overlies silicified mottled and leached bedrock. Where the ironstone layer is locally absent, the surface of the outcrop is silicified. Examples of the duricrust are shown in the various graphic sections in the text. Ironstone is commonly formed on the finer-grained rocks such as siltstone and argillaceous sandstone, whereas thinner siliceous duricrust is formed on coarser-grained quartz sandstone. It is up to 50 feet thick in the central Canning Basin, and much thinner elsewhere.

The duricrust is overlain by sand; lacustrine deposits locally overlie the duricrust in the north-east and south-west Canning Basin, and calcareous rocks in the coastal strip. The duricrust is best exposed in the Morris Sheet area (Fig. 107), over which sand is very thin. Its age is between Upper Cretaceous and the end of the Tertiary.

Inland fluviatile deposits

The *Warrimbah Conglomerate* (Guppy et al.) consists of massive well-rounded water-worn pebbles and boulders that occur in several areas near the lower reaches of the Fitzroy River. Hardman (1884) found *Diprotodon australis* in the Lennard River just below Devils Pass, probably from the Warrimbah Conglomerate. This fossil probably indicates a Pleistocene age.

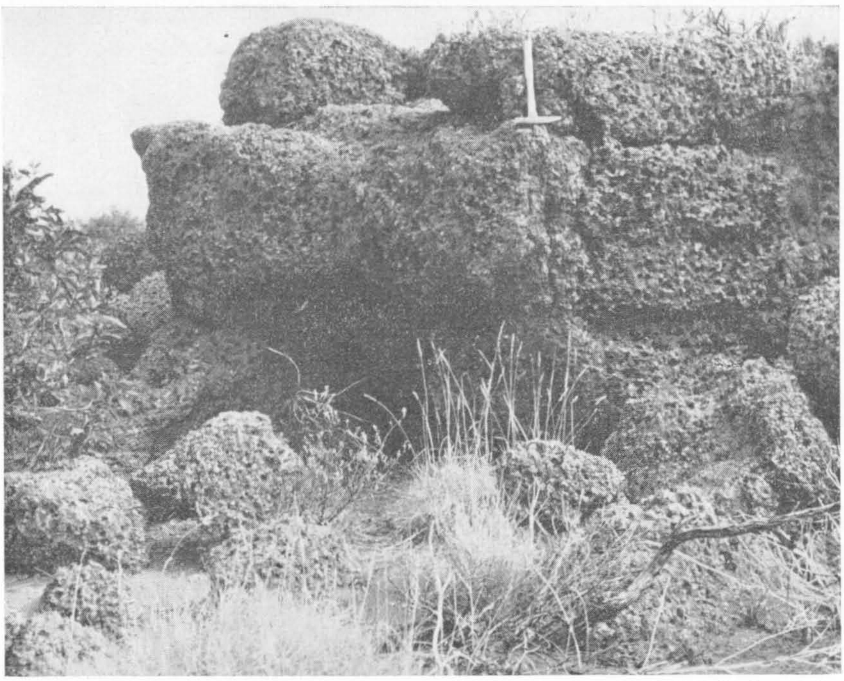


Fig. 120.—Pisolitic ironstone in the upper part of the duricrust at M10a, in the south-central part of the Morris Sheet area.

The *Wolf Gravel* (Casey & Wells) consists of conglomerate, gravel, and sand, of unknown thickness; it occurs principally in a narrow strip on the western banks of Wolf Creek, in the north-east Canning Basin. The present stream bed contains no large boulders, and the ancestral stream was probably much larger.

Lake deposits

The *Oakover Beds* (Maitland, 1904) cover the floor of a large part of the Oakover-Nullagine River valley. According to Traves et al., the Oakover Beds are at least 100 feet thick, and consist of marl and sandy limestone overlain by a 20-foot bed of chalcedony and common opal (Figs. 119, 121). Undiagnostic ostracods have been collected from the limestone beds. The top of the Oakover Beds is eroded.

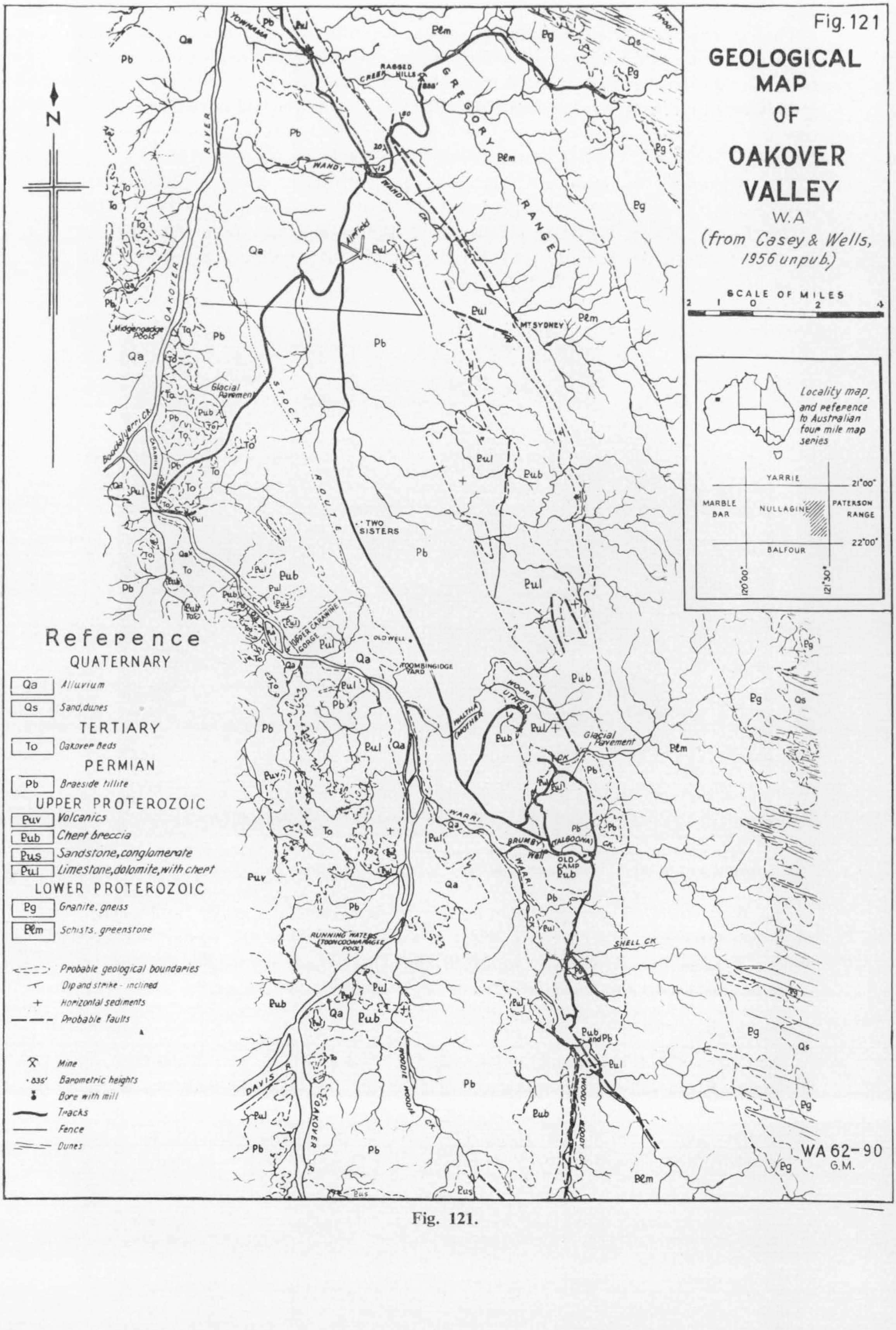


Fig. 121
GEOLOGICAL MAP OF OAKOVER VALLEY
W.A
(from Casey & Wells, 1956 unpub.)
SCALE OF MILES
Locality map and reference to Australian four mile map series
YARRIE
MARBLE BAR
NULLAGINE
PATERSON RANGE
BALFOUR
21°00'
22°00'
120°00'
121°30'
Reference
QUATERNARY
Qa Alluvium
Qs Sand, dunes
TERTIARY
To Oakover Beds
PERMIAN
Pb Braeside tillite
UPPER PROTEROZOIC
Puv Volcanics
Pub Chert breccia
Pus Sandstone, conglomerate
Pul Limestone, dolomite, with chert
LOWER PROTEROZOIC
Pg Granite, gneiss
Plm Schists, greenstone
Probable geological boundaries
Dip and strike - inclined
Horizontal sediments
Probable faults
Mine
Barometric heights
Bore with mill
Tracks
Fence
Dunes
GREGORY RANGE
OAKOVER RIVER
RAGGED HILLS
WANDY CK
Airfield
MT SYDNEY
Midgengadge Pools
Glacial Pavement
STOCK ROUTE
TWO SISTERS
UPPER CARAWINE GORGE
OLD WELL
TOOMBINGIDGE YARD
WOORA
WALTHA (MOTHER)
UTHER
WARRI
BRUMBY Well
(TALBOONA) CK.
OLD CAMP
SHELL CK
RUNNING WATERS (TOONCOONA GORGE POOL)
DAVIS R
OAKOVER R
MOODIE MOODIE CK
WOODY WOODY CK
WA 62-90
G.M.

Fig. 121.

The *Lawford Beds* (Casey & Wells) are exposed in mesas and buttes on the banks of Christmas Creek, Lawford Creek, and Wolf Creek, in the northern parts of the Mount Bannerman and Billiluna Sheet areas. Like the Oakover Beds, the Lawford Beds consist of pisolitic and earthy marl and sandy limestone, with a cap of opaline chalcedony, and, at the base, contain fragments of ferruginous concretions and pisolitic ironstone.

Coastal calcareous rocks

The *Bossut Formation* (Johnstone, 1960) crops out along the coast from Port Hedland to Cape Villaret and on the west coast of Dampier Peninsula. It was penetrated by Samphire Marsh No. 1 and BMR 4, 4A Wallal Bores. In the Samphire Marsh area, the Bossut Formation consists of sandy calcarenite and minor oolitic limestone and calcilutite. According to Johnstone, the formation is a shore-line deposit which includes lithified dunes and beach and offshore bar deposits. The formation underlies Recent silt and sand of the tidal flats, and fills in valleys and irregularities eroded in the duricrust. The Samphire Marsh No. 1 Bore penetrated 107 feet (Fig. 119) of the Bossut Formation, which overlies the pisolitic ironstone cap of the Frezier Sandstone. Elsewhere the formation also disconformably overlies the Parda Formation. The Bossut Formation contains undetermined Recent corals in Samphire Marsh No. 1, and foraminifera and shell fragments in BMR 4A Wallal. The Bossut Formation is tentatively identified with the 'Coastal Limestone' of Western Australia.

The *Chimney Rock Oolite* (Brunnschweiler, 1957) is known from the type locality only, 40 feet above present low-water level. It is calcareous and well bedded, and contains rare foraminifera. The oolites average 1 mm. across. The Chimney Rock Oolite disconformably overlies the Emeriau Sandstone.

The *North Head Limestone* (Brunnschweiler, 1957) is a fine sandy unfossiliferous limestone, up to 15 feet thick, that was deposited during a coastal submergence.

Sand

Sand covers the entire surface of the basin except the outcropping Bejah Beds of the Morris Sheet area, which presumably provide too little sand to form dunes, and parts of the well-watered northern part of the basin (Fitzroy valley). In this sea of sand, called the Great Sandy Desert, the dunes are waves, and outcrops are islands; the sand-sea is static because the sand is held down by vegetation. Dunes are most closely concentrated in the 80-mile wide belt that lies between Wilson Cliffs and McLarty Hills; only a few outcrops in this belt break the continuity of the sand sheet. Madigan (1936) outlined the main features of the Great Sandy Desert in his review of the Australian deserts. No air photographs had been taken of the desert at this time, and Madigan had to rely on explorers' accounts. Guppy (*in* Rennell, 1955) briefly described the sand formations, and pointed out that vegetation covered the area, and fixed the dunes. Evidence that the sand is fixed is as follows:

(1) The only bare sand of any extent in the area, except for small patches cleared by fire, is confined to the uppermost few feet of the dunes. This is the only part of the area, except for bare rock outcrop, where the mantle of vegetation is broken. The

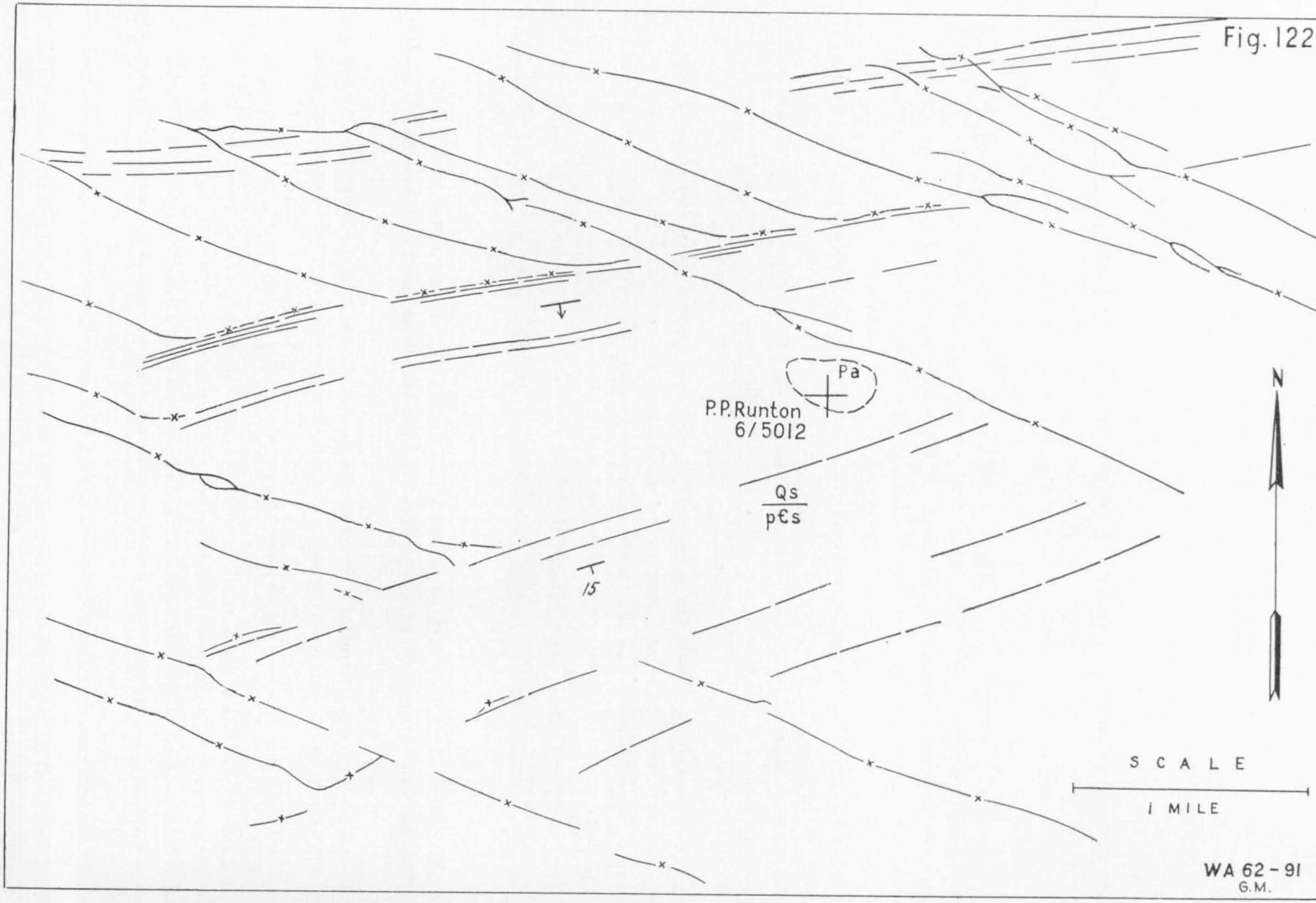


Fig. 122.—Sketch map of part of the Runton Sheet area showing sand shadow behind low strike ridges of Precambrian sedimentary rocks (pCs). Pa—Paterson Formation.

aspect of the desert from the air is thus a plain of green covered by narrow lines of bare, yellow-red sand. When closer examined, these lines are found to be dotted with eucalypts, some quite large, shrubs, and clumps of *Triodia*, or spinifex. In many dunes, beneath which the water table is presumably shallower, the crest is a favourable zone for the growth of larger plants.

(2) Practically no dune possesses the characteristic slip face and sharp transverse outline of the 'live' seif dune. Even in the higher dunes, such as the 120-foot dune illustrated by Traves et al. (fig. 6), a gently rounded outline is preserved. The crestal sand of exceptional dunes has a slip-face on the leeward end.

(3) Net scouring of sand from the windward (eastern) end of dunes, and deposition at the leeward (western) end, are common features, but the amount is small. No bared tree roots were seen, and trees and erections around wells have no sand 'shadow'. Some outcrops (Fig. 122) have ribbons of sand on their leeward side, but these are exceptional.

(4) No ventifacts were seen.

(5) No clouds of dust were seen during high winds. On several days during June to August 1957, the wind reached a speed of 25 knots, but the air remained clear of dust, and only on the ground was movement of sand perceptible. The sand is so tightly held down by vegetation that willy-willies barely raise any sediment.

Holmes (1944, pp. 262-263) distinguishes four main types of desert sand forms: (a) sand drifts caused by protruding rocks or cliffs; (b) crescentic dunes or barchans; (c) longitudinal dunes or seifs; and (d) sand sheets. The seif dune and sand sheet, and exceptionally the sand drift, are found in the Great Sandy Desert. A sheet of sand, interrupted only by rock outcrop and salt lakes, mantles the greater part of the Canning Basin; its maximum thickness is probably about 200 feet. The surface of this sheet is everywhere shaped into seifs, which extend almost continuously across the area. For all their great length, these dunes are low and broad-crested, and most stand barely 30 feet above the sand-covered corridors. The highest is 120 feet. Five different types of seifs are distinguished:

A (Fig. 123): 30 to 70 feet high, 50 to 100 yards across, up to 20 miles long, spaced 1 to 2 miles apart; symmetrical cross-sectional outline, smooth crest, supports spinifex and low scrub; rests on bare rock or gravel surface crossed by shallow sand-choked valleys; no plinth, little or no 'live' sand on crest, few branches. Restricted to rock deserts of Ural and Sahara Sheet areas.

B (Fig. 124): 20 to 40 feet high, 20 to 30 yards across, plinth 50 to 60 yards across, up to 10 miles long, less than 1 mile apart; symmetrical section, smooth crest, supports spinifex and scrub, and, in places, trees, braiding common; rests on sand sheet. Chain dunes incipient. Widespread.

C (Fig. 125): dune chains up to $\frac{1}{4}$-mile across and several miles long, consisting of dunes 20 to 30 yards across, no plinth. Rest on sand sheet. Vegetation, including trees, dense. Distributed in patches in the northern part of Canning Basin, where rainfall is higher, and vegetation denser.

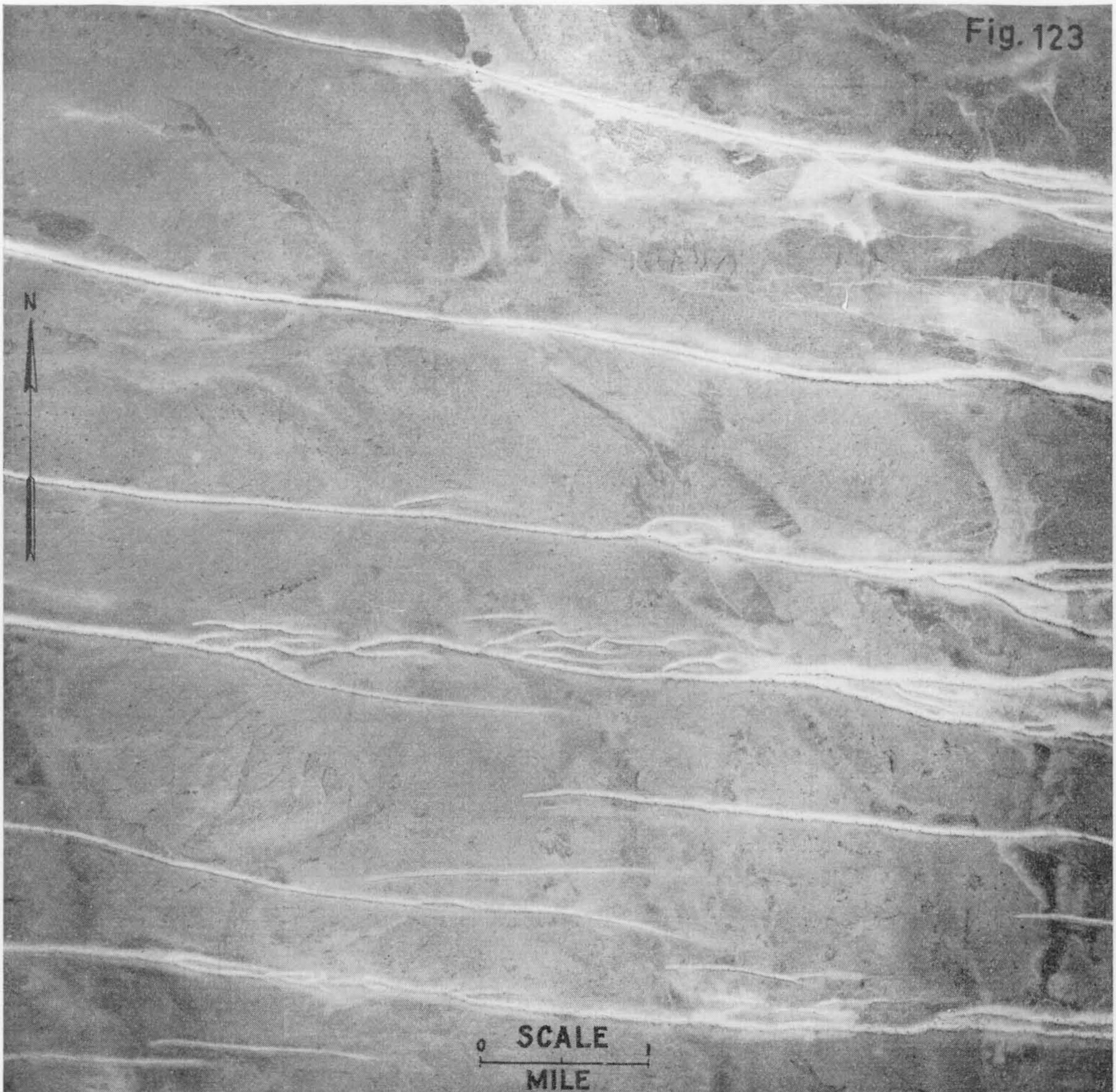


Fig. 123.—Vertical air photograph showing type A dunes. This and the following four air photographs are reproduced by permission of the RAAF.

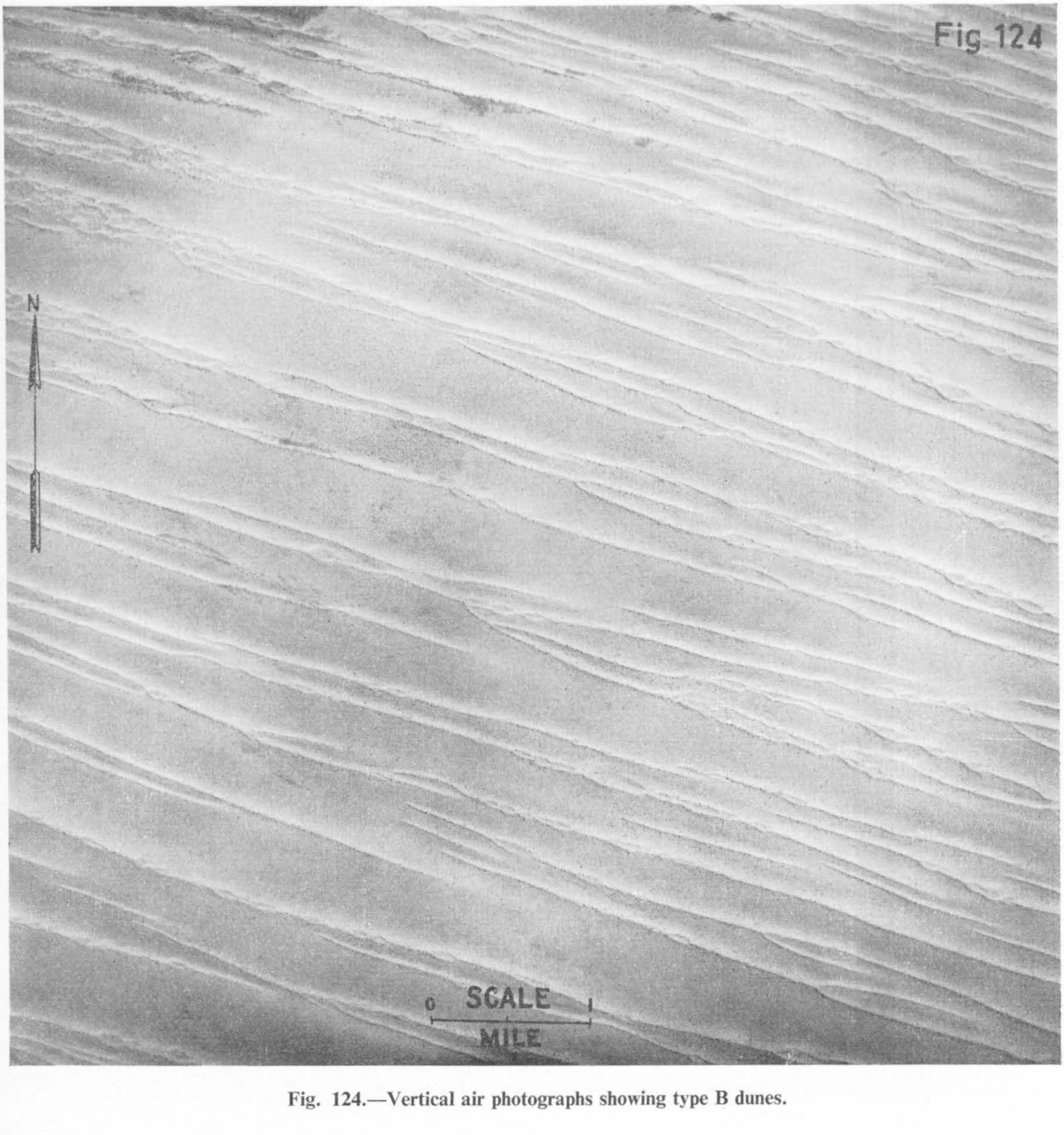


Fig. 124.—Vertical air photographs showing type B dunes.

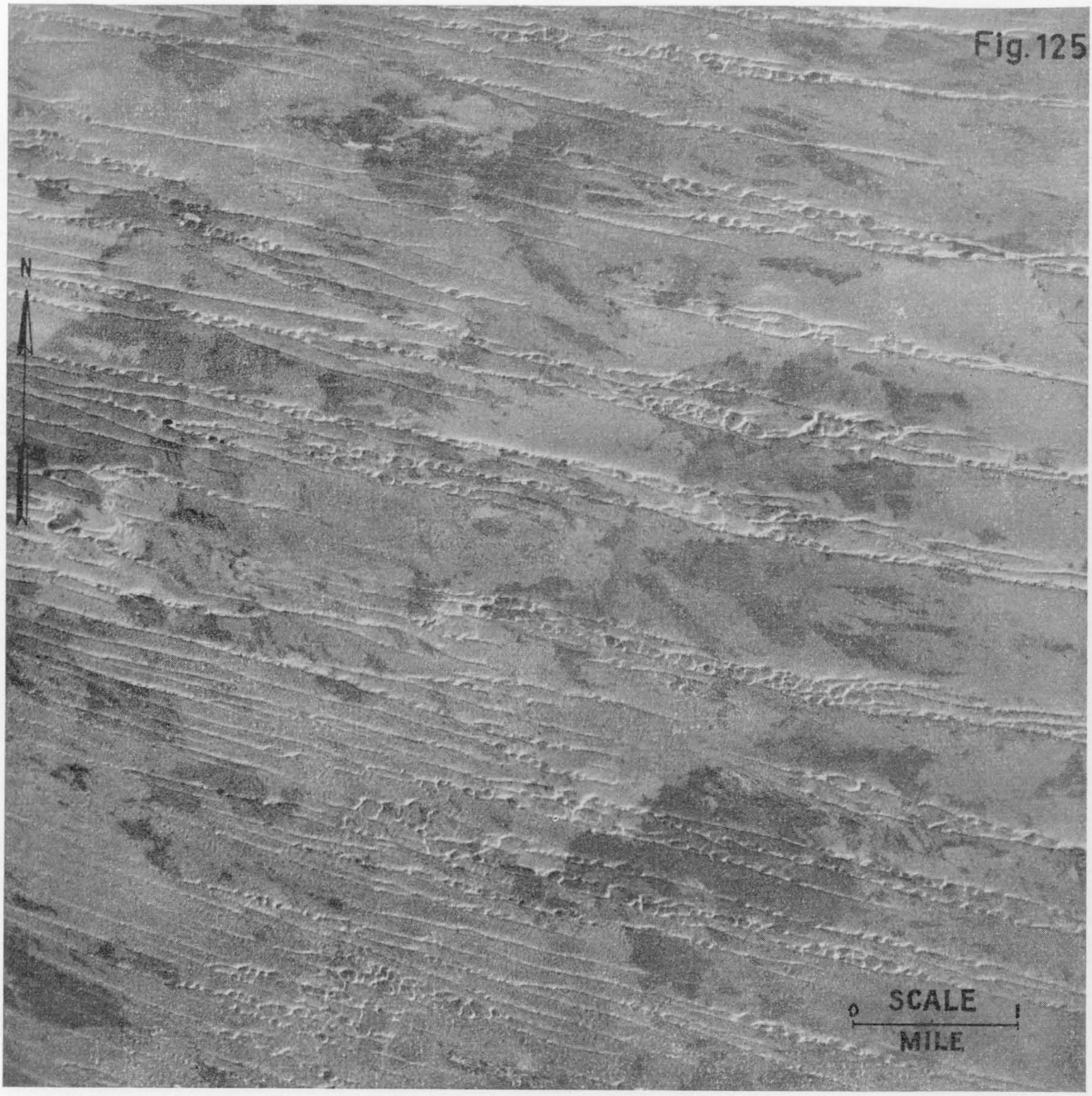


Fig. 125.—Vertical air photograph showing type C dunes.

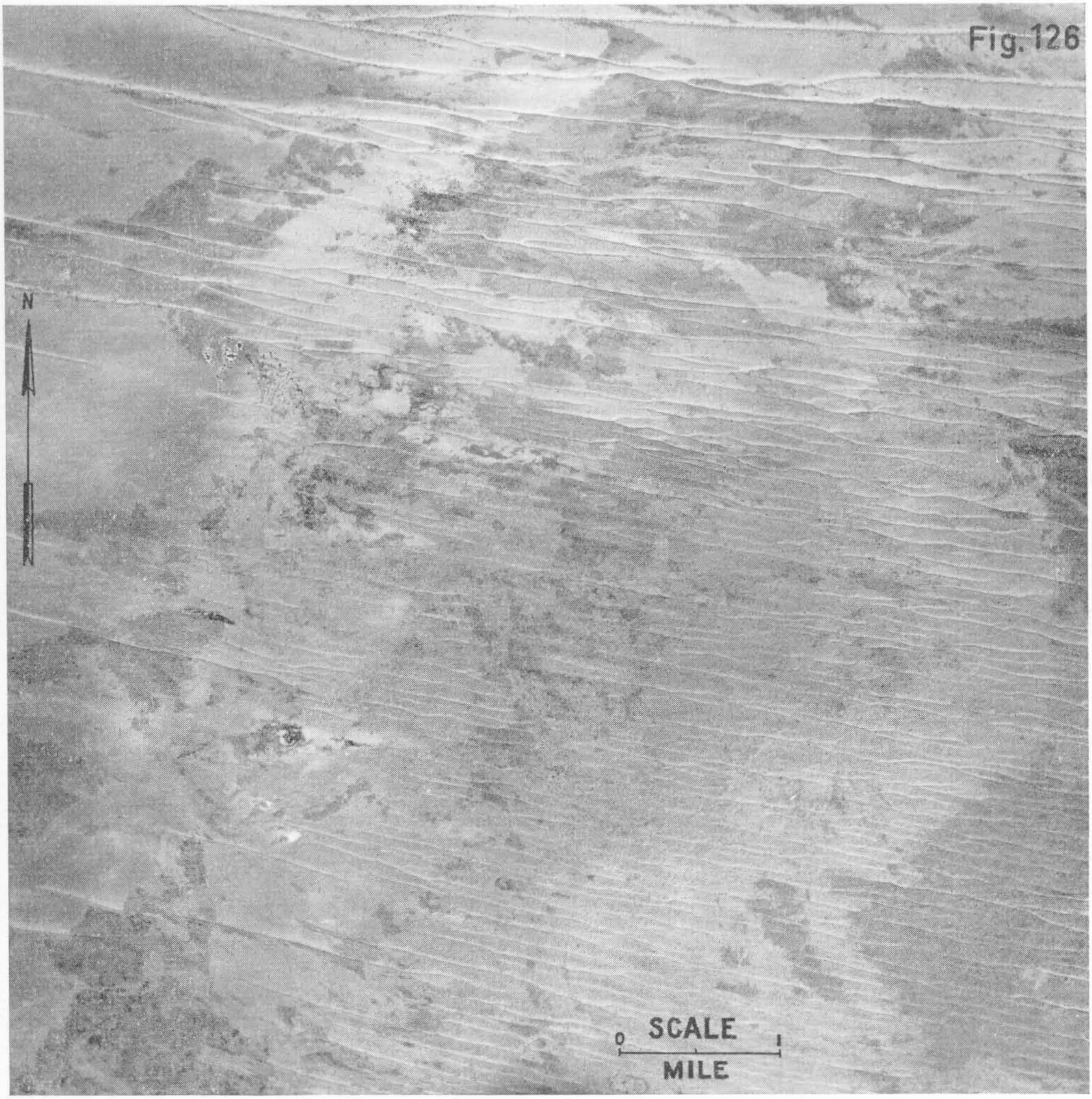


Fig. 126.—Vertical air photograph showing type D dunes.

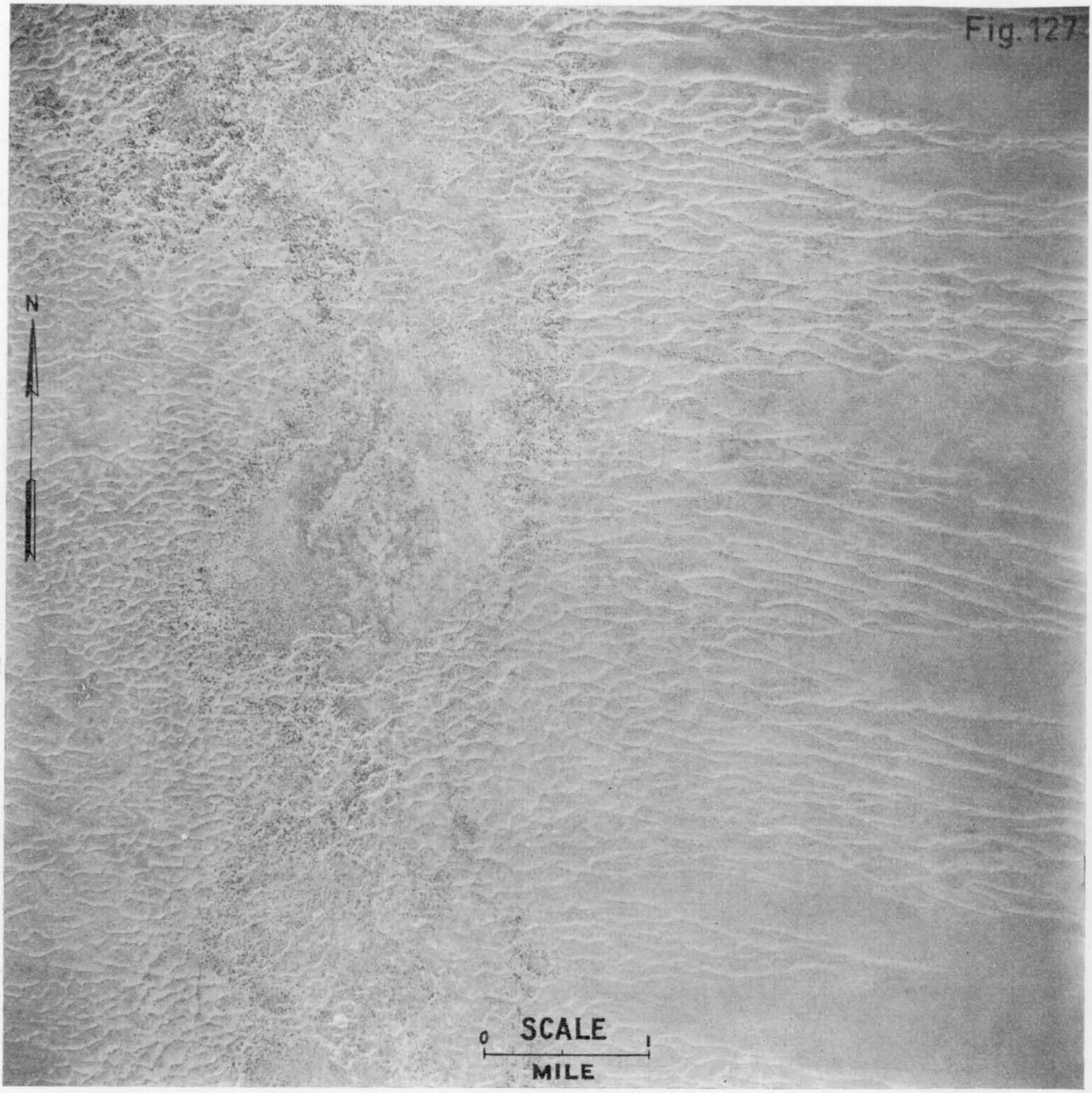


Fig. 127.—Vertical air photograph showing type E dunes.

D (Fig. 126): 10 to 20 feet high, 10 to 20 yards across, up to 2 miles long, 200 to 400 yards apart, symmetrical section, notably straight and parallel, rest on sand sheet. Vegetation of dunes and corridors dense and includes trees. Distributed locally where vegetation dense.

E (Fig. 127): net-like dunes, net pattern formed by short north-trending dunes that link west-trending dunes. Individual dunes same size and shape as type B. Associated with salt pans and lakes. Vegetation fairly dense.

Sand samples from parts of the Canning Basin (Fig. 128) were studied by Brown (1959, unpubl.). Samples from the Fitzroy Basin and from the central and coastal parts of the Canning Basin were not available for the analysis, which is therefore incomplete. The following are Brown's main results:

(1) The sands are bright red, fine grained, and fairly angular, and consist of quartz with very small amounts of feldspar and heavy minerals.

(2) 95% of the grains lie within the range 0.50 to 0.08 mm., and correspond in size with sands from the north-west Sahara (Alimen, 1957). Simpson Desert sand is much finer.

(3) The total heavy mineral content is less than 1%, and the heavy minerals are concentrated in the —150-mesh grade. Brown hornblende is restricted to samples from the Mount Bannerman Sheet area, and was probably deposited by water flowing south in the Sturt Valley. Brown points out that the brown hornblende could possibly have originated in the Cambrian volcanic rocks to the north, from which it has been recorded by Edwards & Clarke (1940).

(4) Brown concludes that most of the sand is derived from the underlying formations. Sand that contains well-rounded zircon and well-rounded tourmaline crowded with rutile needles is common in the Canning Basin, and rare over the marginal Precambrian rocks. These well-rounded minerals must have been derived from sedimentary rocks.

Direction of the dunes. The direction of the sand dunes is shown in Figure 128. The direction ranges from 260° to 300°. North of Latitude 20° S, most dunes trend westward, and south of 20° S, west-north-westward. These directions correspond with the direction of the strongest winds of the present day. At this point, a few words about the present climate are apposite.

The Great Sandy Desert is a region of trade winds and subtropical high-pressure belts, a position that corresponds to that of the other great deserts. Gardner (1944, p. 30) recognizes three climatic zones in Western Australia:

'a northern area of summer rainfall of a monsoonal character, with a cool dry season; a south-western area of winter rainfall with a period of summer drought, and a vast central area of low and unreliable rainfall of no marked periodicity, depending entirely upon extensions of the climatic systems which dominate the northern and southern areas.'

The temperature in the desert ranges from a normal daily maximum temperature for January of 100°F to a normal daily minimum temperature for July of 45°F. According to Blair (1942, p. 462), in the Australian Desert, of which the Great Sandy

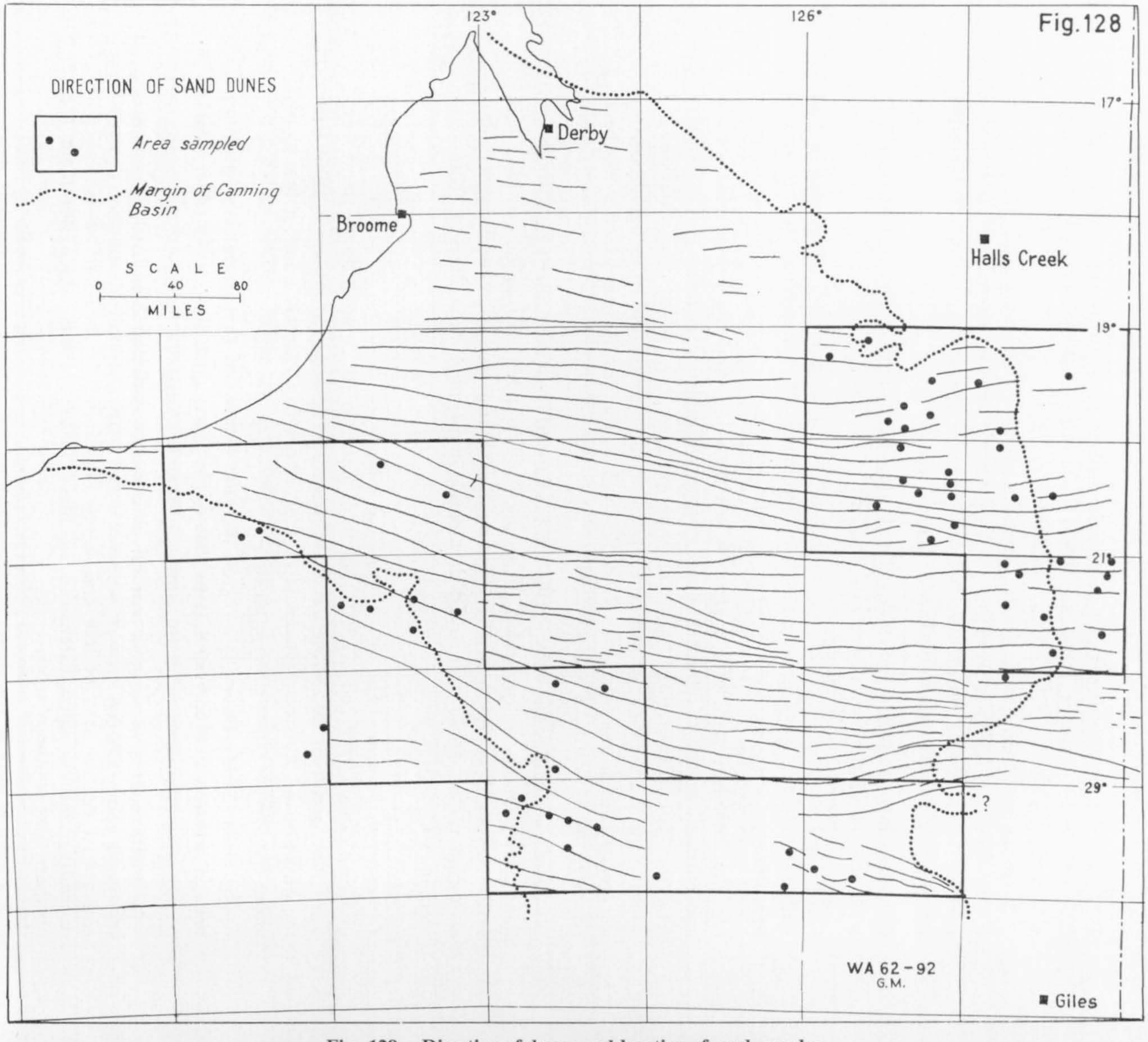


Fig. 128.—Direction of dunes, and location of sand samples.

Desert is the hottest part, 'desert conditions with reference both to heat and aridity are not much less severe than in the heart of the Sahara'. Despite such a severe climate, the Great Sandy Desert supports a scant vegetation, dominated by spinifex, with sparse shrubs and trees, mainly acacias and eucalypts.

The nearest weather stations that provide information on the direction and speed of winds that blow over the Great Sandy Desert are at Halls Creek and at Giles. Both stations lie far from the area under consideration, but supply useful information because they lie on the windward side of the area, and are not affected by coastal influences, which, for our purpose, reduce the value of information gathered at Port Hedland and at Derby. Information on winds from Giles has been plotted for 22 months only, from August 1956 to May 1958. The wind information from Giles, supplied by the Bureau of Meteorology, is expressed as speed in knots to sixteen points of the compass; readings were taken at 0830 and 1430 hours. Wind roses showing the directional frequency of winds of 9 knots and stronger are given in Figure 129. Of the 1338 readings of this period, 101 were calms, 520 were winds of 9 knots or stronger, and 76 were winds of 16 knots and faster; the strongest recorded wind was 28 knots (33 m.p.h.). The sand-driving effect of the wind (Bagnold, 1951, p. 80) is a cubic function of the wind strength, and accordingly the wind rose of winds of 16 knots and stronger (Fig. 129C) is the most informative of the three roses. Whereas B seems to indicate a unidirectional wind from the sector east to south-east, C shows that the wind at Giles is actually bidirectional, winds of 16 knots and stronger blowing with equal frequency from south-east to south-south-east and north to north-north-east. The relative sand-driving effect of winds of speeds of 9 to 16 knots (mean 13 knots or 15 m.p.h.) and 16 knots and stronger (mean $18\frac{1}{2}$ knots or 21 m.p.h.) can be computed from Bagnold's (1951, p. 80) formula, which expresses the relation that, for the same conditions of recording,

$$\frac{S_1}{S_2} = \left(\frac{v_1 - 10}{v_2 - 10}\right)^3.$$

where S_1, S_2 are the volumes of sand which will be driven in any compass direction past a fixed transverse line, and v_1, v_2 are the speeds of winds in miles per hour, blowing from given directions. This formula applies only for sand of average grain size and composition on an open sand surface entirely free from vegetation. The ratio of relative sand-driving effect of winds of 15 mph and 21 mph is, according to Bagnold's formula, roughly one to ten. A 'sand movement rose' can be drawn by adding together wind roses (B — C (i)) and C (ii). C (i) must be subtracted to convert rose B from wind of $v \geq 9$ knots to wind with $9k < v < 16k$. This sum is rose A. The main difference between A and B, and between A and the wind rose of winds of all speeds (not shown) is the relative decrease in the east wind and the relative increase in north and north-north-east winds, and in the south-south-east wind. In its effect on the sand, then, the wind is bidirectional; the main wind blows from the sector south-south-east to east, and the less frequent wind from the north to north-north-east. The wind roses for Halls Creek, which were compiled separately for winds of different speeds, are similar to each other, and only one is figured (Fig. 129). The wind is practically unidirectional; most wind comes from the east, and a less frequent wind blows from the north-east.

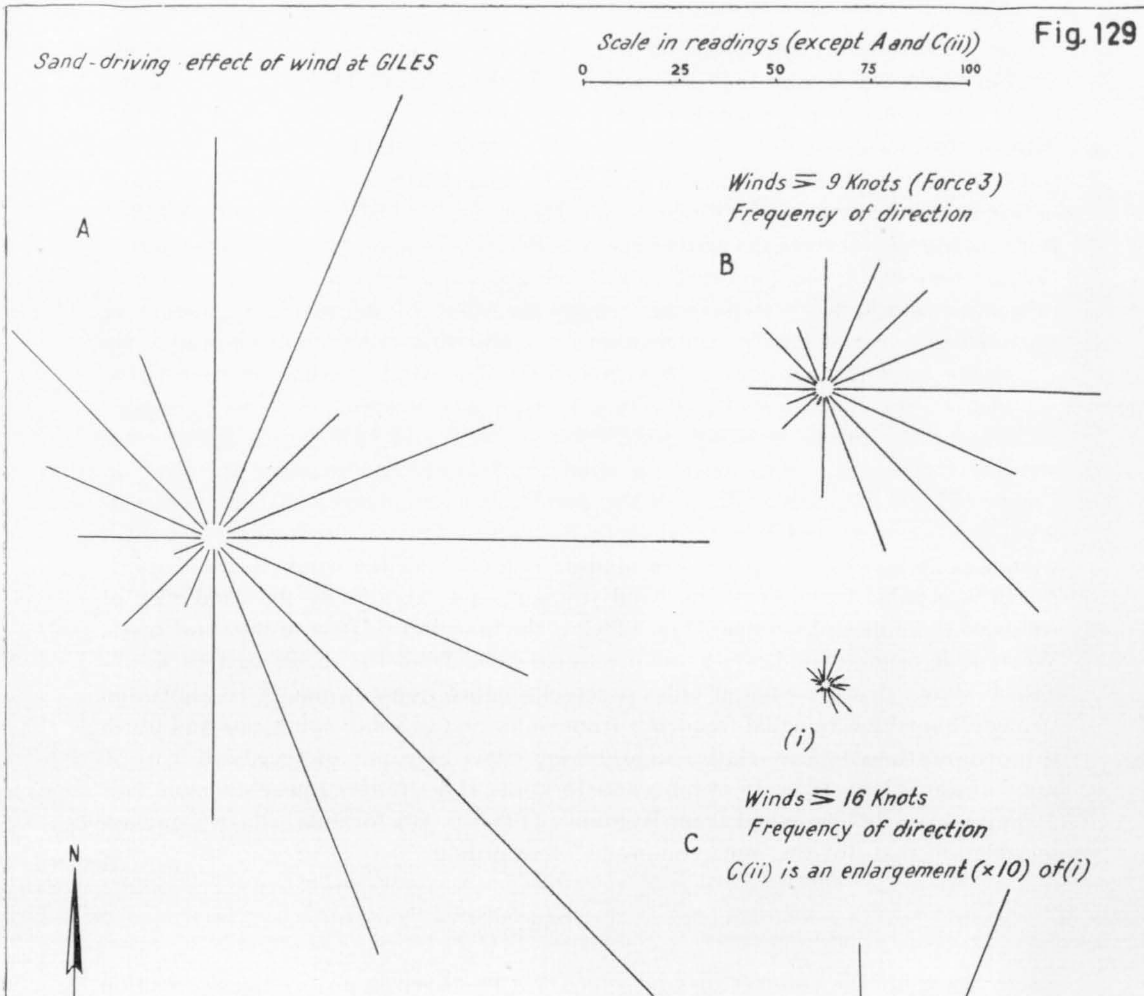


Fig. 129.—Wind roses at Giles and Halls Creek.

The present wind regime, as far as can be estimated from the available data, satisfactorily explains the direction of the dunes. The strongest winds at Halls Creek blow from the east, parallel to the trends of dunes north of 20° S, and the next strongest winds blow from the north-east; at Giles, the strongest winds blow from the south-east and east, parallel to the trends of dunes south of 20° S, and the next strongest winds blow from the north. These directions of wind and dunes agree with Bagnold's theory that longitudinal dunes are formed by bidirectional winds, and that the dunes trend parallel to the direction of the main wind. The dunes of the Great Sandy Desert, however, were formed during an extremely arid period before the present amelioration of climate. The correspondence of wind and dune direction therefore implies that the wind regime was the same in the postulated arid period as it is today. The continuance of the present climate, and the continued growth of vegetation, will probably lead to the further degradation of the dunes to form undulating areas of sand devoid of steep-sided dunes. The Great Sandy Desert will then resemble the 'gozes' of the Kordofan Province of the Sudan (Bagnold, 1941, p. 184).

Present-day rivers supply little sand to the desert, but locally, as along the courses of the sporadically flooded Sturt Creek and Rudall River, rivers deposit large amounts. In the past, rivers probably provided important amounts of sand, but probably at the desert margin only. Most of the sand in the Canning Basin has probably been derived *in situ* from the process of scarp retreat in outcropping ferruginous sandstone, particularly from the A horizon (above the pisolitic ironstone) of the weathered profile.

On the coast of Dampier Peninsula, according to Brunnschweiler (1957), the coastal aeolianites are younger than the inland dunes, and older than the Quaternary eustatic rises in sea level, which have breached the aeolianites to form muddy tidal flats and samphire marshes. Brunnschweiler (1957) considers that the inland dunes of the Dampier Peninsula, which are continuous with dunes farther inland, were formed during an arid period in the early Pleistocene, which he correlates with the Riss Glaciation. Fairbridge (1953(b), pp. 8-9) reviews the concept of the Sahul Shelf as dry land during the Pleistocene, and notes Mayr's (1944) observation that because most of the migrants in Australia from Timor were grassland birds, there must have been arid, savannah-type country on the Sahul Shelf during the periods of migration. Assuming that most of the Sahul Shelf was dry land, C. F. Brooks (*in* Mayr, 1944) reasoned that

'the climate in the southern hemisphere winter would be very dry, and opportunities for rainfall in the southern hemisphere summer would be reduced. The North-West monsoon would be drier than it is today, after passing over the higher mountains and more continuous land of Pleistocene times. I should think that the summer climate in the thus protected area west of New Guinea and north-west Australia might well have been arid.'

Thus from many independent lines of investigation comes the conclusion that the dunes in the Canning Basin were formed during an arid part of the Pleistocene, and that since this time the climate has ameliorated and vegetation has spread over the desert and fixed the dunes.

Alluvium, soil, evaporites, travertine

Widespread alluvium, soil, travertine (*see* Appendix 2, Hel), and salt and clay pans occur in the northern and southern marginal areas of the Canning Basin, particularly in the Fitzroy, Oakover-Nullagine, and Sturt valleys. In the coastal area, Recent sediments include silty and sandy delta deposits of the Fitzroy and De Grey Rivers, and fluviatile-estuarine tidal flats that consist of calcareous silt and silty sand. Samphire Marsh No. 1 Bore penetrated 13 feet of calcareous alluvial silt. The only alluvium in the central Canning Basin is wash at the foot of breakaways.

Brunnschweiler (1957) describes two soil horizons, a red soil, that lies between the duricrust and the red sand, and a yellow-brown soil, that lies between the dunes and the coastal aeolianites. The Recent and present-day beach rock of Dampier Peninsula consists of calcareous sandstone and sandy shell breccia.

IGNEOUS ROCKS

The Fitzroy Lamproite (Guppy et al.), the gabbro and dolerite in the Fraser River No. 1 Bore (McWhae et al., p. 138), and possibly the sheared volcanic rocks that underlie the Ordovician rocks in BMR 3 Prices Creek Bore (Condon & Henderson, 1960(b), MS.) are the only known igneous rocks in the Canning Basin.

The lamproite in the form of plugs and craters intrudes Devonian and Permian rocks and the Triassic Blina Shale of the Fitzroy Basin, and Precambrian granite on the northern margin, and is probably Jurassic (145 $\pm$ 10 million years). Wade & Prider (1940) first described in detail these rocks and their field relations. Prider's recent account (1960) of these rocks makes further reference here superfluous.

According to McWhae et al. the gabbro and dolerite in Fraser River No. 1 Bore intrude the Anderson Formation (Carboniferous), and are probably the result of Mesozoic activity. Condon et al. (1958) regarded the gabbro and dolerite as Precambrian.

The sheared volcanics in BMR 3 Prices Creek Bore probably belong to the Hart Basalt (Guppy et al., p. 16), which is either Lower Cambrian or Upper Proterozoic.

STRUCTURE AND GEOPHYSICS

The Canning Basin, including the Rowley Shelf (Fig. 130), is bounded by the Kimberley Block, the Sturt Block, the Pilbara Block, the Dampier Rise, the North Australian Basin, and the Leveque Rise. The Canning Basin is separated from the Ord Basin by a belt, 100 miles across, of folded Precambrian sedimentary rocks; and from the Phanerozoic rocks of the upper Fortescue River Valley and from the Carnarvon Basin by the Pilbara Block. According to our interpretation of the air photographs, the sedimentary rocks of the Macdonald Sheet area, south of Lake Mackay, which probably belong to the Amadeus Basin, are separated from the Canning Basin by a granitic ridge, two outcrops of which are interpreted from air photographs on the eastern part of the Ryan Sheet area. The Macdonald area was investigated by a Bureau party in 1960 (Wells, Forman & Ranford, in preparation).

The southern boundary of the Canning Basin is unknown. It has only been mapped as far south as Latitude 24° S, where it is 260 miles across and its surface is of Permian and Cretaceous rocks, both punctured at Woolnough Hills by a probable salt dome. Previous maps, including the recently published sketch map by the Geological Survey of Western Australia (1957), show the Canning Basin bordered in the south by

Precambrian (Nullagine) rocks, and have led to the belief that the Canning Basin terminates near 24° S. The only descriptions of the country immediately south of 24° S are those of explorers. L. A. Wells (1902) noted that exposures between the Hutton Range and Bejah Hill consist of 'clay rock capped with quartzite conglomerate' (the 'conglomerate' is presumably a siliceous duricrust). This evidence suggests that the Bejah Beds extend 120 miles south-south-west from Bejah Hill. The further distribution of the Bejah Beds, the southern extent of the Permian rocks, and the

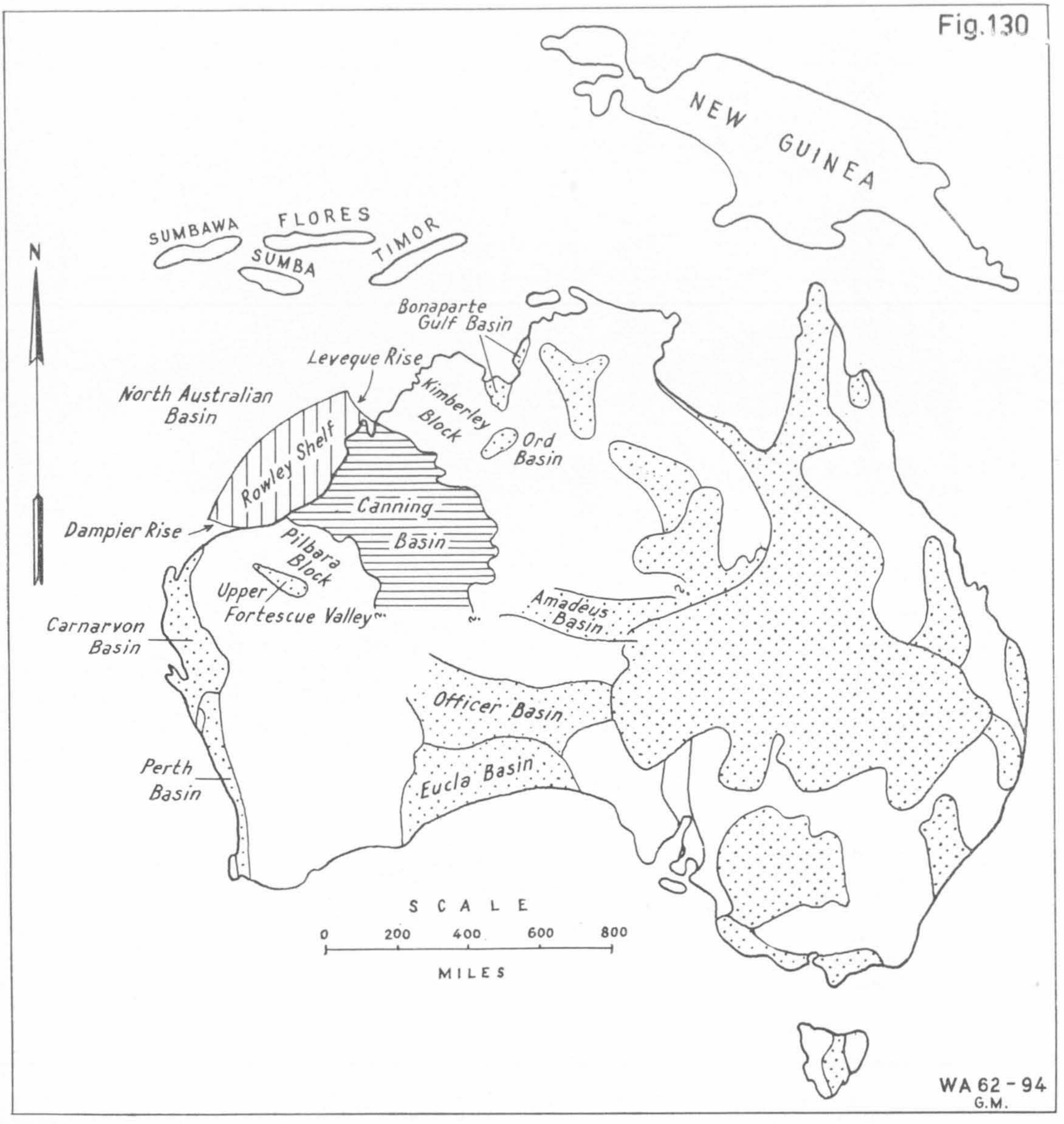


Fig. 130.—Map of Australia, showing sedimentary basins (after Condon et al., 1958).

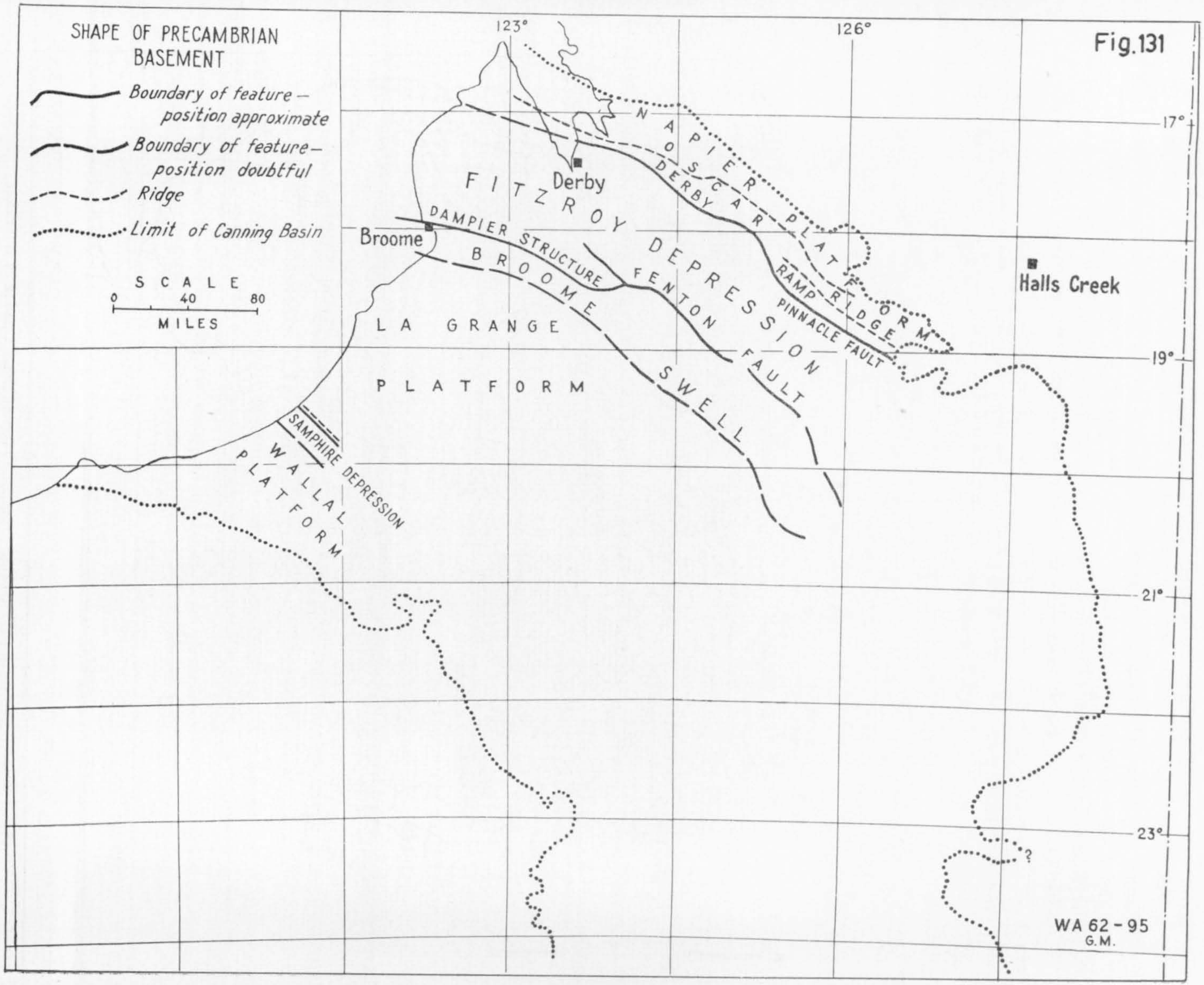

SHAPE OF PRECAMBRIAN BASEMENT
Boundary of feature — position approximate
Boundary of feature — position doubtful
Ridge
Limit of Canning Basin
SCALE
0 40 80
MILES
Fig.131
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
NAPIER PLATFORM
OSCAR RIDGE
DERBY RAMP
PINNACLE FAULT
FITZROY DEPRESSION
DAMPIER STRUCTURE
FENTON FAULT
BROOME SWELL
LA GRANGE PLATFORM
SAMPHIRE DEPRESSION
WALLAL PLATFORM
?
WA 62-95
G.M.

Fig. 131.

relationship between the Canning Basin and the Officer Basin must be left for determination by future workers.

We first describe the major structural subdivisions of the basin, and then the individual structures within these subdivisions.

Major Structural Subdivisions

Work in the last ten years has notably increased our knowledge of the structure of the Fitzroy Basin, and indicated some of the structure of the area to the south. The structure of the greater part of the Canning Basin remains unknown, and work in the better-known areas has created almost as many problems as it has solved, as is only to be expected in a basin as big as Spain.

In terms of the present shape of the Precambrian floor, the better-known area of the basin is divided into several parts, as shown in Figure 131 and Plate 2. It is emphasized that the named portions of the basin floor refer to the present shape only, without palaeogeographical or genetic implication. This is to avoid confusion between descriptive terms and genetic terms.

The *Napier Platform* is the basement platform limited by the basin margin and the Oscar Ridge. The Napier Platform is shallow, less than 5000 feet deep, except in its western part north of Meda No. 1 Bore, where the depth probably exceeds 8663 feet. It is overlain in various parts by Ordovician, Devonian, probable Lower Carboniferous, Permian, and Triassic rocks. The main structure is best shown by the Devonian rocks, which dip south-westward near the basin margin and in the opposite direction near the Oscar Ridge to form an elongate syncline, as in the Fairfield Valley. The Bouguer gravity contours (Pl. 2) roughly parallel the boundaries of the Napier Platform, and show an elongate negative anomaly in the Napier Range area. The only aeromagnetic anomaly recorded over the Napier Platform is situated 20 miles north-east of Yarrada Hill, and, according to Quilty (1960, unpubl.) (Fig. 132), indicates that basement is 6000 feet deep. Faults in the Devonian rocks overlying the Napier Platform are discussed in the Devonian chapter.

The *Oscar Ridge* is the basement ridge which is indicated by inliers of Precambrian rock in the Oscar Range and Virgin Hills, and of Ordovician rock in the Prices Creek area, by the 'promontory' of Precambrian rock in the Bulka Hills, and by the thin cover of Palaeozoic rock in the 67-mile Bore, and in BMR 3 Prices Creek Bore. The ridge is probably offset south-eastwards in the Fitzroy Crossing area. Aeromagnetic anomalies are recorded over the ridge at Virgin Hills, the Oscar Range, and the 67-mile Bore. An elongate positive Bouguer anomaly corresponds with these indications of the Oscar Ridge, and the west-north-westward continuation of this anomaly through the Meda No. 1 Bore area, where an aeromagnetic anomaly is also recorded, is interpreted as indicating the ridge. According to this interpretation, the Oscar Ridge is deepest (8663 feet) in the Meda No. 1 Bore area. Where it is exposed or penetrated by the drill, the Oscar Ridge consists of crystalline Precambrian rocks (schist, gneiss) except in the Oscar Range, which consists of sheared conglomeratic quartzite. The ridge is immediately overlain by Ordovician rocks in the Prices Creek area, by possible Ordovician in the Bulka Hills, by overlapping Permian rocks in the Oscar Range and Bulka Hills, and by Devonian rocks elsewhere. The structure of the overlying Devonian rocks is described in the Devonian chapter.

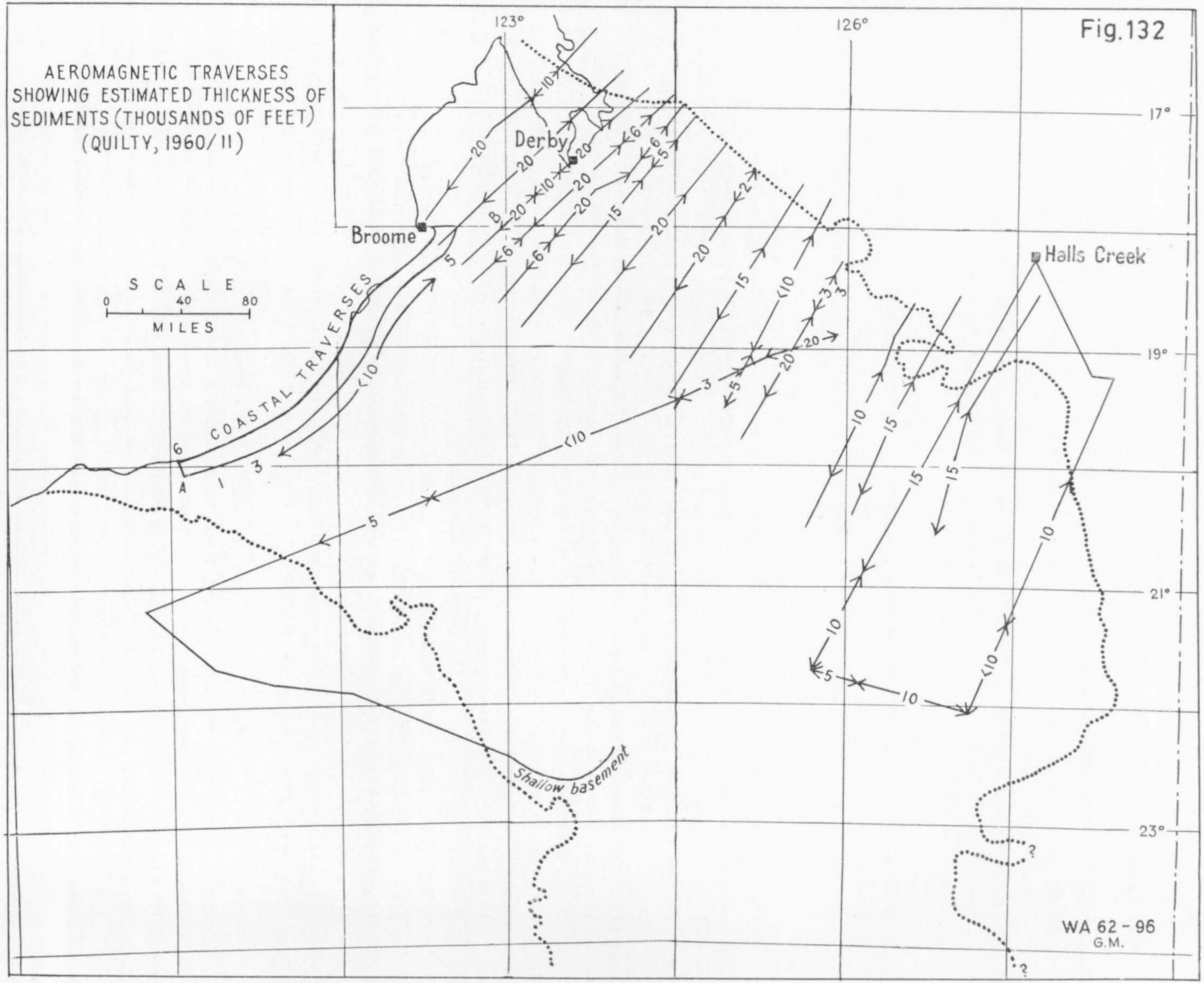


Fig.132
AEROMAGNETIC TRAVERSES
SHOWING ESTIMATED THICKNESS OF
SEDIMENTS (THOUSANDS OF FEET)
(QUILTY, 1960/11)
SCALE
0 40 80
MILES
123°
126°
17°
19°
21°
23°
Derby
Broome
Halls Creek
COASTAL TRAVERSES
Shallow basement
WA 62 - 96
G.M.

Fig. 132.

The *Derby Ramp* is the basement ramp that connects the Oscar Ridge and Napier Platform with the low-lying Fitzroy Depression. The Derby Ramp is probably widest in The Sisters area, as indicated by The Sisters Bore and by the Bouguer anomaly in this area, and narrowest near Prices Creek. In The Sisters area, the basinward slope of the Napier Platform is negligible, of the Derby Ramp 2° to 5°, and of the northern part of the Fitzroy Depression 5° to 15°. No aeromagnetic anomalies were recorded from the Derby Ramp.

The *Fitzroy Depression* is the basement depression bounded by the Oscar Ridge and the Broome Swell. The Fitzroy Depression is at least 20,000 feet deep and is filled with Devonian, Carboniferous, Permian, Triassic, Jurassic, and Cretaceous rocks and probably Ordovician rocks. Many structures, including long anticlines and faults, have been recognized in the rocks filling the Fitzroy Depression; they are described below (p. 220ff.).

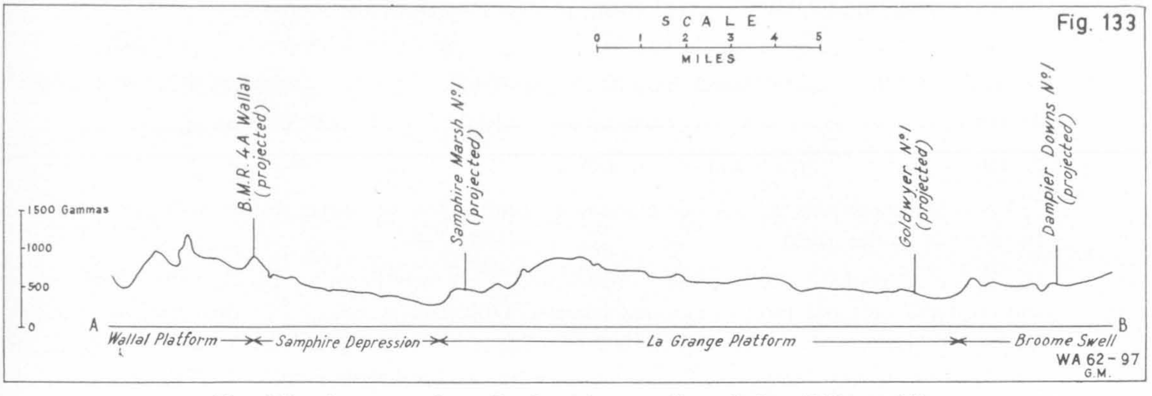


Fig. 133.—Aeromagnetic profile along the coast (from Quilty, 1960, unpubl.).

The *Broome Swell* is the basement swell that is indicated in the Broome/Dampier Downs area by aeromagnetic anomalies (Fig. 133) and by thin sedimentary cover, as shown by bores. The Broome Swell corresponds with an elongate positive Bouguer anomaly. There are no bores south-east of Dampier Downs, but the Broome Swell is indicated by the continuation of the Bouguer anomaly to the Dummer Range, and by aeromagnetic anomalies in the north-western part of the Crossland Sheet area. The northern boundary of the Broome Swell is indicated by the Fenton Fault south-east of Mount Arthur, and by the Dampier Structure west-north-westward. The southern boundary of the swell is poorly defined except 10 miles north of the Goldwyer Bore, where a line of aeromagnetic anomalies from Cape Villaret 20 miles south-eastward indicates the southern boundary of the swell. The shallowest known basement in the Broome area is the Precambrian granite recorded at a depth of 4660 feet in Goldwyer No. 1 Bore, which is situated on a gravity culmination in a belt of negative Bouguer anomalies, and was so located presumably because seismic surveys indicated shallow basement. The shallow basement at Goldwyer Bore indicates that the boundary between the La Grange Platform, on which the bore is located, and the Broome Swell is indistinct, and suggests that the Broome Swell is simply the northernmost, slightly elevated, part of the La Grange Platform. In profile, the Broome Swell probably resembles a south-dipping cuesta. Future work should be aimed at determining the shape of the Broome Swell, and finding out its precise relationship to geophysical anomalies.

The *La Grange Platform* is the basement platform that lies between the Broome Swell and the Samphire Depression. The La Grange Platform lies about 4500 to 8000 feet below the surface, and is overlain by Ordovician, Permian and Mesozoic rocks, and at Samphire Marsh No. 1 Bore by probable uppermost Cambrian rocks. Four elongate negative Bouguer anomalies trend south-eastward across the La Grange Platform, and probably indicate areas with slightly deeper basement. The only Bureau seismic survey (reflection) on the La Grange Platform was located near the La Grange Telegraph Station (Smith, 1960, unpubl.) (Fig. 134). The results are as follows:

1. Numerous horizontal reflections were recorded to an average depth of 4400 feet.
2. Good reflections were recorded from an average depth of 2760 feet.
3. The average seismic velocity (from a $t - \Delta t$ analysis) above 2760 feet is 7650 feet/second, and below it, 11,760 feet/second, corresponding to a major change in lithology.
4. Scattered reflections were recorded between 4400 feet and 8000 feet.
5. The reflections indicate almost flat rocks.

Two interpretations are possible from a comparison of these results with data from bores to the north:

(a) Mesozoic rocks lie between the surface and 2760 feet, Permian rocks from 2760 feet to 4400 feet, and Ordovician rocks below 4400 feet. According to this interpretation few reflections are recorded below 4400 feet because shallow rocks reflect most of the energy; and the change in lithology at 2760 feet is between Mesozoic and Permian rocks.

(b) Mesozoic and Permian rocks lie between the surface and 2760 feet, Ordovician rocks between 2760 feet and 4400 feet, and basement at 4400 feet. The reflections below 4400 feet are multiples of shallow reflections. The change in lithology at 2760 feet is between Permian sandstone and Ordovician shale and carbonate.

Like the Goldwyer Bore area, the La Grange Telegraph Station area lies near a gravity culmination in an elongate negative Bouguer anomaly; and for this reason, and because little lithological contrast is found between Mesozoic and Permian rocks in the region, the second interpretation, that basement lies at a depth of about 4400 feet at La Grange, is favoured.

The *Samphire Depression* is the basement depression that lies between BMR 4A Wallal and Samphire Marsh No. 1 Bores. Granitic basement is 2224 feet deep at BMR 4A, and 6610 feet deep at Samphire Marsh No. 1. Both bores are located near aeromagnetic anomalies (Fig. 133) that indicate shallower basement, and consequently the intervening Samphire Depression must contain deeper basement. The Samphire Depression probably contains Mesozoic, Permian, Ordovician, uppermost Cambrian, and possibly older Cambrian rocks.

The *Wallal Platform* is the basement platform that is bounded by the basin margin and the northern edge of the basement ridge at BMR 4A Wallal Bore. In the Wallal

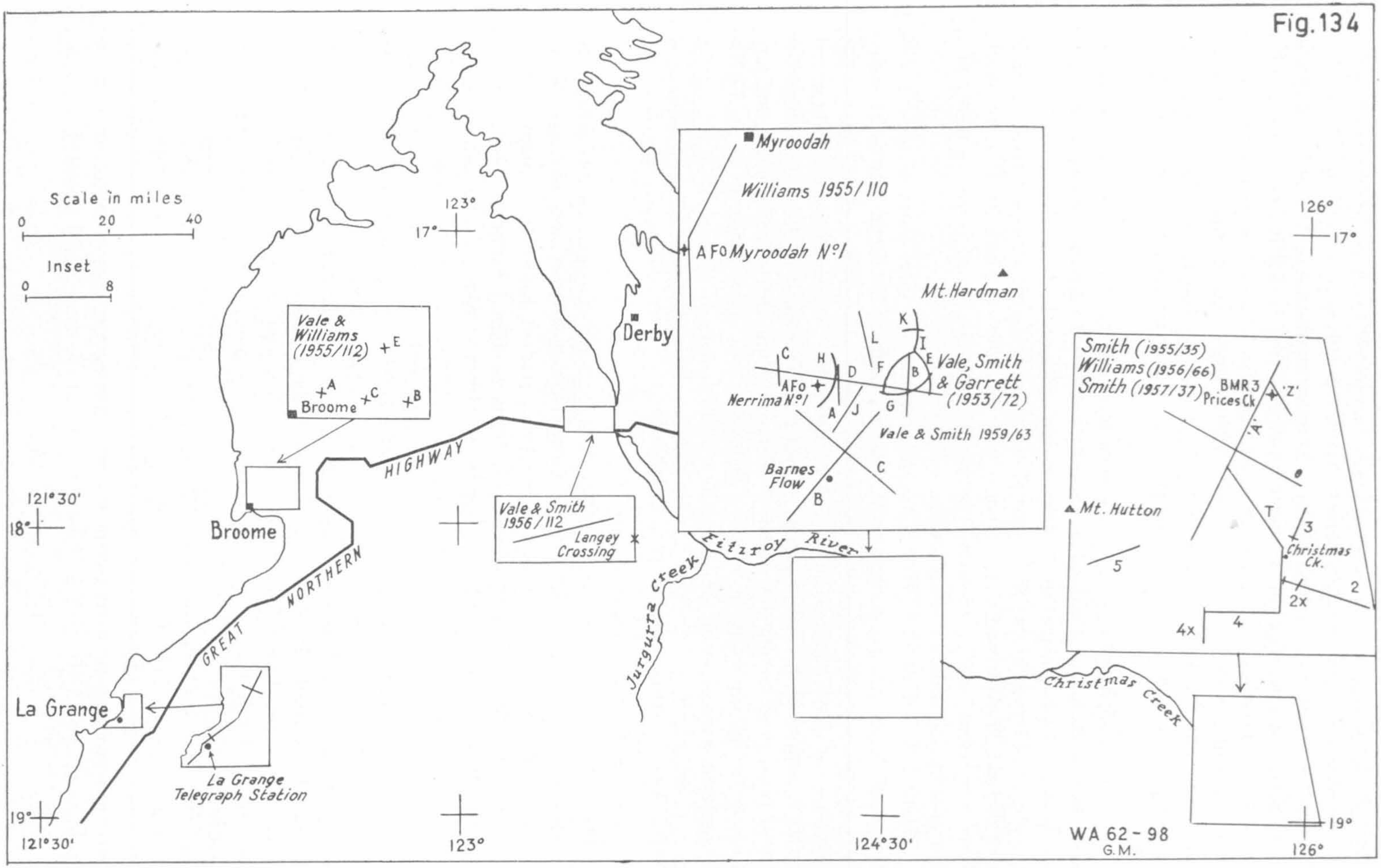


Fig. 134.—Locality map of BMR seismic surveys.

area, an elongate positive Bouguer anomaly that trends south-east corresponds with a line of sharp aeromagnetic anomalies that also trends south-eastward. The positive Bouguer anomaly that extends at least 70 miles south-east of Wallal is interpreted as indicating a low ridge on the northern edge of the Wallal Platform. Its depth is 2224 feet at BMR 4A Wallal. The sharp Bouguer anomalies over Precambrian rocks, mainly granite, in the Port Hedland and Yarrie Sheet area continue north up to the positive anomaly at Wallal. We interpret this pattern of anomalies as indicating either very thin cover over the Wallal Platform, or a shallow depression south of the Wallal area.

Mesozoic and Permian rocks are known to overlie the Wallal Platform at Wallal 4A, and, according to Playford & Johnstone (1959), Ordovician rocks may occupy the bottom of a postulated shallow depression south of the Wallal area.

Faults and trends in the 'promontory' of Precambrian metamorphic rocks 20 miles east of Lake Waukarlycarly are collinear with the ridge on which BMR 4, 4A Wallal Bore is situated, and are possibly continuous with the buried ridge, as Bulka Hills are continuous with the Oscar Ridge.

Playford & Johnstone (1959) also name various structural parts of the Canning Basin, but because many of their terms—such as Lennard Shelf and Fitzroy Trough—have genetic connotations, we prefer to use terms which relate to the present-day, determinable shape of the basin floor. This distinction between descriptive and genetic terms is important, because it can be shown that a present-day ridge in the basement stood from time to time no higher than surrounding areas; furthermore, the term Fitzroy Trough, for example, suggests deep water, but many sediments in the Fitzroy Depression were probably deposited in shallow water.

Structures Within the Fitzroy Depression

The Pinnacle Fault and nearby structures

The outcrop of the Pinnacle Fault extends from the Bohemia Downs area north-westward to a point 10 miles west of Gogo Homestead, but only one part of this outcrop, the Prices Creek area, has been closely studied. Information about structure in this area (Figs. 135, 136) is available from geological mapping (Guppy et al.), drilling (Wade, 1924; Condon & Henderson, 1960(b), MS.), seismic refraction and reflection surveys (Smith 1955, 1957; Williams, 1956; all unpubl.), and gravity surveys by the Bureau. The Pinnacle Fault divides shattered outcrops of Grant Formation (Permian) on its north-east side from unaffected outcrops of Permian rocks on its south-west side. One to two miles north-east of the Pinnacle Fault, and parallel to it, is the Cadjeput Fault, which is the south-western limit of outcropping Ordovician rocks in the Fitzroy Basin. Two miles south-west of the Pinnacle Fault, and parallel to it, is the axis of the Talbot Syncline; 14 miles south-west of the Pinnacle Fault is the crest of the Poole Range Dome, which is cut by numerous north-trending normal faults.

BMR 3 Prices Creek Bore revealed Precambrian schist and hornfels at a depth of about 700 feet. The Freney Kimberley Oil Company bores in the Prices Creek area were inadequately logged; the following identifications are tentative: FKO No. 1 Prices Creek cut 1008 feet of Emanuel Formation, No. 2 350 feet of Emanuel Formation, No. 3 809 feet of Emanuel Formation, and No. 4 Grant Formation.

FKO Poole Range No. 3 cut 3264 feet and No. 5 1545 feet of Grant Formation. The main results of seismic surveys are shown in Figure 136. The traverses (line A, traverses 1-4) are shown in Figure 135. The profile of the Bouguer anomaly from Prices Creek to the Poole Range is given in Figure 136.

Seismic surveys along line AA′ south-west of the Pinnacle Fault indicate

(1) a minimum thickness of sediments of 20,000 feet;

(2) unconformities at 7000 to 8000 feet, 13,000 feet, and 20,000 feet;

(3) the persistence of the Talbot Syncline to a depth of 7000 to 8000 feet;

(4) that the surface of the unconformity at 7000 to 8000 feet probably dips 9° north-westward near S.P. 40;

(5) that the rocks down to 7000 feet have seismic velocities that are related to those of Permian rocks at Nerrima, and accordingly, 7000 feet is taken as the approximate depth of the base of the Permian rocks at S.P. 40; the rocks below 7000 feet have seismic velocities not recorded at Nerrima;

(6) that north-east of the Cadjeput Fault, a refractor at a depth of 1600 feet at S.P. 5 has a seismic velocity of 19,950 feet/second; this refractor is probably Precambrian crystalline basement (indicated by the basement reached in BMR 3 Bore);

(7) that between S.P. 23 and S.P. 16, dips are steep; Smith (1955, unpubl.) interprets them as fault dips but they may also be interpreted as those of strata in a hinge area.

In Figure 136 the Poole Sandstone, Noonkanbah, Liveringa, Emanuel, Gap Creek, and Pillara Formations have been drawn in by reference to their measured thickness in outcrop.

The only data regarding structure at depth between the Cadjeput and Pinnacle Faults are the steep-dipping seismic reflections (Fig. 136) and the gravity anomaly. The Grant Formation and possibly the Pillara Formation are exposed in the area between the faults. The maximum Bouguer anomaly, at the outcrop of the Cadjeput Fault, corresponds with the thinnest section of sediments, as indicated by BMR 3 Prices Creek Bore. North-north-eastward, the anomaly decreases with a uniform low gradient that corresponds to an increasing thickness of sediments. The low gradient between the Cadjeput Fault and S.P. 18 is interpreted as indicating a gradually thickening sedimentary section, and relatively little displacement along the Cadjeput Fault; the steeper gradient between S.P. 18 and S.P. 27 independently indicates a discontinuity at the Pinnacle Fault, with a considerable 'downthrow' on the southern side, and the low uniform gradient between S.P. 27 and the end of the section indicates that the sedimentary section probably thickens slightly at greater distances from the fault.

A fundamental question, first put by Condon & Casey in an appendix to Guppy et al. (pp. 115-116), remains unsolved: is the main structure a fault, a monocline, or a combination of both? The fault hypothesis is shown in Figure 136 AA′, and the monocline hypothesis in Figure 136 DD′. In the monocline hypothesis, the Pinnacle Fault is a near-surface structure only, and the reflections recorded by Smith between the Pinnacle and Cadjeput Faults indicate steep-dipping strata. This hypothesis, at least as indicated by our section, is not supported by the gravity data and geological mapping: a low Bouguer gradient corresponds with the postulated steeply sloping

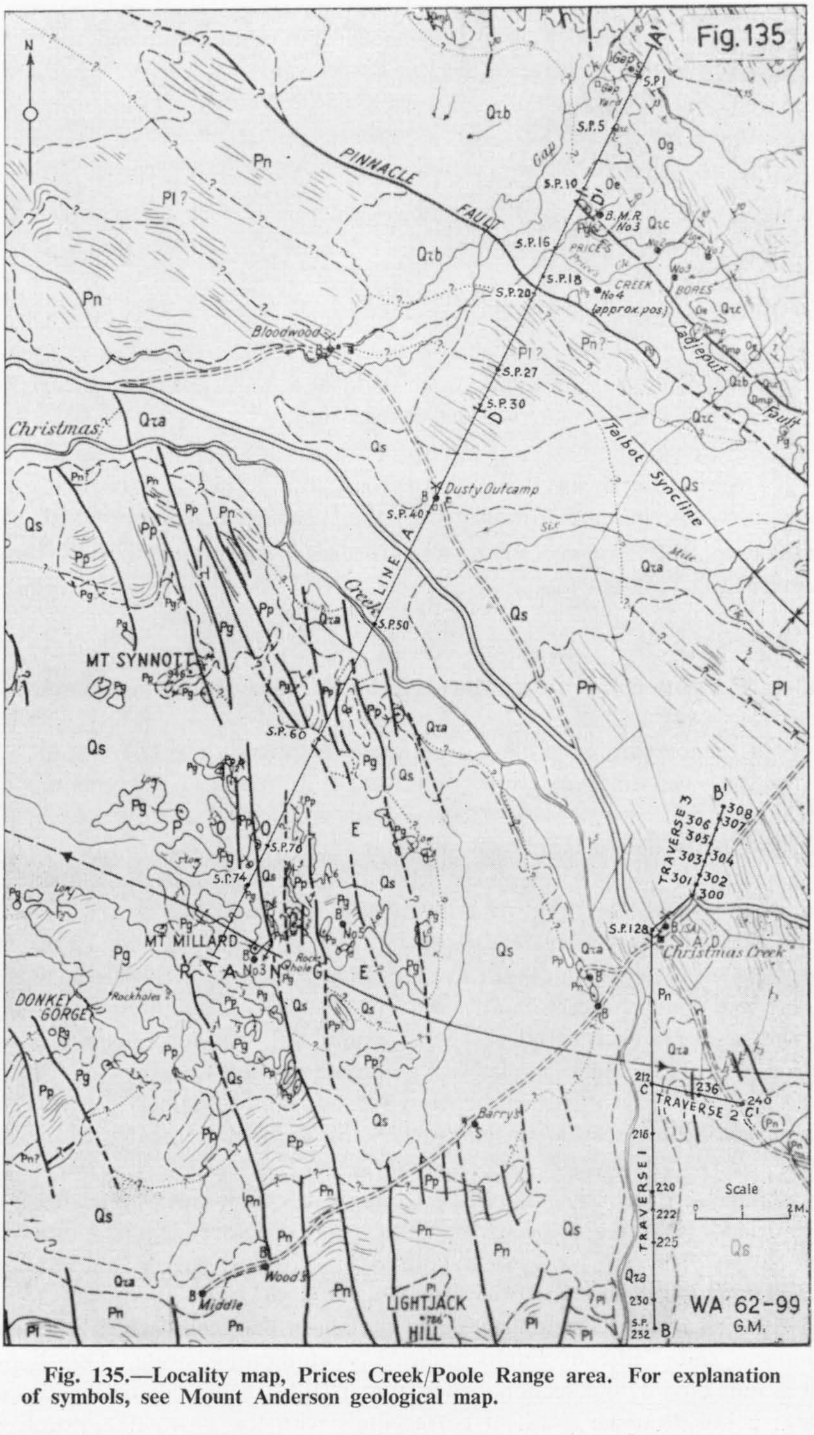


Fig. 135.—Locality map, Prices Creek/Poole Range area. For explanation of symbols, see Mount Anderson geological map.

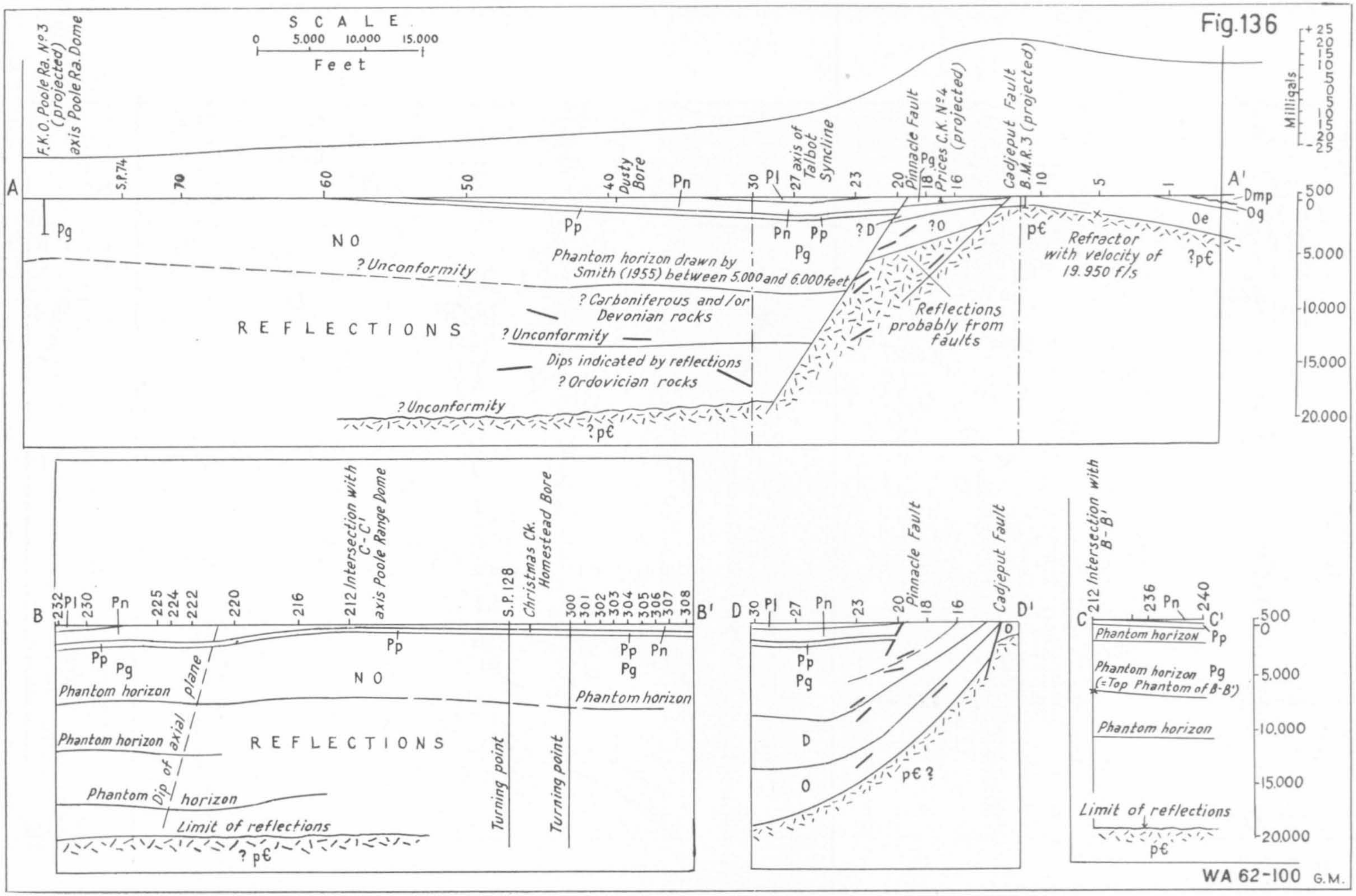


Fig. 136.—Sections Prices Creek/Poole Range area. pC—Precambrian; O—Ordovician; Oe—Emanuel Formation; Og—Gap Creek Formation; D—Devonian; Dmp—Pillara Formation; Pg—Grant Formation; Pp—Poole Sandstone; Pn—Noonkanbah Formation; Pl—Liveringa Formation.

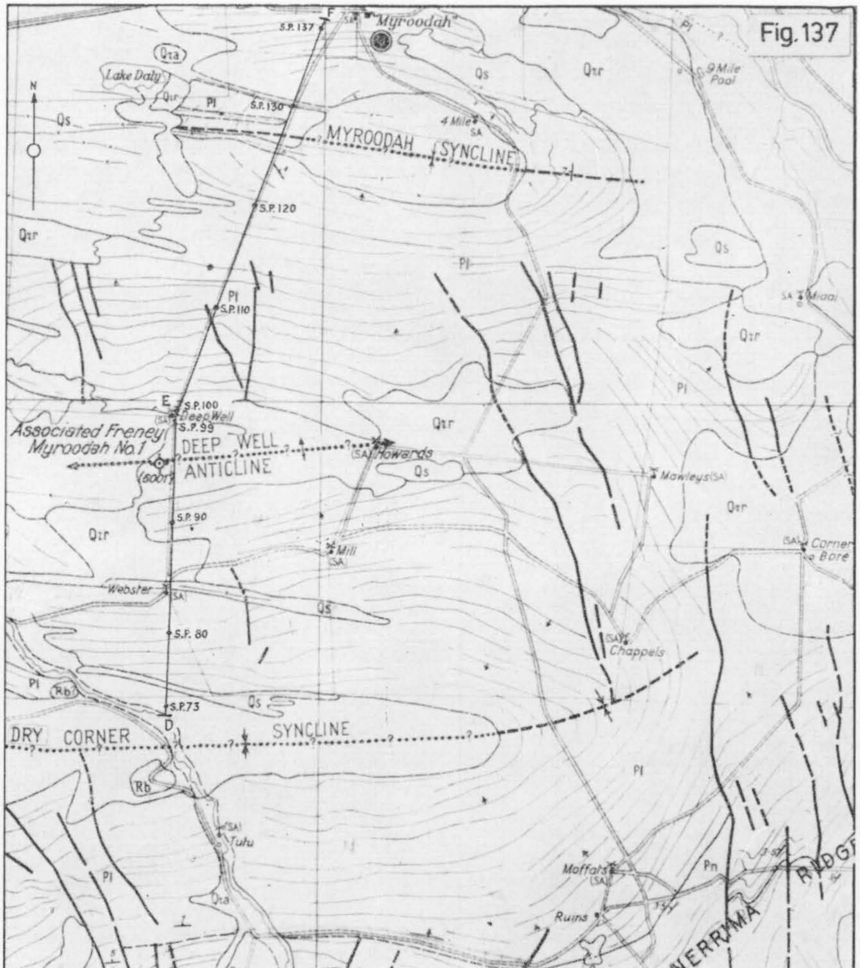


Fig. 137.—Locality map, Myroodah/Barnes Flow area. For explanation of symbols, see Mount Anderson geological map.

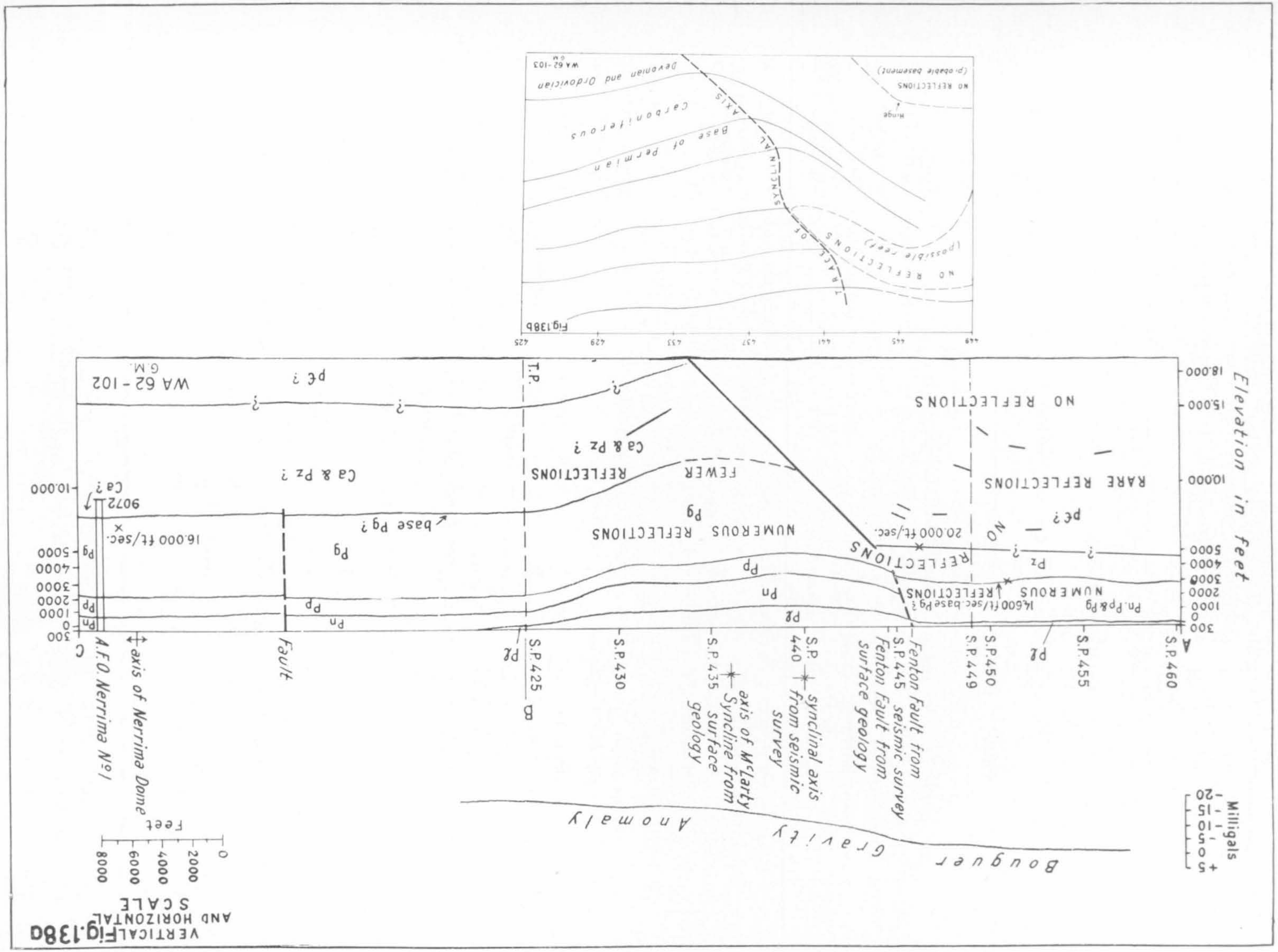


Fig. 138(a).—Section Myroodah/Barnes Flow area. pC—Precambrian; P2—undifferentiated Palaeozoic rocks; Ca—Anderson Formation; Pg—Grant Formation; Pp—Poole Sandstone; Pn—Noonkanbah Formation; Pl—Liveringa Formation. (b) Section near Barnes Flow (M.A. Condon).

basement between the faults, and the steep Bouguer gradient between S.P. 18 and 23 is not obviously explained by the postulated structure; outcrops of the Grant Formation and of Devonian rocks between the faults do not dip so steeply as our section requires them to do. These objections incline us to favour the hypothesis that the basement was warped mainly by movement along the Pinnacle Fault.

Regardless of the precise interpretation of the structure the Prices Creek area was a hinge area in the Permian, probably also in the Devonian, and possibly in the Ordovician. The hinge is indicated by down-sagging, which was effected either by faulting or by folding, or by both. The structural history is described below.

The Fenton Fault

The outcrop of the Fenton Fault extends for 110 miles between Clanmeyer Pool and a point 25 miles south of the Millyit Range; it cuts Permian rocks. Guppy et al. (p. 66) state that 'Mesozoic beds have been faulted along the Fenton Fault with a downthrow of 140 feet to the south-west', but do not supply details. The Fenton Fault in the Barbwire Range (Fig. 89) does not displace the probable Jurassic Barbwire Sandstone.

A section through the Fenton Fault at Barnes Flow is shown in Figure 138. Information on structure in this area is derived from the geological mapping by Guppy et al. (Fig. 137), seismic surveys (Vale & Smith, 1959, unpubl.), gravity surveys (Wiebenga & van der Linden, 1954, unpubl.), and a bore, AFO Nerrima No. 1. The geophysical work is unpublished, and a summary of results is as follows:

(1) Section AB is a dip section;

(2) reflections are numerous between S.P. 425 and S.P. 443 to a depth of 8000 feet to 9000 feet and less numerous to 16,000 feet;

(3) these reflections show a dip 6° south-westward near the surface, and an increase of dip with depth to 25° at 16,000 feet, except for reflections between S.P. 439 and S.P. 445, which show steep north-east dips between 9000 and 13,000 feet;

(4) very few deep reflections were recorded between S.P. 446 and S.P. 460; reflections are relatively numerous and near horizontal at 3000 feet, and below this there are only a few isolated reflections, as shown in Figure 138A;

(5) V = 14,600 feet/second at a depth of 2700 feet on the south side of the fault; and V is greater than 20,000 feet/second at 5500 feet. This high velocity is interpreted by Vale & Smith as indicating Precambrian crystalline basement. The only other rock for which such a high velocity is recorded by Bureau geophysicists in the Fitzroy Basin is the crystalline basement in the Prices Creek area. Vale & Smith relate the good reflector at 3000 feet (with a seismic velocity of 14,600 feet/second at 2700 feet) to the rocks at Nerrima with velocity of 16,000 feet/second at a depth of 7000 feet (Vale, Smith, & Garrett, 1953, unpubl.), which, from AFO Nerrima No. 1, are identified as the basal part of the Grant Formation.

The section at Nerrima is traced south-eastward from AFO Nerrima No. 1 Bore (BC) by means of surface structure—most of BC is a strike section—and from B to A by the reflection data. By this method, the good reflections at depths of 1000 feet to 2000 feet between S.P. 445 and S.P. 427 are found to come from the top of the Noonkanbah Formation. North of the Fenton Fault, the thickness of the Noonkanbah Formation in the section is roughly the same as that of nearby outcrops, and the thickness of the Grant Formation and Poole Sandstone is extrapolated from AFO Nerrima No. 1. This method is prone to error, and the section as drawn is tentative only. Reflections north of the Fenton Fault indicate that the Poole Sandstone is roughly the same thickness throughout, that the Noonkanbah Formation thickens in the McLarty Syncline, and that the Grant Formation thickens near the Fenton Fault. North of the Fenton Fault to point B, the section is probably conformable, and the axial planes of folds dip 80° north-eastward.

Vale & Smith interpret the steep north-east dips as a fault plane. M. A. Condon (pers. comm.) provides an alternative (Fig. 138B). He interprets the recorded velocity of 20,000 feet/second as possibly indicating limestone or dolomite, the part of the section with no reflections as a possible carbonate reef, and the scattered reflections below this part as indicating the south limb of a syncline. The postulated carbonate rock between 3000 and 8000 feet would have the same density as crystalline basement, and hence would produce the same gravity anomaly. Minor faults, of which the Fenton Fault is one, are the result of differential compaction over a deep basement step.

We advance a third hypothesis, that the part of the section with no reflections consists of an intrusion of salt, the nearest known occurrence of which is 50 miles away at Frome Rocks. The 20,000 feet/second refractor is rock salt or cap rock. This postulated salt intrusion lies in the same situation with respect to the outcropping Fenton Fault as the Frome Rocks Salt Dome.

Anticlinal Belts

The Permian rocks within the Fitzroy Depression are faulted and broadly folded. Three belts of anticlines are recognized by Guppy et al. (p. 66): the Southern Anticlinal Belt, which extends 120 miles from east of Christmas Creek Homestead to the Fenton Fault east of Tutu Bore, with culminations at Poole Range, Mount Hutton, St George Range, Nerrima, and Tutu; the Central Anticlinal Belt, 60 miles long, with culminations at Mount Wynne and Grant Range; and the poorly defined Northern Anticlinal Belt, with a culmination at Warrawadda. The structure of part of the Poole Range is shown in Figure 136. A fourth feature, beneath the Mesozoic rocks 30 miles north-east of Broome, the Barlee Anticline, has been recently drilled by Wapet.

Vale & Williams' (1955, unpubl.) seismic investigation of the Broome area shows that the sedimentary section is roughly 12,500 feet thick, that a major unconformity possibly lies at 7000 feet, and that the subsurface structure is probably an anticline that trends north-west. Near Langey Crossing (Vale & Smith, 1956, unpubl.), the sedimentary section probably exceeds 16,000 feet, and possibly exceeds 20,000 feet. The deep structure is probably a broad syncline of low relief.

The Poole Range Dome is expressed on the surface by a roughly oval outcrop of Grant Formation surrounded by successive rings of Poole Sandstone, Noonkanbah and Liveringa Formations. Dips in these rocks, which are cut by numerous north-trending normal faults with throws less than 200 feet, do not exceed 8°. The dome is elongated along a west-north-west axis. Williams (1956, unpubl.) recorded seismic reflections from a syncline whose axis (not shown in Figure 135) lies 2.6 miles south of the axis of the Poole Range Dome. No reflections were recorded north of S.P. 216 across the crest of the dome. The axial plane of the syncline dips 76° southward. The sedimentary section is at least 19,000 feet thick, and is conformable.

Reflections recorded north of Christmas Creek Homestead indicate a phantom horizon at 7000 feet, which is identified with the phantom at about the same depth between S.P. 232 and S.P. 216. These horizons are interpolated across the crest of the dome. The depth of the phantom at S.P. 212 is taken from CC′. The structure of the phantom corresponds roughly with the surface structure.

A longitudinal section along the eastern part of the dome shows dips of 2° at 1500 feet, and 4° at 6500 and at 11,000 feet.

The main information provided by the seismic surveys is summarized thus:

(1) Structure continues from the surface to a depth of at least 16,000 feet.

(2) The sedimentary section is 20,000 feet thick, and is conformable. Smith's unconformities (AA′) pass basinwards into conformities.

Lying between the western parts of the Central and Southern Anticlinal Belts are the Dry Corner Syncline, Deep Well Anticline, and Myroodah Syncline, which have been seismically examined by Williams (1955, unpubl.). A section (Figs. 137, 139) has been constructed from geological mapping (Guppy et al.), from bore data from Myroodah No. 1, and from the seismic data. A shallow reflector is identified from the bore data as the top of the Noonkanbah Formation. No reflections are recorded over the axis of the Deep Well Anticline, and hardly any were recorded beneath the good reflector at a depth of 4000 to 5000 feet in the Myroodah Syncline, probably because little energy passed through this reflector. Numerous reflections were recorded on the southern flank of the Deep Well Anticline to a depth of about 24,000 feet, and indicate a conformable section. A break in the shallow reflector between S.P. 115 and S.P. 120 is interpreted as a fault.

The estimated thickness of the Liveringa Formation in the Myroodah Syncline —5000 feet—exceeds the thickest measured section of 3000 feet between Mount Ibis and Mount Hardman (Guppy et al., p. 52). A brief discussion of the geophysical work carried out in the Myroodah area is also given by Guppy et al. (p. 69).

The *Frome Rocks Salt Dome* is shown in Figure 140.

The *Fraser River Structure* (Brunnschweiler, 1957) is a very broad anticline in the Cretaceous rocks of the Fraser River area. According to Brunnschweiler, the Fraser River Structure is best indicated by the structure contours of the base of the Melligo Quartzite, which ranges from sea level in the northern part of the Dampier Peninsula to 400 feet above sea level in the Fraser River area. The deep structure of the Fraser River area is unknown. The Fraser River No. 1 Bore bottomed in gabbro at 10,004 feet. According to McWhae et al., the gabbro is intrusive, and stringers of dolerite were found 1000 feet above the bottom. Condon et al. (1958) regard the gabbro as Precambrian basement. The aeromagnetic survey indicates that sedimentary rocks are 10,000 feet thick in this area, but this method does not distinguish clearly enough between basement and intrusive igneous rock. The solution of this problem clearly lies with the radiochemists.

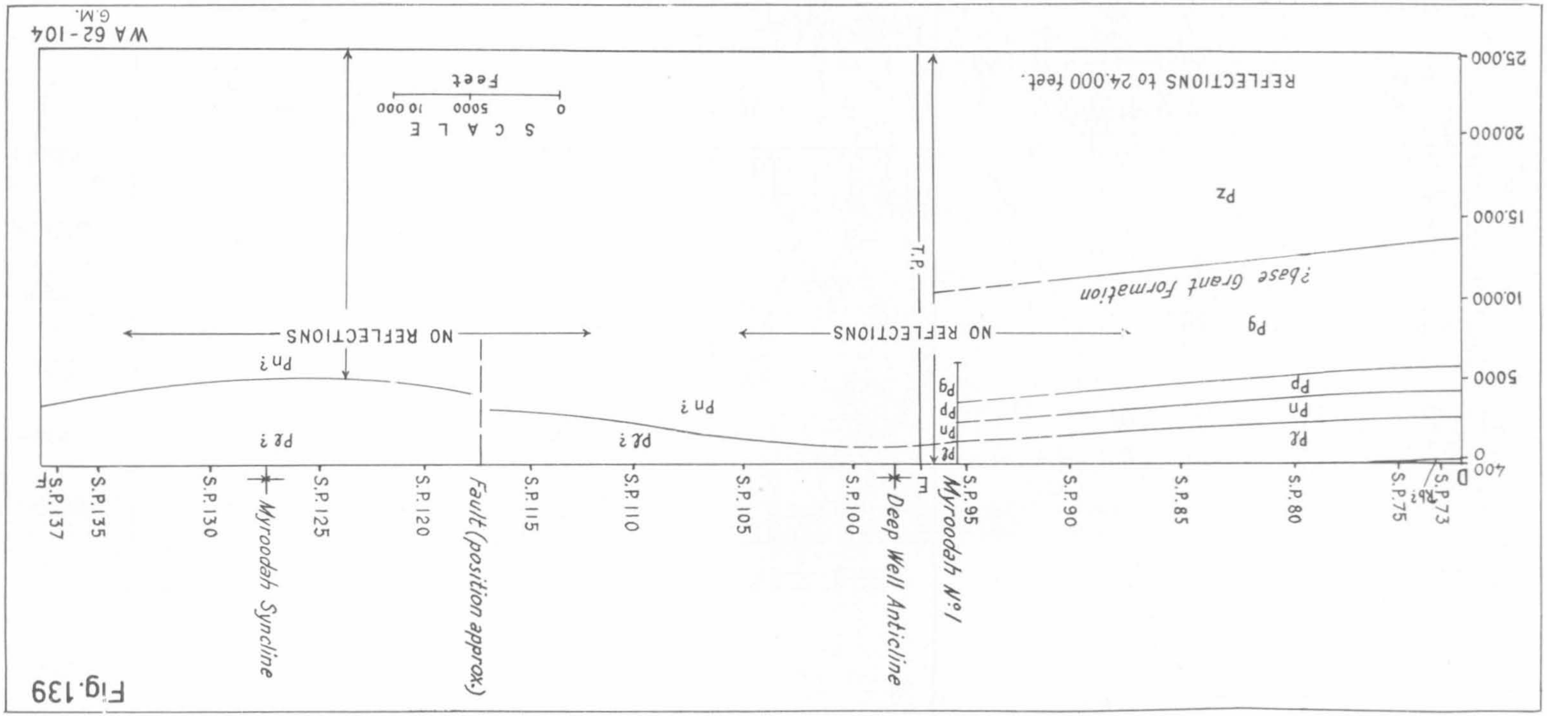


Fig. 139.—Section Deep Well Anticline. P2—Undifferentiated Palaeozoic; Pg—Grant Formation; Pp—Poole Sandstone; Pn—Noonkanbah Formation; Pl—Liveringa Formation; Rb—Blina Shale.

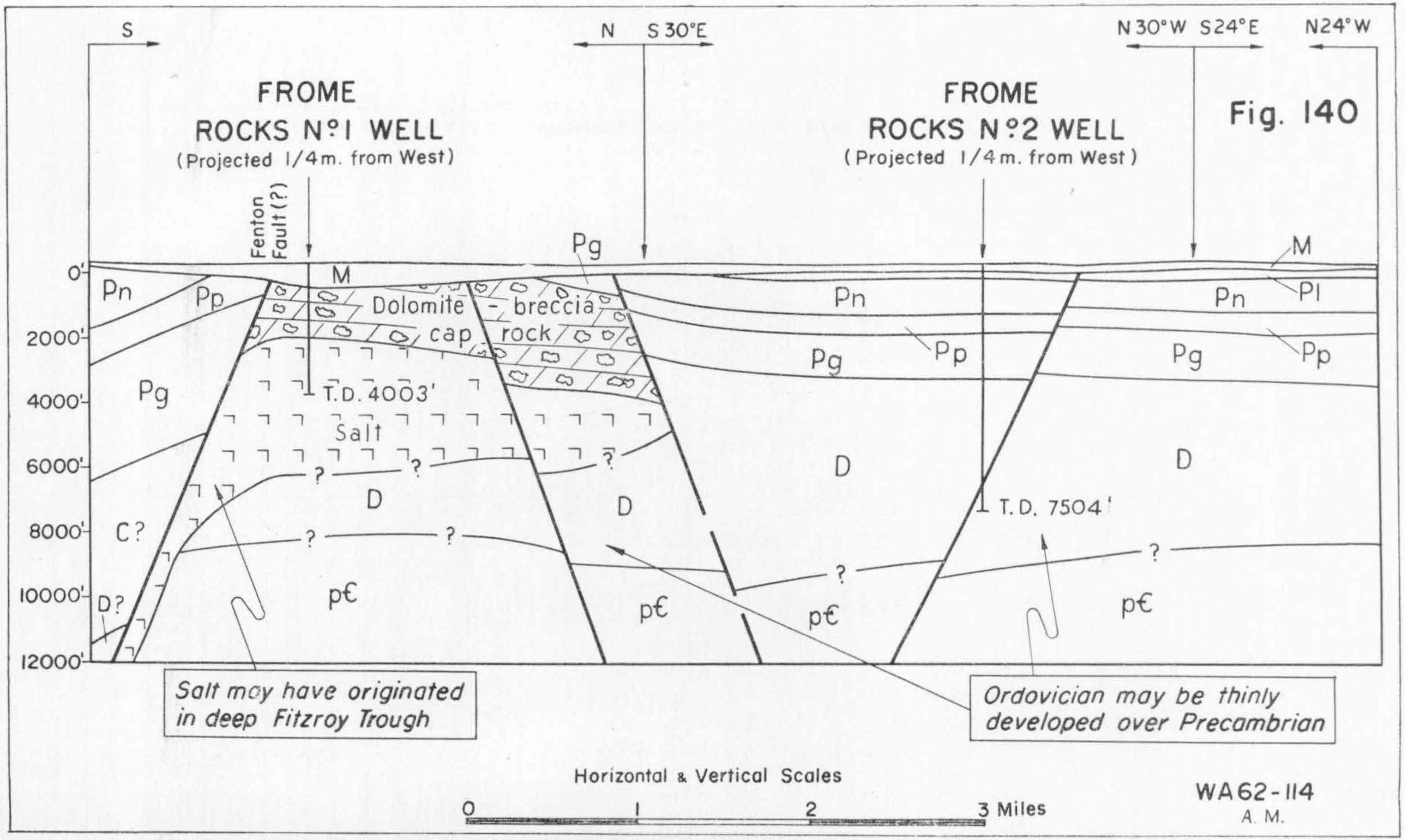


Fig. 140.—Section across Frome Rocks Salt Dome. Adapted, with permission of Wapet, from enclosure 4 of Willmott (1960).

The aeromagnetic survey (Fig. 132) indicates two shallower parts (15,000 feet deep) of the Fitzroy Depression—one west of the Grant Range, the other east of the St George Range.

Other structures in the Fitzroy Depression are described by Guppy et al. (pp. 66-71).

The *Dampier Structure* marks the northern boundary of the Broome Swell at its western end. Unlike the Fenton Fault, the Dampier Structure is not exposed, and has been detected by geophysical means only. Its position is indicated by the northern side of the positive Bouguer anomaly that corresponds with the Broome Swell. Playford & Johnstone (1959, section BC of fig. 8) show that the Dampier Structure is a fault that cuts possible Ordovician and Devonian rocks, but not the overlying Permian and younger rocks.

North-east Canning Basin

The only information on structure is from geological mapping, and gravity and aeromagnetic surveys. No drilling or seismic surveying has been carried out, and consequently the deep structure is unknown.

The *Stansmore Fault* crops out between the Stansmore Range and the Bishop Range, a distance of 110 miles. It is best expressed in the Stansmore Range (Fig. 55), where the Liveringa Formation and probably the Noonkanbah Formation are exposed on the downthrow (western) side. Outcrops on the eastern side are poor, and are mapped as undifferentiated Permian. Rocks immediately west of the fault dip up to 30° westward, and flatten off within 5 miles of the fault. In the Stansmore Range, the Bouguer gravity contours parallel the fault, and the anomaly across the fault, 5 miles south of Warri Creek, ranges from —30 mgals one mile east of the fault to —50 mgals 3 miles west of the fault, indicating a considerable downthrow to the west. The Stansmore Range is the only area in which the gravity results are obviously connected with surface structure. North-west of the Stansmore Range, the fault runs oblique to a broad positive anomaly south of the Gregory Salt Lake. In the Stretch Range, the fault cuts the Liveringa Formation and the Blina Shale on both sides. We believe that the gravity and aeromagnetic data do not indicate the surface of the Precambrian rocks for the following reasons:

(1) An elongate negative anomaly (Fig. 141) trends north of Waterlander Breakaway across the Stansmore Fault in the Stretch Range, and through Balgo Hills, and branches at Knobby Hills; one branch continues northward through the Wolf Creek Meteorite Crater, the other trends westward to Mount Erskine. No change is registered over the Precambrian sedimentary rocks at the basin margin near the Meteorite Crater, and this suggests that the anomaly is related, at least in part, to the underlying, probably thick, Precambrian sedimentary rocks. A saddle in the negative anomaly west of the crystalline Precambrian rocks of the Kearney Range probably reflects thin Precambrian and younger sedimentary rocks over the crystalline rocks.

(2) An aeromagnetic traverse (Quilty, 1960, unpubl., traverse 14R) passed without anomaly from the Canning Basin near Mount Bannerman northward to the Precambrian quartzite of the Cummins Range, showing that the Precambrian sedimentary rocks of this area are indistinguishable magnetically from the Phanerozoic rocks.

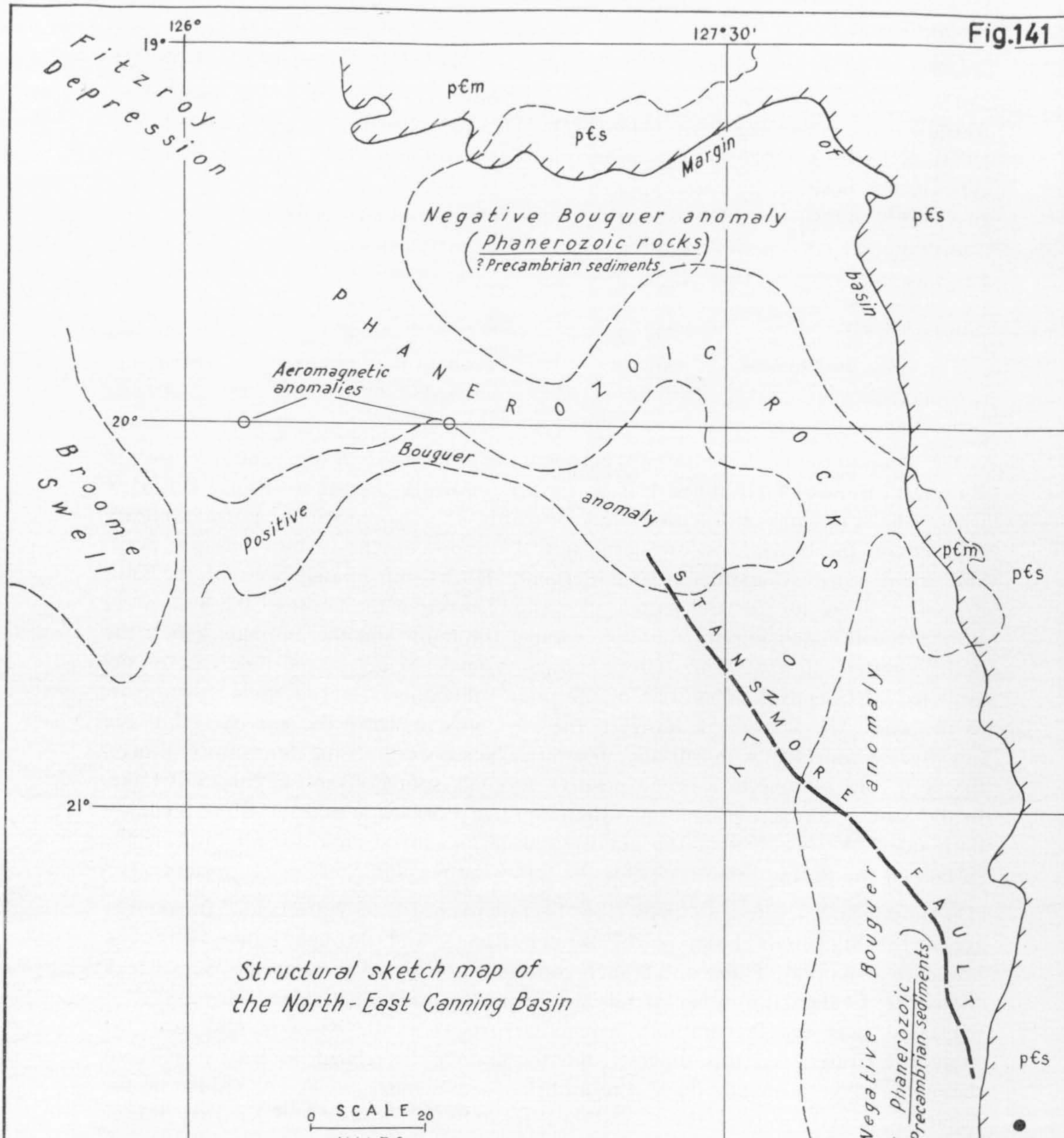


Fig. 141.—Structural sketch map of the north-east Canning Basin. pCs—Precambrian sediments; pCm—Precambrian metamorphics.

The area of the negative Bouguer anomaly is covered either by younger Precambrian sedimentary rocks and Phanerozoic rocks or by Phanerozoic rocks alone. The gravity and aeromagnetic evidence supports the idea that Precambrian sedimentary rocks extend from the margin into the basin, and perhaps are thickest in the basin. The basinward limit of the postulated Precambrian sedimentary rocks is possibly marked by the west and south parts of the negative Bouger anomaly.

The Stansmore Fault, except its southernmost part, and almost all other faults in the north-east Canning Basin strike obliquely to the Bouguer contours; the displacement on the Stansmore Fault is considerable (an estimated 5000 feet or more) in its southernmost part, and probably negligible elsewhere. The numerous faults that trend south-south-eastward in a belt south-east of the Fitzroy Depression have small displacements (Figs. 64, 66). Structural domes and basins are known in various places in the north-east Canning Basin (Figs. 55, 66, west side of Lake Betty, and 40 miles south-south-east of Godfrey Tank). M. A. Condon (pers. comm.) suggests that these structures may have been formed by large-scale slumping.

The broad Bouguer anomalies with low gradients, and the smooth aeromagnetic anomalies, indicate by comparison with these features in the Fitzroy Depression that the crystalline basement is deep. The positive Bouguer anomaly that extends from the postulated southern end of the Broome Swell in the Dummer Range to Chilpada Chara and further to Gregory Salt Lake possibly indicates the southern end of the Fitzroy Depression. Two aeromagnetic anomalies, one 20 miles north-east of the Dummer Range, the other 10 miles north-west of Chilpada Chara, lie near the northern edge of the postulated swell. These anomalies may also be interpreted as indicating the sides of the Fitzroy Depression.

The part of the Canning Basin outside the named areas and the north-east Canning Basin is structurally unknown. The only indications of structure in this area are as follows:

(a) a reconnaissance gravity survey that covers most of the remaining area indicates that the floor of the basin is probably fairly flat;

(b) the elongate positive Bouguer anomalies at Sufficiency Knob, in the eastern part of the Wilson Sheet area, at Ryan Range, and 50 miles north-east of Woolnough Hills are interpreted as possibly indicating shallow basement;

(c) three aeromagnetic traverses indicate that the floor of the basin is probably shallower than 10,000 feet;

(d) the dome at Woolnough Hills is probably a salt dome. Salt domes require at least roughly 10,000 feet of overburden above the mother salt bed to rise upward;

(e) according to Traves et al. (p. 35), the Percival Lakes arc traces the outcrop of the Dora Shale, and shows a syncline between Lakes Dora and Auld and probably an anticline between Lakes Auld and Percival. The Shale is known to have a 1° NE dip near Lake Blanche, and the Triwhite Sandstone dips ½° to 1° ENE at Triwhite Hills;

(f) a syncline can be traced at Anketell Hills, whose limbs dip 4°.

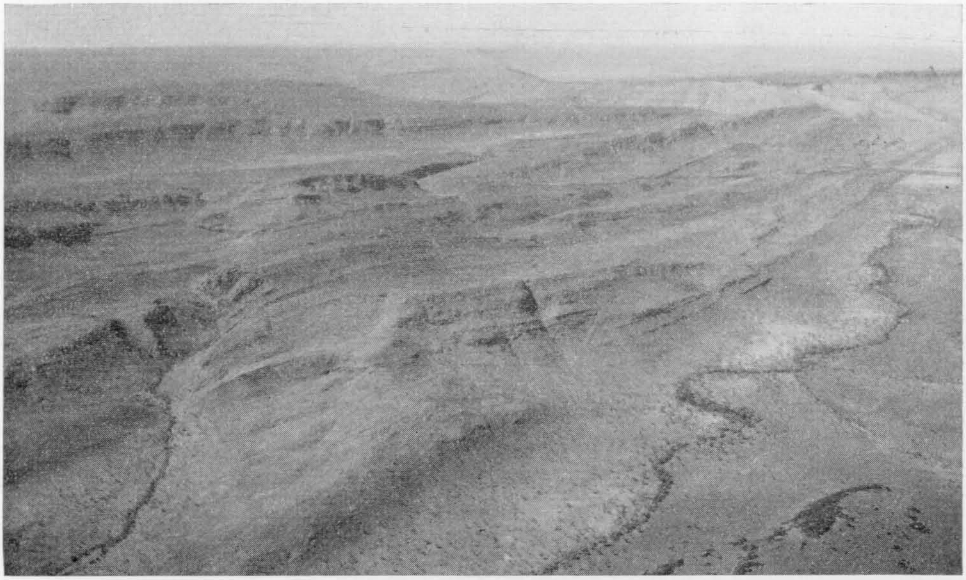


Fig. 142.—Folded rocks in the King Leopold Mobile Zone. This and the next figure were supplied by the News and Information Bureau, Department of the Interior.

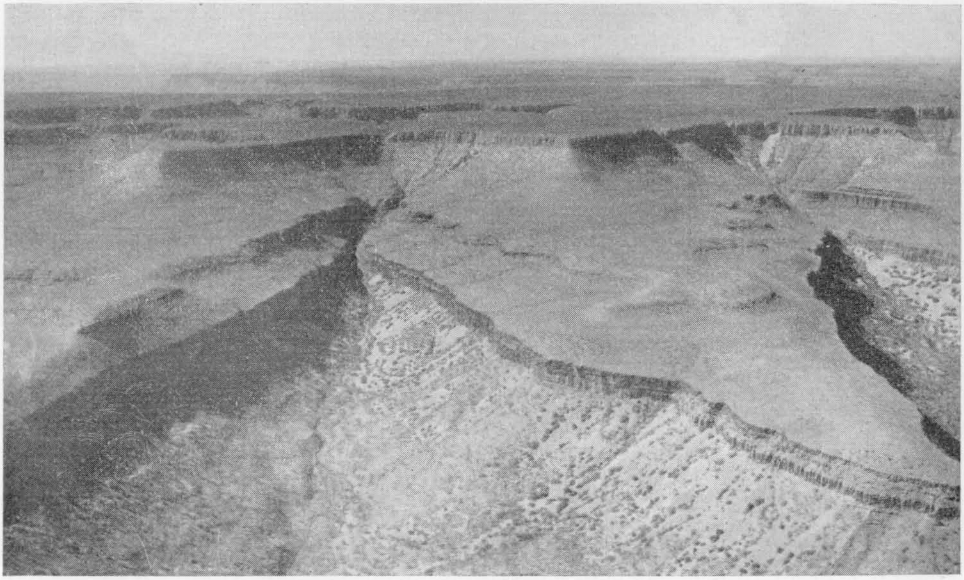


Fig. 143.—Precambrian rocks of the Kimberley Plateau.

Structural History

Weeks' (1958) observations on the structure of sedimentary basins apply aptly to the Canning Basin:

'The forces that directly cause the development of basins in the earth's crust appear to be essentially gravitational. An area or belt will subside when and where, for any cause, there is transfer of materials in the subcrust and loss of support relative to adjoining areas or belts. The subsidence is generally marked by gravity faulting. Very commonly the sagging is concentrated along one side of a major fault or zone of faulting. This results in an asymmetric basin form, deepest adjacent to the master fault or fault zone. This type of asymmetric basin has been termed a "half-graben". . . .

'If major gravity faulting develops more or less equally on opposite sides of the subsiding basin there develops what has long been known as a graben basin. A critical study soon discloses that the true graben form of basin is far less common than the half-graben. . . .

'Though the most pronounced fault subsidence in an asymmetric or half-graben form of basin is along one side, moderate to minor gravity faulting commonly occurs along the more stable side as well. It is most common in the belt between the relatively stable shelf and the more rapidly subsiding trough of the basin, where the differential sagging simulates a down bend. This commonly occurring flexure the writer many years ago termed a "hinge belt". It is an important element of the architecture of many basins. It is a common site of merging of source and reservoir environments and their resulting facies in the deposition basin; hence, it is a favored locus of oil occurrence or oil trends.'

The section (Pl. 2) across the better-known part of the Canning Basin is asymmetrical, but counterparts are present on either side of the La Grange Platform: the ridge at Samphire Marsh Bore corresponds to the Broome Swell, Samphire Depression to the Fitzroy Depression, the postulated ridge at BMR 4A Wallal to the Oscar Ridge, and the rest of the Wallal Platform to the Napier Platform.

Drilling to date has confirmed the hypothesis, first stated by Fairbridge (1953(a), I/40) and developed by Traves et al. (p. 34), that the floor of the Canning Basin consists of crystalline Precambrian rock. The only known Precambrian sedimentary rocks within the Canning Basin are those of the Oscar Range inlier, which lies near the margin, and probably does not extend further into the basin. On the Kimberley Plateau (Guppy et al.; Traves, 1955), the Precambrian sedimentary rocks unconformably overlie crystalline Precambrian rocks. This is the grand unconformity. The sedimentary rocks are regarded as Upper Proterozoic, and the crystalline rocks as Lower Proterozoic or older. Similar, presumably Precambrian, sedimentary rocks unconformably overlie crystalline rocks in other parts of the basin margin. The Precambrian sedimentary rocks of the King Leopold Range (Fig. 142) and of the Oscar Range inlier are deformed in what Traves (1955, fig. 31) calls the King Leopold Mobile Zone. The sedimentary rocks of the Kimberley Plateau are only slightly disturbed (Fig. 143). The rocks of the Mobile Zone were deformed before the Hart Basalt was erupted; according to Guppy et al., the Hart Basalt is either late Proterozoic, or, by comparison with the volcanics in East Kimberley, Lower Cambrian. The age of folding of Precambrian sedimentary rocks along other parts of the margin of the basin is unknown. The Precambrian sedimentary rocks of the Wolf Creek Meteorite Crater area are overlain by Tremadocian rocks, but the contact is not exposed. The probable Upper Devonian rocks at Knobby Hills unconformably

TABLE 9

STRUCTURAL HISTORY

Area / *Age*	*Wallal Platform*	*Samphire Depression*	*La Grange Platform*	*Broome Swell*	*Fitzroy Depression*	*Derby Ramp*	*Oscar Ridge*	*Napier Platform*	*North-east Canning Basin*
Tremadocian-Llanvirnian	probably local subsidence (Playford & Johnstone, 1959)	slow subsidence from uppermost Cambrian or lowermost Tremadocian to Arenigian	slow subsidence Arenigian to Llanvirnian	slow subsidence	probably subsided	local subsidence	northern limit of subsidence except at Prices Ck	probably land except Prices Ck area	subsidence at least along northern margin
U. Ordovician-L. Devonian	probably land	folding and uplift, erosion probably from Upper Ordovician to Lower Permian			uplift, erosion at northern margin	uplift, erosion		land	land
M. Devonian (Givetian)					probably subsided		subsided slowly		
Early U. Devonian (Frasnian)							differential uplift and erosion by block faulting and tilting. Local marginal uplift, local reef growth on some fault blocks		
Rest of U. Devonian						local uplift, erosion at end of Devonian or early L. Carboniferous	subsided slowly		local subsidence in lakes
L. Carboniferous						subsided slowly		probably subsided in Station Ck area	land
U. Carboniferous					rapid subsidence in central part of depression & in Permian & U. Carb. in Meda area	uplift, erosion, except western part which subsided			

TABLE 9—*continued.*

<table>
<tr><th>Age \ Area</th><th>Wallal Platform</th><th>Samphire Depression</th><th>La Grange Platform</th><th>Broome Swell</th><th>Fitzroy Depression</th><th>Derby Ramp</th><th>Oscar Ridge</th><th>Napier Platform</th><th>North-east Canning Basin</th></tr>
<tr><td>L. Permian</td><td rowspan="3">very slow subsidence</td><td>moderately fast subsidence</td><td colspan="2">slow subsidence, local land</td><td>very rapid subsidence except in Frome Rocks area</td><td>moderately rapid subsidence in Sisters area</td><td>local slow subsidence, most of ridge land</td><td>locally very slow subsidence, most land</td><td>slow subsidence</td></tr>
<tr><td>U. Permian</td><td colspan="3" rowspan="2">land</td><td>rapid subsidence</td><td rowspan="2">slow subsidence Derby area</td><td colspan="2" rowspan="2">land</td><td>folding, uplift, erosion in late U. Permian</td></tr>
<tr><td>L. Triassic</td><td>slow subsidence</td><td>slow subsidence</td></tr>
<tr><td>M. Triassic-L. Jurassic</td><td colspan="4">uplift, erosion, folding</td><td colspan="3">folding, faulting, uplift, erosion. Salt intrusion at Frome Rocks</td><td rowspan="2"></td><td>folding, uplift, erosion</td></tr>
<tr><td>M. Jurassic-L. Cretaceous</td><td>very slow subsidence</td><td colspan="3">slow subsidence</td><td>local subsidence in Meda area. Intrusion of Fitzroy Lamproite</td><td colspan="2">intrusion of Fitzroy Lamproite</td><td>slow subsidence represented by L. Cretaceous seds. at Godfreys Tank & Lake Hazlett</td></tr>
<tr><td>U. Cretaceous-Recent</td><td colspan="9">uplift, erosion except for local coastal subsidence</td></tr>
</table>

overlie Precambrian sedimentary rocks. Elsewhere on the eastern and southern margins of the basin, the oldest rocks overlying the Precambrian rocks are Permian.

On the geophysical evidence presented above, Precambrian sedimentary rocks presumably extend across the margin into the north-east Canning Basin (Fig. 141). The phyllite at the bottom of Thangoo 1A Bore is pre-Arenigian; whether it is Cambrian or older is unknown. In all other areas that have been drilled to basement, the basin floor is granite or metamorphic crystalline rock.

In the part of the Precambrian during which the sedimentary rocks were deposited, the area of the Canning Basin, except the Oscar Range and the north-east corner of the basin, was probably land, which shed sediment into the surrounding areas. Subsequently, probably after the deformation of rocks in the King Leopold Mobile Zone, and in other areas, the tectonic roles were reversed, and sediment derived from the surrounding areas was deposited over the former land.

The Phanerozoic structural history is summarized in Table 9 (pp. 236-7).

History of Selected Structures

Movement along the *Pinnacle Fault* probably started in the early Upper Devonian and continued intermittently to the end of the Permian. The tentatively determined Ordovician and Carboniferous or Devonian rocks south of the Pinnacle Fault (Fig. 136) are only a little thicker than the Ordovician and Devonian rocks on the north side of the Oscar Ridge, and any difference in thickness could be explained by a gentle basinward slope of the Precambrian basement. The Cadjeput Fault also probably dates from the early Upper Devonian, but probably did not move again, because its south-eastern extension (Fig. 11) is overlain by unaffected younger Upper Devonian rocks. Rapid sagging south of the Pinnacle Fault accompanied the deposition of the Permian formations, after which movement ceased. Near the fault, according to Guppy et al., the Noonkanbah Formation is exceptionally sandy; the sand was probably derived from the erosion of the Grant Formation north of the fault.

Fenton Fault and the Dampier Structure. The Fenton Fault was probably initiated before or during the Upper Devonian, as indicated at Frome Rocks by thick Upper Devonian rocks, which are missing south of the Fenton Fault and Dampier Structure. Movement continued in the Upper Carboniferous and Permian. The 'downthrow' was to the north-east. According to Brunnschweiler (1953) and Guppy et al. (p. 66), Jurassic rocks are down-faulted 140 feet to the south-west.

The *Frome Rocks Salt Dome* intrudes Permian rocks and is overlain by horizontal Middle Jurassic rocks. The age of the salt intrusion is therefore Triassic to Lower Jurassic. The oldest known rocks intruded by the salt are Upper Devonian.

Woolnough Hills Dome. The age of the postulated salt intrusion is younger than Lower Cretaceous. The upper age limit of the intrusion must be inferred from an estimate of the time required to form the dome and reduce it by erosion to its present shape. On these grounds, an estimate of late Tertiary could be made. The age of the postulated mother salt bed is Permian or older.

The *Anticlinal Belts* of the Fitzroy Depression were probably folded during Middle Triassic to Lower Jurassic. The rocks were folded by differential uplift of the basin floor, and not by lateral pressure. The Permian formations in the anticlinal belts are as thick as if not thicker than those in the synclinal areas in between: for example, the Grant Formation is estimated to be 9500 feet thick in the Grant Range (in the Central Anticlinal Belt), and 7000 to 8000 feet thick in the synclines near Myroodah. Folding, therefore, did not take place during deposition.

The diastrophisms. The Canning Basin was initiated by a diastrophism near the end of the Precambrian, which elevated the Precambrian sedimentary rocks that lie near the present margin of the Canning Basin, and depressed the Precambrian crystalline rocks that underlie the basin. The second diastrophism, at some time between Upper Ordovician and Lower Devonian, gently folded and uplifted the Ordovician rocks. The third diastrophism, which took place during the early Upper Devonian, faulted the Precambrian basement and the Middle Devonian and older Upper Devonian rocks of the Napier Platform into blocks, some of which were uplifted and eroded; the Pinnacle and Fenton Faults were probably initiated at this time. Minor diastrophisms probably took place locally on the Derby Ramp at the end of the Devonian, and in the north-east Canning Basin at the end of the Permian. The fourth main diastrophism probably took place between Middle Triassic and Lower Jurassic, and gently folded Permian and possibly Triassic rocks in long anticlinal belts.

Subsidence after the Cretaceous was confined to the coastal strip, along which coastal (aeolian) limestone was deposited, and to the valley of the Oakover River, in which lacustrine marl and chalcedony were deposited.

GEOMORPHOLOGY

In their geomorphological studies of Western Australia, Clarke (1926) and Jutson (1934) described what was then known of the surface of the Canning Basin. This surface can be more adequately described now that the area has been air-photographed, and crossed in many places by field parties. The morphological divisions now recognized are shown in Figure 144; these include the divisions of the Fitzroy Basin described by Guppy et al. Plate 3 shows the main data related to morphology; these include topographical contours (based chiefly on levels determined by the Geophysical Branch of the Bureau), bathymetric contours (compiled from Admiralty Charts 475, 1047, 1048, and 1055), the distribution of bottom sediments on the Rowley Shelf (after Carrigy & Fairbridge, 1954), and, on the land, the distribution of salt pans and clay pans, evaporites, travertine, and the sediments of the coastal plain. Too little is known of the area for sound conclusions and a geomorphological history would therefore be speculative and subjective.

The CSIRO Division of Land Research started a survey of the western part of the Kimberley Division in 1959 but no results have yet been published.

The *King Leopold Ranges* (Guppy et al., p. 11) (Fig. 142) are rugged strike ranges carved out of the folded Precambrian sedimentary rocks at the southern margin of the Kimberley Plateau. The *Richenda Valley* lies between the King Leopold Ranges and the Limestone Ranges of the Fitzroy Basin. The Richenda Valley is underlain by Precambrian crystalline rocks, and its surface is subdued except for locally rough areas. The *Limestone Ranges* (Guppy et al.) (Figs. 26, 32, 35) mark the northern

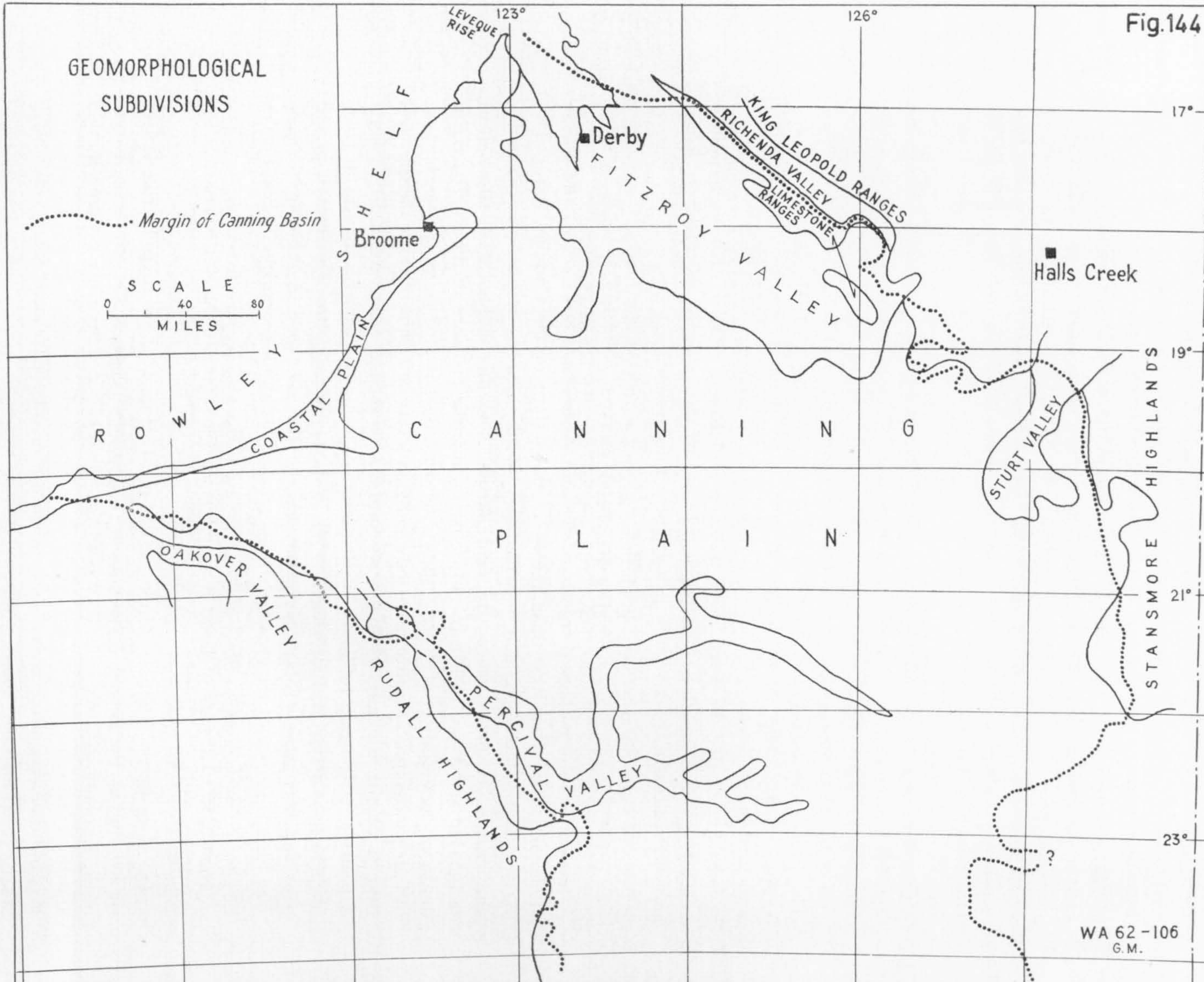


Fig.144
GEOMORPHOLOGICAL
SUBDIVISIONS
Margin of Canning Basin
SCALE
0
40
80
MILES
123°
126°
17°
19°
21°
23°
LEVEQUE RISE
Derby
Broome
Halls Creek
KING LEOPOLD RANGES
RICHENDA VALLEY
LIMESTONE RANGES
FITZROY VALLEY
ROWLEY SHELF
COASTAL PLAIN
CANNING
PLAIN
STURT VALLEY
STANSMORE HIGHLANDS
OAKOVER VALLEY
RUDALL HIGHLANDS
PERCIVAL VALLEY
?
WA 62-106
G.M.

Fig. 144.

boundary of the Fitzroy Basin, and have been shaped into a karren-feld. The ranges narrow to a few hundred yards across in the Napier Range and widen to 10 miles across in the Oscar area and in the area south-east of the Fitzroy River. The *Fitzroy Valley* (Guppy et al.) includes the lower parts of the valleys of the Fitzroy, Lennard, Barker, and Margaret Rivers, and Christmas and Jurgurra Creeks. The Fitzroy, Lennard, Barker, and Margaret Rivers rise in the King Leopold Ranges or in the Richenda Valley, and enter the Fitzroy Valley through gorges in the limestone ranges. The Fitzroy River, Jurgurra Creek, and Cherrabun Creek extend southward to the boundary of the Canning Plain. The Fitzroy Valley is flat except for low fold ranges (Poole, St George, Grant Ranges) and scattered buttes and mesas (Erskine Hill, The Sisters, Mount Arthur). Most of the surface of the Fitzroy Valley is covered by alluvium, rubble, and residual soil.

The *Sturt Valley* is an area of internal drainage that terminates at Gregory Salt Lake. The valley is covered by alluvium deposited by the distributaries of Sturt Creek and Wolf Creek.

The *Stansmore Highlands* consist of strike ridges of Precambrian rocks (Gardiner, Lewis, Phillipson, and Erica Ranges) and the fault-bounded Stansmore Range of Permian rocks. Salt lakes (Lakes Lucas, White, Wills, Hazlett) cover a large area between the Phillipson Range and Red Cliff Pound.

The *Canning Plain* has a known area of 150,000 square miles; its southern and south-eastern limits are unknown. Most of the Canning Plain consists of a series of plains, which roughly conform with the structure of the underlying horizontal beds. The structural plains grade imperceptibly into one another, or are separated from one another by breakaways. The structural plains are underlain by flat-lying Phanerozoic rocks, which are covered by a sheet of aeolian sand, or by a ferruginous or siliceous duricrust. Isolated mesas (Colorado Outcrop, McLarty Hills, Godfrey Tank area, Ryan Buttes) rise above the plain. Sand is less widespread in the south-western part of the plain (Anketell, Sahara, Ural, and Morris Sheet areas), where ironstone and siliceous rubble thinly covers a lightly dissected, deeply weathered platform of Jurassic and Cretaceous rocks. The drainage system of this platform runs into the Percival Valley. Near Lake Mackay, the plain is not structural, and is underlain by Precambrian gneiss and sandstone. Ranges of gneiss capped by sandstone (Mount Webb) or of folded sandstone (Pollock Hills, in the south-western corner of the Webb Sheet area) rise 100 feet above plain level. Drainage channels, except on breakaway slopes, and on the rocky surface of Sahara, Ural, and Morris Sheet areas, are lacking on the Canning Plain. Clay pans cover a large area east of Samphire Marsh, and probably indicate the course of a river that flowed into it, and travertine covers a large area north-west of Lake Mackay.

The *Percival Valley* is the depression which includes Percival Lakes, Gwenneth Lakes, Lakes Auld, George, Winifred, Blanche, Dora, and Waukarlycarly, and the unnamed valley that extends eastward from Lake Auld into the Ural Sheet area. The elevation of the Percival Valley decreases from 1100 feet at the eastern end of the Percival Lakes to 650 feet at Lake Dora; Lake Waukarlycarly is 690 feet above sea level, and is separated from Lake Dora by higher ground. The Percival Valley is underlain by Permian rocks (Dora Shale) from Lake Dora to Lake George, by probable Permian rocks from Lake Auld to the eastern end of Percival Lakes, by Jurassic and Cretaceous rocks east of Lake Auld, and by Precambrian metamorphic rocks at Lake Waukarlycarly. According to Traves et al., the Lakes follow the outcrop of the broadly folded Dora Shale in the Tabletop Sheet area.

The *Rudall Highlands* bound the south-western part of the Canning Plain and the western part of the Percival Valley. The Highlands consist of strike ridges of Precambrian rocks that range in elevation from 900 to 1300 feet, and rise 200 to 300 feet above the sand plain. The ranges are drained by the Rudall River, which flows into the Percival Valley, and by streams that flow into the Oakover Valley.

The *Oakover Valley* is the alluvial valley which contains the Oakover, Nullagine, and De Grey Rivers. The valley is bounded to the north by the Rudall Highlands and to the south by the highlands of the Nullagine area. Deposits in the Valley include the Permian Braeside Tillite, the Tertiary Oakover Beds, and Quaternary alluvium, sand, and boulders (Fig. 121).

The *Coastal Plain* extends south-west of Broome and is about 10 miles wide, except at Roebuck Plains and at Samphire Marsh, which extend 40 miles inland. Most of the plain lies between 30 feet and sea level, and is covered by samphire marsh and coastal dunes. Remnants of the Canning Plain extend to the coast and stand above the coastal plain as cliffs at Gourdon Bay and near Cape Frezier. These remnants are too small to be shown on Figure 144.

According to Fairbridge (1953(b)) and Carrigy & Fairbridge (1954) the *Rowley Shelf* extends from the coast to the 300-fathom line. In Plate 3, the same contour interval for bathymetric and topographic contours was chosen to facilitate comparison of the morphology of the sea-floor and land. Carrigy & Fairbridge (1954, p. 69) placed the boundary of the inner shelf at 60 fathoms, but the contours on Plate 3 indicate that the change in slope between inner and outer shelves occurs at either the 500-foot or 600-foot (100-fathom) contour. The inner shelf slopes 600 feet in 150 miles opposite the 80-mile Beach, and the outer shelf slopes 1200 feet in 60 miles. Farther seaward, the continental slope drops steeply (2700 fathoms in 110 miles) into the North Australian Basin (3000 fathoms). The Rowley Shoals are atolls that lie at the edge of the shelf in 300 fathoms of water. The Rowley Shelf is an attractive area for marine geology, but to the present-day it remains virtually unexplored.

The *Leveque Rise*, which is described by Fairbridge (1953(b)) and Carrigy & Fairbridge (1954), runs north-west from Cape Leveque to the 40-fathom (240-foot) line, and then slopes down to the continental slope. The epicentre of a powerful earthquake lies on or near the Leveque Rise. The Leveque Rise probably continues landward into the northern margin of the Canning Basin.

The southern, seaward boundary of the Canning Basin is not known; it is possibly marked by the Dampier Rise.

No new data on the seaward part of the Canning Basin have appeared since Carrigy & Fairbridge (1954) described the Rowley Shelf, and our ideas about the history of the shelf are based on information about the landward part of the Canning Basin. The strata of the Samphire Marsh area, on the coast, are flat-lying, and the stratigraphical sequence penetrated by Samphire Marsh No. 1 Bore (Johnstone, 1960)

(Pl. 3, section CD) can reasonably be extrapolated seaward under the inner part of the Rowley Shelf. How far seaward these strata continue is of course not known. The shelf on which the Jurassic and Cretaceous rocks were deposited probably included the area of the Rowley Shelf, but how much sediment was deposited over this part of the Jurassic and Lower Cretaceous shelf is unknown. The extent of the Permian and Ordovician deposits under the Rowley Shelf is also unknown. According to the interpretation shown in section CD, the surface of the Rowley Shelf, at least its inner part, is a structural plain. During the low eustatic sea levels of the Pleistocene, part of this plain must have been continuous with the Canning Plain, and was probably shaped at this time by subaerial erosion. The low relief of the present shelf and Canning Plain, the slow rate of either deposition or erosion on these surfaces, and the presumed structural quiescence in the region, have maintained the former shape of these surfaces.

ECONOMIC GEOLOGY

Petroleum Prospects

The history of oil exploration in the Canning Basin up to 1958 is described by Condon et al. (1958, pp. 45-49), by Guppy et al. (appendix 1), and by Playford & Johnstone (1959). Since these reports were written, Wapet has drilled Goldwyer No. 1 and Meda No. 2 Bores, and, with the assistance of Commonwealth subsidy, Meda No. 1, Frome Rocks Nos. 1 and 2, Thangoo 1 and 1A, and Barlee No. 1. In 1958, the Bureau drilled BMR 4 and 4A Wallal.

The main rocks that have been prospected in the Canning Basin are buried Devonian organic reefs and associated strata, and Lower Carboniferous rocks, both on the north-western part of the Oscar Ridge, the Ordovician of the Samphire Depression, La Grange Platform, and Broome Swell, and the Permian of the Fitzroy Depression. Whether or not Ordovician rocks extend into the Fitzroy Depression is unknown; the Devonian rocks of the Fitzroy Depression have been penetrated only in Frome Rocks No. 2 Bore but, from palaeogeographical considerations, are possible source rocks.

All the known Ordovician rocks of the basin, except the outcropping sandstone near the Wolf Creek Meteorite Crater, and possibly the section in Samphire Marsh No. 1 Bore, are potential source rocks, and the main search in these rocks is for reservoirs. Thangoo 1A Bore penetrated shale and carbonate rocks of low porosity. The nearby Thangoo No. 1 Bore terminated in a cavern that was probably eroded between Upper Ordovician and Carboniferous time. No hydrocarbons were reported in the Ordovician rocks of Roebuck Bay No. 1 and Dampier Downs No. 1 Bores; porosity is low. Some beds in the Ordovician section penetrated by Goldwyer No. 1 Bore are stained with oil, and contain some gas; once again, the section has low porosity. The only permeable rock at Prices Creek is the basal arkose. If the Ordovician rocks continue basinward beneath the surface, as the seismic results suggest, movement along the Pinnacle hinge probably induced permeability, and perhaps provided small fault traps. The Ordovician sandstone near the Wolf Creek Meteorite Crater is permeable, and in suitable structures beneath younger Palaeozoic rocks could provide potential reservoirs for oil that migrated from equivalent deeper-water carbonate and shale sequences. Wapet's bores in Ordovician rocks on the La Grange Platform have been sited on structural culminations, probably over Precambrian hills. The negative results therefore apply solely to this type of structure, and off-structure sites remain untested. Permeable rocks possibly surround the basement hills, and should be tested.

The Oscar Ridge in the Oscar and Emanuel Ranges was the site of reef growth in the Devonian. The postulated north-western continuation of the Oscar Ridge is buried beneath Carboniferous, Permian and Triassic rocks, and is a good prospect for oil. The lateral equivalents of the reefs, as shown by BMR 2 Laurel Downs Bore, are potential source rocks, as also are the reefs that were killed by rapid burial. Reefs with sufficient porosity are potential traps if they are sealed by cap rocks. The 67-mile Bore, on the Oscar Ridge, produces artesian water from several aquifers, including the basement or the rocks immediately above the basement. The other bores on the Oscar Ridge, Meda Nos. 1 and 2, penetrated a reef complex and associated strata; the reef contains a small show of gas, and one of the associated beds a doubtful oil zone.

Another line of Devonian reefs may have grown along the southern edge of the Derby Ramp. The Sisters No. 1 Bore is the only bore sited along this line; the Devonian section in The Sisters No. 1 consists of limestone of low porosity interbedded with siltstone and sandstone, which contain fresh water. Some small hydrocarbon shows were reported.

The only outcropping Devonian rocks that could be regarded as potential reservoir rocks besides reefs are the lenses of sandy limestone at the base of the Pillara Formation. If these rocks extend basinward from the main outcrop, they will be prospects for the drill, because they probably lie unconformably on Ordovician rocks, and both Ordovician and Middle Devonian rocks were probably involved in the early Upper Devonian diastrophism, which provided structural traps and possibly also induced some permeability.

The Lower Carboniferous dolomitic sandstone in Meda No. 1 Bore produced salt water and several gallons of paraffin-base crude oil, the first recovered by Wapet in the Canning Basin. The discovery of two hydrocarbon-bearing zones in Meda No. 1 indicates that the Oscar Ridge should be regarded as a most favourable area for future oil exploration. The Lower Carboniferous rocks probably extend beneath the Permian rocks into the Fitzroy Depression, and, in favourable structures, are potential source and reservoir rocks.

The Permian rocks in the Fitzroy Depression are folded into long anticlines, which are vast potential reservoirs. Potential sources are the older Palaeozoic rocks. The main task in exploring these anticlines for oil is to find potential reservoir rocks that have not been flushed by fresh water. The Grant Formation contains fresh water in Fraser River No. 1, Grant Range No. 1, and Nerrima No. 1 Bores. The intrusions of Fitzroy Lamproite in Permian rocks are too small to have adversely affected the oil potential of these rocks.

Seismic data in the Prices Creek/Poole Range area indicate that the unconformities between Permian and Carboniferous or Devonian rocks, and between Devonian and Ordovician rocks, pass basinwards into conformities. Hydrocarbons in the porous rocks beneath the unconformities would probably be trapped between impermeable rocks basinward, and by impermeable Precambrian rocks in the Prices Creek area.

The hinge areas are probably the best prospects in the Canning Basin. Outside these areas, most of the sediments were folded and faulted long after deposition, so that if petroleum was generated in the sediments, it probably migrated before reservoirs were formed. In the hinge areas (Pinnacle, Fenton, Dampier, Samphire, Wallal), movement during deposition and lateral change from deeper-water source rocks to shallower-water reservoir rocks favour the accumulation of petroleum. The intrusion of salt along the Fenton hinge at Frome Rocks increases the prospects.

The unnamed part of the Canning Basin is *terra incognita* as regards petroleum prospects.

The main task in the search for oil in the Canning Basin should be to locate areas of favourable reservoir lithologies and, within these areas, to locate particular stratigraphic-structural traps. The drilling of closed anticlines only is inadequate.

Underground Water Supply

Recent reports which include information on water supply in the Canning Basin are Guppy et al. (Fitzroy Basin), Traves et al. (south-west Canning Basin), Casey & Wells (north-east Canning Basin) and Wyatt (1959) (Fitzroy Basin). A description of the water supply in these areas is summarized below. Other sources of information on water supply are the completion reports of stratigraphic bores of the Bureau of Mineral Resources and of the subsidized bores of Wapet (Table 10). Information on shallow wells along the Canning Stock Route has been compiled from unpublished maps of A. W. Canning (Table 11). The figures quoted in the table refer to the initial production of the wells during the period 1908-1910. Some of the wells were visited recently by BMR geological parties, and new figures are incorporated in the table.

We use the term artesian water for ground water that is under sufficient pressure for it to issue at ground level; that is, water whose piezometric surface lies above ground level. Sub-artesian water is pressure water whose piezometric surface lies below ground level. The water table is the upper surface of the zone of saturation where that surface is not confined.

Most of the water supplies in the Canning Basin are obtained from ground water in shallow wells. The Fitzroy River Valley and the coastal area between Broome and Port Hedland are the only areas in which the deeper sub-artesian or artesian aquifers have been penetrated. Stratigraphic oil exploration bores and some town water bores have been drilled in these areas, and most produce potable artesian water.

Guppy et al. give details of water bores in the Fitzroy area. The most successful bores are those that penetrate the Grant Formation, Liveringa Formation, and Poole Sandstone (all Permian), and the Jurassic, Cretaceous, and more recent sediments. They say: 'These units are primarily sandstone sequences with numerous horizons from which a supply of subartesian water can be expected.' The water is fresh except in dry or salty bores in the Noonkanbah Formation and, less frequently, in the Liveringa Formation and the Jurassic sediments. The Blina Shale is unsuitable as an aquifer, and the Erskine Sandstone is the main producer in the Triassic rocks. The Devonian rocks have not been tested thoroughly; the conglomerates are probably the best source. Successful bores have been sunk in the Devonian conglomerates on some stations north-east of Fitzroy Crossing.

Wyatt (1959) discusses the water prospects of the Fitzroy Basin and indicates the most favourable drilling sites for artesian or sub-artesian water. He suggests that wherever possible the Poole Sandstone or Grant Formation should be selected as target beds.

In the Oakover-Nullagine River Valley, bores in the boulder clays of the Permian Braeside Tillite yielded salt water (Traves et al.). A deep bore through the boulder clays to the underlying Precambrian sediments would probably yield good water.

There are few wells in the desert area of the south-west Canning Basin. Wells in the Mesozoic or Permian rocks, by analogy with other areas, should strike abundant supplies of potable water at depths from 30 to 80 feet.

The supply from Well 22 to Well 51 inclusive on the Canning Stock Route is shown in Table 11. Many wells are sited in areas underlain by travertine; most of these produce ample water from a shallow depth. Most other wells are in Permian or Mesozoic rocks. In 1956 a party from the Bureau of Mineral Resources traversed from Well 22 to Well 27, and measured water level and well depth. Well 23 has recently been retimbered by the State Government.

In the north-east Canning Basin, wells and bores in the Noonkanbah Formation or Balgo Member near Balgo Mission yield little water, and most of it is salty. More promising bore sites lie farther east near the Kearney Range, in the Upper Devonian or Lower Carboniferous sandstone. At Billiluna Homestead ample supplies of fresh water are obtained from wells in the Grant Formation or from Recent residual deposits. At Sturt Creek Homestead ample supplies of good water are obtained from the Precambrian sediments. In this area, the demand for subsurface water is not as great as in many other areas in the Canning Basin because there are many large permanent pools in Sturt Creek.

Table 10 shows the water supply obtained from deep bores in the coastal area and in the Fitzroy River Valley. The analyses of total soluble salts were carried out by the Western Australian Government Chemical Laboratory. In most bores, a depth of 600 feet marks the boundary between artesian and sub-artesian water. Production from the shallow sub-artesian wells near deep oil or stratigraphic bores is obtained by air-jetting, bailing, or pumping.

In the coastal bores, the large flows of artesian water are from the coarser sandstone at the base of the Mesozoic succession; the Alexander Formation is also a copious producer. The sandstone is friable and has caved and filled many bores. The coastal area is probably more favourable for the production of artesian water than the Fitzroy Valley.

TABLE 10

WATER SUPPLY FROM BORES IN THE CANNING BASIN

BORE	TOTAL DEPTH (feet)	SUPPLY (g.p.h.)	DEPTH OF AQUIFER TOP OR TEST DEPTH (feet)	QUALITY	REMARKS
Broome Town No. 2	1775	43,000A	1500	....	....
Jurgurra Ck BMR 1 (Water Well)	230	poor	...	TDS 28,052 ppm NaCl 19,140 ,,	Noonkanbah Formation
Meda No. 1	8809	2000SA	...	....	....
Meda No. 1 Water Well 1	103	poor	...	Salty water	Water rises to 30 ft. in 14 hrs after bailed dry
,, Water Well 2	121	dry	...	....	....
,, Water Well 3	63	400	...	TDS 1263 ppm NaCl 408 ,,	Pumped supply
,, Water Well 4	103	270	69	TDS 2750 ,, NaCl 2650 ,,	....
,, Water Well 5	63	240–360	...	NaCl 68 ,,	....
Myall's	...	3000A	...	....	....
Myroodah No. 1	6001	450DST	730	NaCl 500 ,,	....
Nerrima AFO No. 1	9072	2500DST	2685–2691	NaCl 950 ,,	....
Prices Creek Water Well 1	108	"Ample"	...	Excellent	Supply for drilling Prices Ck BMR No. 2
Samphire Marsh No. 1	6664	850A 500A 720A	730– 742 900– 924 1090–1124	....	....
Samphire Marsh Water Well 1	1047	... 5000	... 964–1047	NaCl 70,000 ppm	First flow at 278 ft. ....
67 Mile Water Bore	3012	40 1500 2500 6000 6000 1500A 5000A	173 208– 225 260 1003 1332 2518 3012	....	.... Temp. 90° F. ....
Talgarno No. 1	1324	45,000A	1272–1314	TDS 1952 ppm	Main production this depth
Thangoo Water Well 1	305	500	260– 275	Excellent	....
Water Well 2	...	600	...	Excellent	....
Wallal BMR 4, 4A	1410	42,000A	900	....	....
Wallal Corehole No. 1	1014	21,000A	...	....	....

TDS — Total dissolved solids.
SA — Sub-artesian.
A — Artesian flow.
DST — Drill stem test.

TABLE 11

CANNING STOCK ROUTE WELLS

WELL NO.	DEPTH (feet)	SUPPLY gal./hr	WATER LEVEL IN WELL (feet)	STORAGE gallons	QUALITY (See notes)	REMARKS
22	53	1000	(39)	1575	G.S.W.	Camel whip but no windlass or cover. Recently retimbered
23	19	1450		1275	G.S.W.	Clay, travertine, chalcedony spoils
24 (Karara)	33	360	3 (10)	4350	E.W.	29′ drift sand, 4′ sandstone
25	37	600		3000	G.S.W.	Slightly brackish. Now caved in
26	23 (now 17)	2016	10 (13)	1950	E.W.	
27	24 (24)	330	(14)	1800	E.W.	In hard fine-grained sandstone
28	30	840		2750	E.W.	
29	45	230		4800	G.W.	
30 (Dunda Jinda)	26	2000		2475	G.W.	
31	23	3000		600	E.W.	
32	25	950		1875	E.W.	
33 (Gunowaggi)	22	1000		2400	E.W.	
34 (Nibil)	18	900	4	1725	G.S.W.	
35 (Minju)	16	1500		1350	E.W.	
36 (Wanda)	18	900		1950	E.W.	
37 (Libral)	16	1240		1500	E.W.	
38 (Wardabunna Rock Hole)	Rock Hole improved			30,000		Horizontal sandstone
39 (Murguga)	15	1100		1425	E.W.	Travertine
40 (Waddawalla)	12	1200	6	1275	G.W.	
41 (Tiru)	19	950		2250	E.W.	
42 (Guli)	25′ x 14′ x 4′ 6″ deep	1000		5990	E.W.	Travertine
43 (Billowaggi)	19	1000		1500	G.S.W.	
44	43	1000		1950	E.W.	Timbering burnt out
45	28	1000		2250	E.W.	Travertine flat
46 (Kuduarra)	26	2000		1300	E.W.	
47	24	1250		1500	E.W.	Travertine flat
48	65	130		1650	E.W.	Now caved in
49 (Lumba)	50	500		4800	E.W.	Travertine rises
50	62	500		3300	E.W.	
51 (Werriaddo)	22	1750 (1200—Talbot, 1910)		900	P.	

G.W. — Good water
G.S.W.— Good stock water
E.W. — Excellent water
P. — Poor quality water

} Quality as recorded by A. W. Canning.

Figures in brackets are those measured by BMR geologists.

Salt

The salt of the Frome Rocks Salt Dome (Elliott, 1960) is halite, and lies 2256 feet beneath the surface. If elsewhere this salt lies nearer the surface, it may prove commercial.

Lead, zinc, silver

Two outcrops of lead-zinc-silver ore, chiefly carbonates, occur in the limestone of the Napier Formation, 1 mile south-east of the northern side of the Barker Gorge, in the north-western part of the Lennard River Sheet area, and were worked in the Narlarla Lead Mine (Finucane & Jones, 1939). Prider (1941) suggested that the ore deposit is related to the Fitzroy Lamproite magma.

Iron Ore

The pisolitic ironstone of the Poondano Formation (p. 189, Fig. 116) is rich in iron, as the analysis of one of the specimens from Deposit A shows:

	%	% recalculated to 100%
Fe_2O_3	77.50	76.04
Loss on ignition (1000°C)	13.80	13.53
Al_2O_3	8.75	8.58
SiO_2	1.89	1.85
	101.94	100.00

This rock contains 53.2% Fe.

After ignition, the residue has the following composition:

	%
Fe_2O_3	87.93
Al_2O_3	9.93
SiO_2	2.14
	100.00

The residue contains 61.5% Fe.

Since Deposits A and B are the only ones that were visited, estimates of the tonnage of ironstone are given for these deposits only. Only Deposit A was sampled, and its thickness measured. Thus three types of estimates are given:

probable estimates of tonnage at Deposit A;

possible estimates at Deposit B;

and possible estimates of the relative amount of ironstone at the other deposits.

Deposit A

From the air photographs, the area of pisolitic ironstone is conservatively estimated to be 1,500,000 square feet. The deposit is approximately 20 feet thick, so the volume is 30,000,000 cubic feet. The average value of bulk density of the two samples of ironstone is 11.84 cubic feet/ton. The estimated weight of this deposit is therefore 2,600,000 tons, containing 52.3% Fe, that is, about 1,400,000 tons Fe. If the water were removed from the ironstone, the figure would be 2,250,000 tons of ore containing 61.5% Fe.

Deposit B

The possible figures for Deposit B are: area 1,700,000 square feet, thickness (?) 10 feet, tonnage 1,400,000 tons of ore.

Other Deposits

The estimated amount of ironstone at the remaining deposits is conjectural. The amount at C or J is possibly similar to A or B, at D, E, F, G or H much less, and at K much larger.

As described above (p. 194), radioactive anomalies occur over granite close to the ironstone deposits.

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APPENDIX 1

PRECAMBRIAN ROCKS ON THE SOUTH-EASTERN AND SOUTH-WESTERN MARGINS OF THE CANNING BASIN

by

J. J. VEEVERS and A. T. WELLS

On the south-eastern and south-western margins of the Canning Basin (p. 14), Precambrian sedimentary rocks unconformably overlie metamorphic and igneous rocks. The 1956 Bureau party briefly examined the south-western margin (Rudall and Runton Sheet areas, Fig. 1), and the 1957 party the south-eastern margin (*see* Pl. 1). Some of the rock descriptions, including those giving percentages of minerals present, are by J. Kerry Lovering.

Precambrian Sedimentary Rocks

The Precambrian sedimentary rocks on the south-western margin are quartz sandstone and some conglomerate; they unconformably overlie metamorphics and granite, and, in the Runton Range, are unconformably overlain by the Permian Paterson Formation. In the Runton Range, silicified sandstone and shale with minor siltstone dip 30° or less in symmetrical folds. The thickest measured section (Fig. 2), of 2500 feet of alternating quartz sandstone and shale, is exposed between Rn51 in the Runton Range and Rn52 near Lake Disappointment. The southern part of the Runton Range (Rn51, Fig. 2) consists of hard silicified sandstone, which stands about 250 feet above plain level. Some of the sandstone is colour-banded. The shale is softer and is exposed in valleys or on wide flats. The shale at Rn53 shows large-scale drag-folds. The thin beds of greywacke at Rn54 are laminated and cross-bedded, and contain rounded quartz grains and chlorite pseudomorphs of an unknown mineral, cemented by hematite and chlorite.

Several columnar sections of Precambrian sedimentary rocks are shown in Figure 3, including one at Mount Webb, on the south-eastern margin.

Most sections of Precambrian sediments on the Rudall Sheet in Wells Range, Emu Range, Bocrabee Hill, and Tarcunyah Creek are quartz sandstone with thin beds of shale. In some of the sections the sandstone is silicified at the surface and contains rare quartz pebbles, most 2 inches or less across, and thin beds of conglomerate. At Ru14 (this and other localities mentioned in this appendix are shown in Figure 1) a coarse clay-pellet sandstone contains rare boulders up to one foot across. Where bedding is discernible in the sandstone it is medium to thick, and ripple marks and cross-bedding are common. Laterite cappings on the sandstone are rare. Thin quartz stringers found in some beds of sandstone were probably re-deposited from percolating water.

At Ru15 at the north-western end of the McKay Range the sandstone is coarse-grained and contains some quartz pebbles up to one inch across, and beds of fine conglomerate. The rock is not so well sorted as the Precambrian sediments seen farther west on the Rudall Sheet.

On the south-eastern margin, low-dipping argillaceous quartz grit and sandstone unconformably overlie granite gneiss (*see* Appendix 2) at Mount Webb (Fig. 3). Forty miles to the west, quartz sandstone is folded into a broad anticline; 50 miles west-south-west of Mount Webb, about 2000 feet of quartzite and slate are exposed at Corroboree Valley (Fig. 2). Thirty miles south of Corroboree Valley, equivalent rocks are vertical.

Precambrian Metamorphics

The Precambrian metamorphic rocks on the south-western margin consist of quartz-feldspar schist, quartzite, amphibolite, gneiss, slate, and shale, intruded by batholiths of granite and diorite; they are unconformably overlain by Precambrian sediments, by the Paterson Formation near the headwaters of Cotton Creek (p. 74), and by the Paterson Formation and Cronin Sandstone

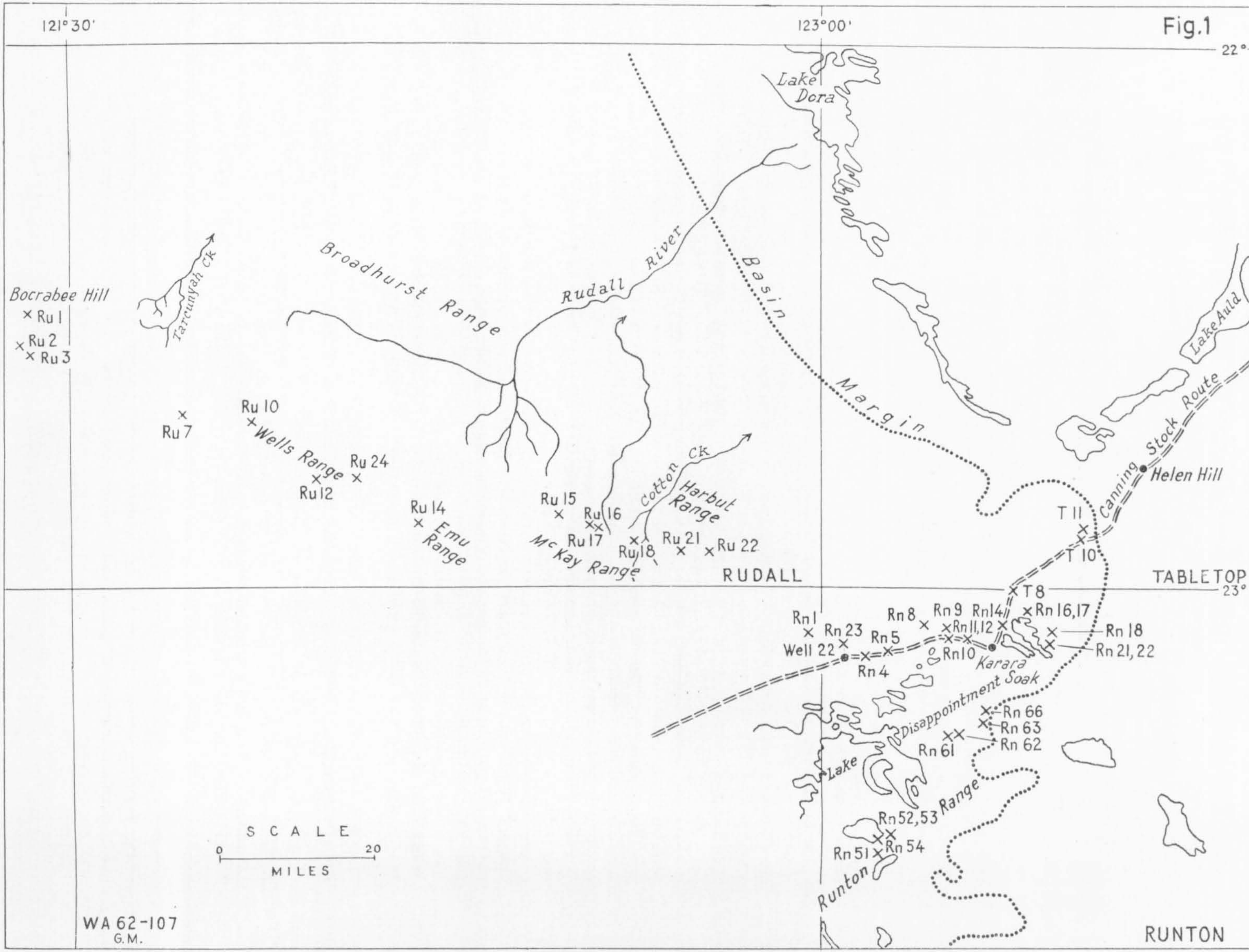

Fig. 1.—Locality map, showing Precambrian rocks on the south-western margin of the Canning Basin.

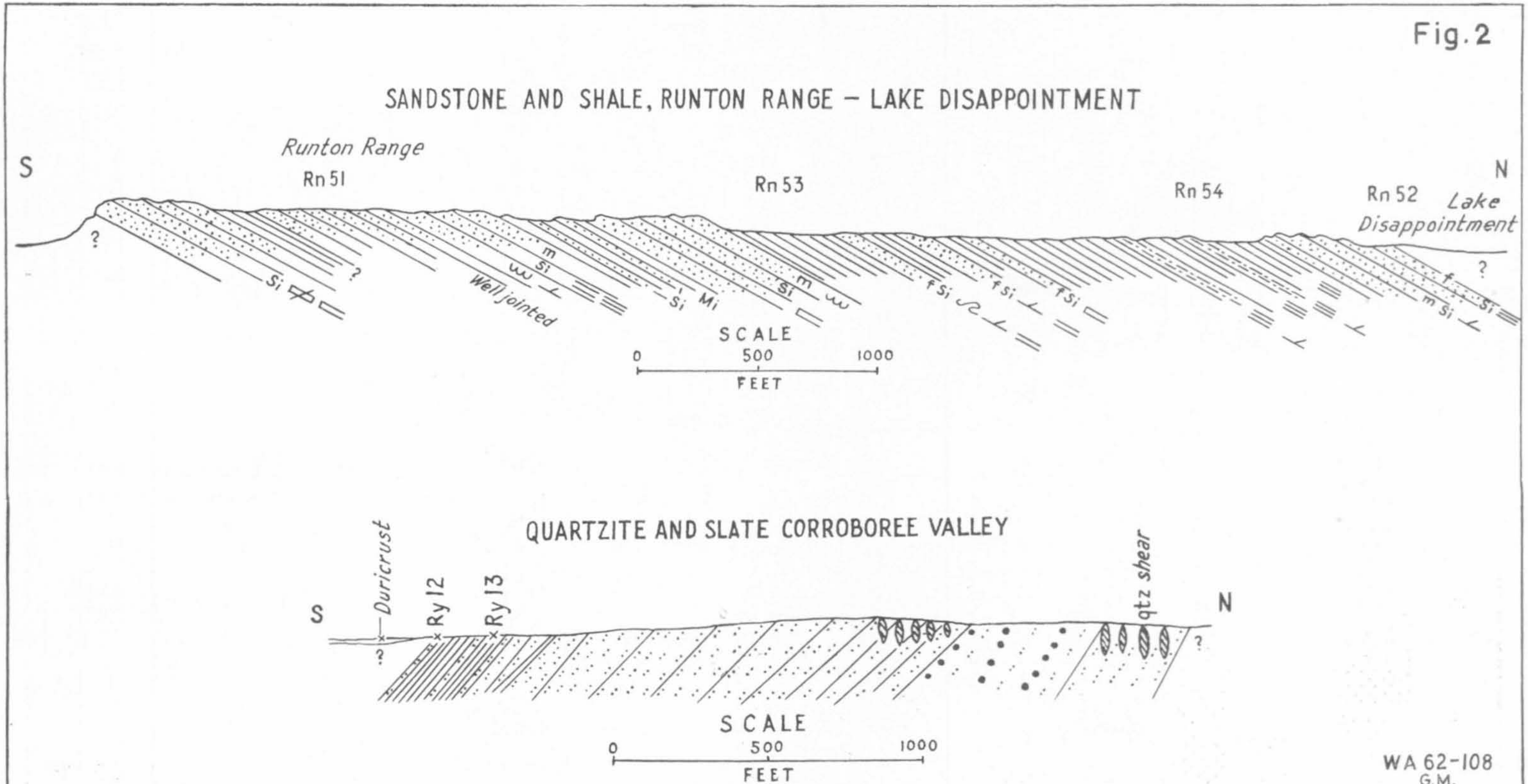

Fig. 2.—Sections of Precambrian rocks, Runton Range and Corroboree Valley.

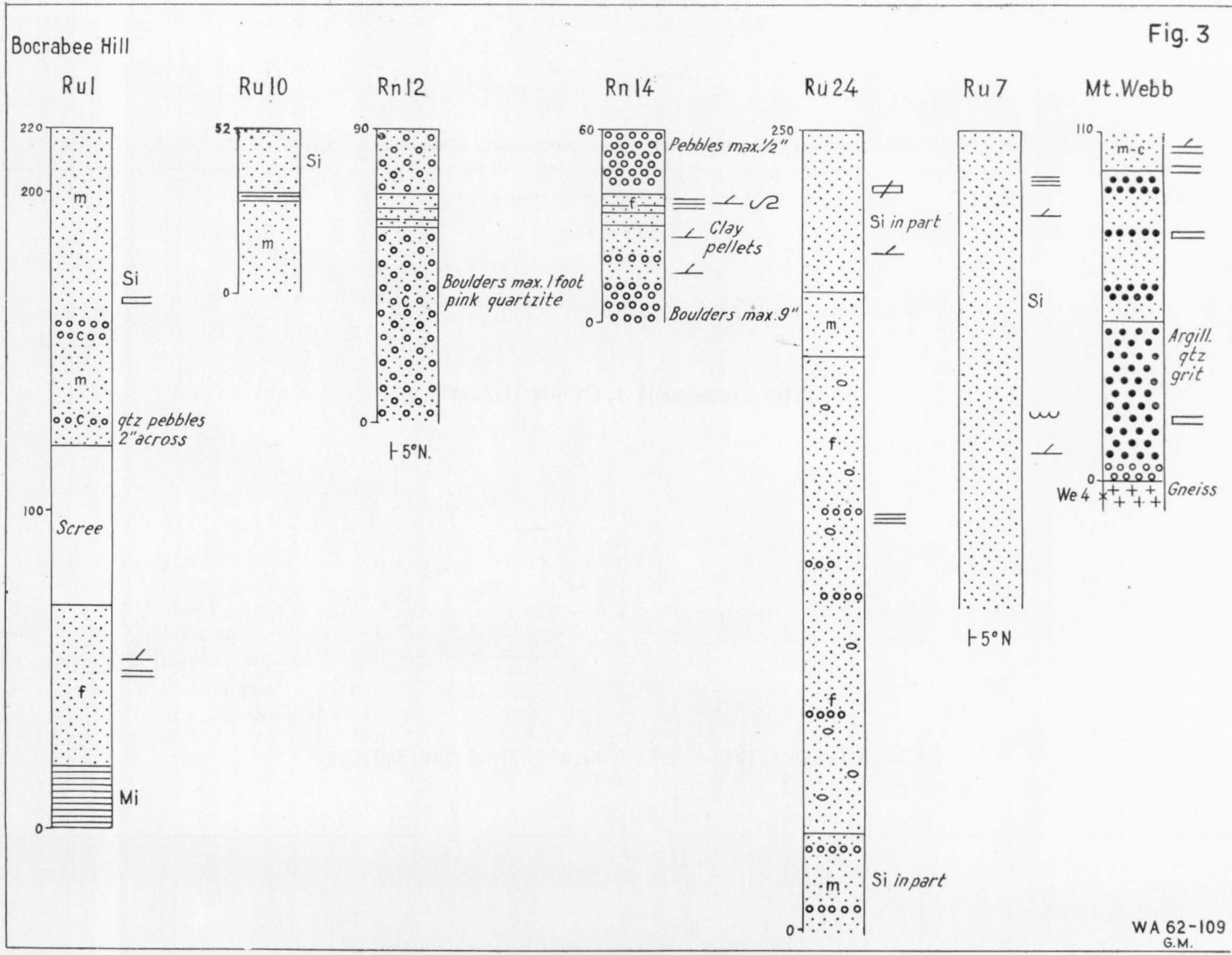

Fig. 3.—Columnar sections of Precambrian rocks.

near the Runton Range (p. 129). About 10 miles north-east of Karara Soak (Well 24, Canning Stock Route) the Cuncudgerie Sandstone unconformably overlies amphibolite (p. 82).

Vertical quartz-feldspar schist exposed near the north face of the McKay Range (Ru16 and Ru17) contains quartz (70%), microcline (5%), perthite (10%), and muscovite (5%), in a finely granulated matrix (10%); it may be a gneissic granite whose outcrop is bounded on the south by a faulted contact against a silicified sandstone veined with quartz.

The debris from Permian glacial deposits near Ru18 consists of limestone, pink quartzite, basic amygdaloidal lava, contorted gneiss, granite, and quartz, but only the pink quartzite and quartz can be traced to nearby outcrops.

The rocks in the McKay Range and some outcrops near Well 22 on the Canning Stock Route are transitional between sedimentary and metamorphic rocks. Many of the rocks are folded with nearly vertical dips, and we have grouped them with the metamorphics.

At Ru21 on the northern face of the McKay Range, a pink quartzite with abundant quartz veins is exposed on the northern limb of an east-plunging anticline. The beds dip at 60° to 80° to the north, but some of the dip may be due to the presence of an east-trending fault at this locality. Except for metamorphism these rocks are similar lithologically to the rocks described under Precambrian sediments.

Silicified sandstone, quartzite, and conglomerate are exposed in other localities; some appear to be granitized; others have re-oriented minerals. For example, at Rn4 and Rn5, granitized quartzite (partly gneissic) is isoclinally folded and crenulated, and intruded by quartz veins.

Granitized quartzite with clear quartz veins is exposed at Ru22 and Rn1. Rugged hills 2 miles north of Well 22 (Rn23) consist of conglomerate and shale associated with basic volcanics. The shape of the igneous body, and its relationship to the sediments, are unknown. It occurs in a small valley near the centre of the group of hills. The only other known occurrence of basic volcanics is a small isolated outcrop at Ru3 on the western edge of the Rudall 4-mile Sheet area.

Dolomite and hematitic shale crop out at Rn61. The dolomite is fine grained and contains veins of iron ore and calcite. The only other outcrop of dolomite is at Ru2; the rock is fine and granular, and is crossed by fine quartz and hematite-rich veins. Thick beds of dolomite may be present in the Runton Range, but are too soft to crop out.

The unconformity at Rn62 between the metamorphics (slate, shale, quartzite, sandstone and greenstone) and the Paterson Formation is shown on p. 77. Outcrops of the Mesozoic plant-bearing Cronin Sandstone at Rn63 and Rn66 occur very close to Precambrian metamorphic rocks and undoubtedly overlie them unconformably (p. 129).

Intrusive Rocks

Intrusive rocks were seen at T10 in the Tabletop Sheet area, and at Rn16-18 in the Runton Sheet area.

Gneissic granodiorite crops out at T10, and at T11 probably intrudes a quartz-mica schist. The granodiorite is crossed by quartz veins and pegmatite veins and contains plagioclase (50%), biotite (10%), and epidote (5%) in a groundmass of recrystallized quartz.

Granite, with dolerite dykes, and amphibolite probably intrude quartz-feldspar schist preserved as roof pendants at Rn16-18. The granite is locally gneissic. The amphibolite at Rn18 crops out as a large irregular body, whose shape and origin are unknown. The amphibolite at Rn17 consists of green hornblende (80%), poikilitic laths of epidote (20%), anhedral grains of zoned andesine (10%) and quartz (7%), sericitic fragments (5%), clusters of sphene, chlorite, and accessory ilmenite. The amphibole and quartz grains are recrystallized. The amphibolite is unconformably overlain by the Permian Cuncudgerie Sandstone near this locality (p. 82).

At T8 a small outcrop of sphene-bearing epidosite is associated with metamorphosed sandstone, shale, and conglomerate. A description of the epidosite by W. R. Morgan is as follows:—

'The texture is granoblastic. Quartz occurs as a mosaic of xenoblastic grains showing sutured margins and amoeboid intergrowth: their average size is 0.2 mm. Epidote occurs as granular crystals enclosed in quartz, the aggregates range in size between 0.03 mm. and 0.21 mm. It is pleochroic in yellow. Sphene occurs as subidioblastic, roughly prismatic crystals, which are light brown, and dusty: the dust is white in reflected light, and may be leucoxene. Some apparently folded veins of granular quartz are present. The rock consists of 65% quartz, 32% epidote, and 3% sphene.

'Much of the quartz contains very thin, parallel veinlets of greenish chlorite, giving the impression of cleavage. Quartz also commonly includes a fine, opaque dusty material.'

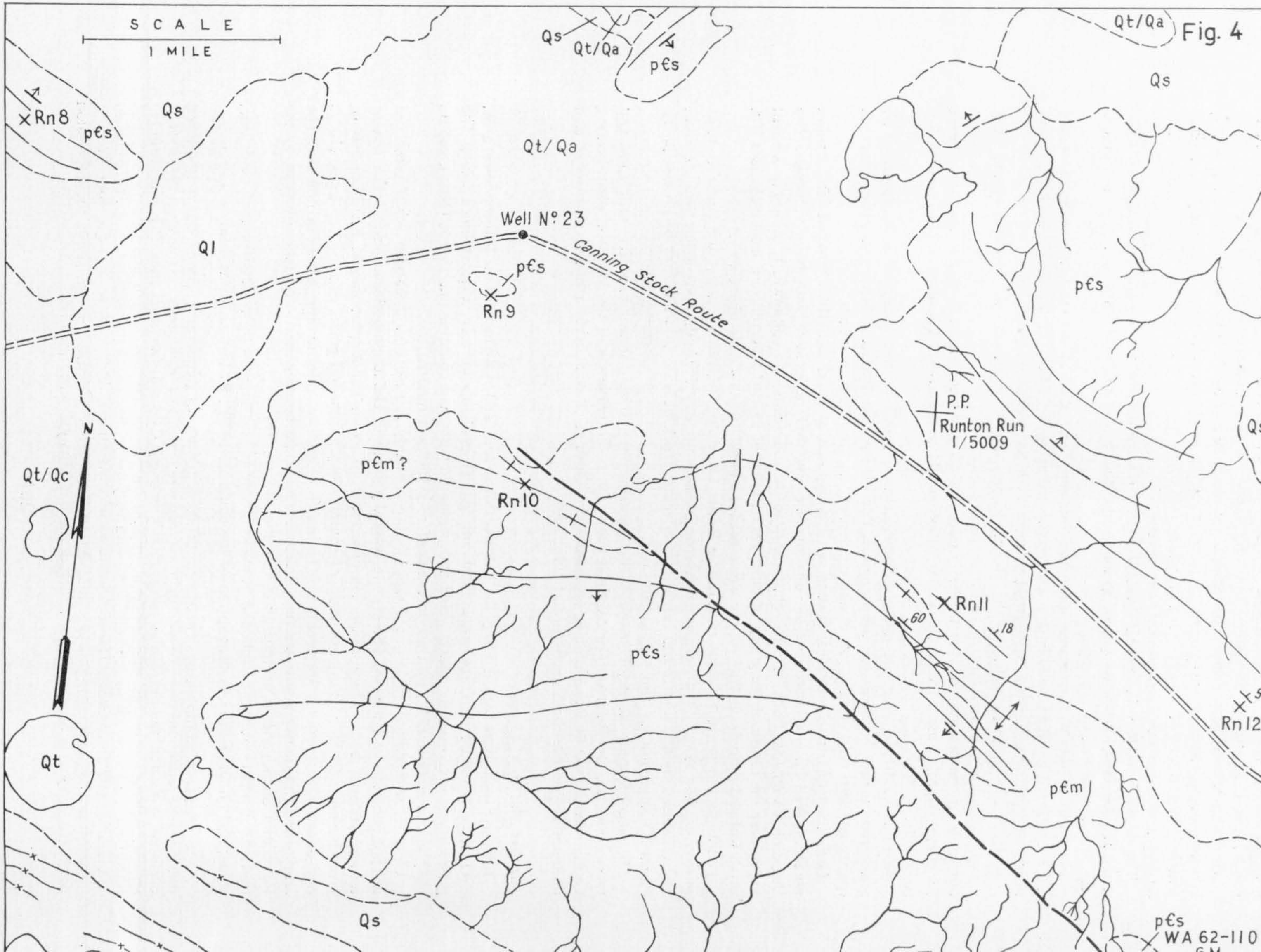

Fig. 4.—Sketch map, Well 23 area.

Granite at the headwaters of the Rudall River intrudes quartz-mica schist (N. R. Miles (Westralian Oil) pers. comm.; Talbot, 1910). The schist crops out in the Broadhurst and Harbut Ranges.

On the south-eastern margin, gneissic granite unconformably underlies Precambrian quartz sandstone and grit at Mount Webb, and is exposed in the south-western corner of the Webb Sheet area. The only other occurrences of granite gneiss on the south-eastern margin are two small outcrops in the eastern part of the Ryan Sheet area (identified by photo-interpretation).

Contacts between Precambrian Sediments and Metamorphics

The angular unconformity between the Precambrian sediments and metamorphics was seen at several localities on the south-western margin.

The relationship between the sediments and metamorphics is illustrated in Figure 4, opposite. The sediments at Rn8 (Fig. 4) are soft muscovite shales and interbedded wave-ripple-marked sandstone. At Rn9 interbedded coarse-grained sandstone, shale and conglomerate crop out. The pebbles in the conglomerate are quartzite, magnetite, and a mixture of finely granulated hematite, sericite, and quartz. The angular unconformity is exposed at Rn11: the metamorphics are exposed in the core of an anticline in the sediments. On the northern limb 100 feet of thick-bedded sandstone and 20 feet of basal conglomerate and breccia dip north-eastward at 18°, whereas the underlying hematitic schist dips north-eastward at 60° to vertical. The schists contain many quartz veins with hematite. The coarse and fine sandstone and shale at Rn10 are only slightly altered; near a large fault on the northern side of the hill they are crossed by quartz veins that contain specular hematite. The fault-line is marked by a breccia and large quartz veins. The sediments near the fault are vertical and slightly sheared; farther south, away from the fault, the beds dip at a much lower angle, probably less than 20°.

The coarse conglomerate at Rn12 (Fig. 3) is probably a basal conglomerate resting on the Precambrian metamorphics. The average size of the phenoclasts is 6 inches and the maximum size 1 foot. Most consist of pink quartzite. Conglomerate and interbedded sandstone crop out at Rn14 (Fig. 3) also. The conglomerate contains fragments of sericitic schist, hematitic-sericitic schist, hematite, quartz, and quartzite.

At Rn21 (p. 82) vertical quartz-feldspar that crops out at the base of a cliff is overlain by silicified massive fine quartz sandstone which dips at 10° to the south. This unconformity is also exposed at Rn22 and here the overlying pink quartzite contains rare fine conglomerate beds.

The contact of Precambrian sediments and gneissic granite is exposed at Mount Webb (Fig. 3).

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Appendix 2

PETROGRAPHY OF SELECTED ROCKS FROM THE CANNING BASIN

by

N. E. A. Johnson and W. B. Dallwitz

Localities of the rocks are shown in Figure 1. The Four-mile Sheet areas from which specimens were collected are abbreviated as follows: Webb (We), Ryan (Ry), Mount Bannerman (MB), Helena (He), Percival (Pe), Runton (Rn), Joanna Spring (Jo), Cornish (C), Ural (Ur), Morris (M), Sahara (Sa), Dummer (Du), Wilson (Wi).

Most of this appendix was written after the text of the bulletin was completed. References to petrographic descriptions in this appendix are noted in appropriate places in the text, but petrographic names used in the text are based on hand specimen examination only.

Precambrian

Specimen We6 (20 miles west of Mount Webb): *Gneissic granite.*

Hand specimen: A gneissic, poorly foliated acid igneous rock consisting of pink and yellowish white feldspars, and biotite.

Thin section (Slide 6400): The rock consists of potash feldspars (microcline and microcline-perthite) (40 %), quartz (35 %), sodic plagioclase (20 %), biotite (5 %), and a little black iron oxide and limonite. The rock has been strongly crushed, and its grainsize ranges from 0.03—2.5 mm. The plagioclase is heavily kaolinized and sericitized, but the potash feldspars are fresh. Biotite is pleochroic with X = golden yellow and Y = Z = very dark brown.

Specimen We2 (Elizabeth Hills): *Fine-grained, ferruginous and argillaceous quartz sandstone.*

Hand specimen: A fine-grained, heavily iron-stained, argillaceous sandstone. Fine bedding is brought out by variations in iron-oxide and clay content, and may be accentuated by differential weathering.

Thin section (Slide 6401): Minerals present are quartz (65 %), iron-stained, argillaceous matrix (30 %), quartz-sericite fragments (5 %), and rare muscovite, chert, tourmaline, and zircon. Grainsize ranges from 0.04—0.2 mm., and grain-shape is angular to subrounded. The composite quartz-sericite grains may have been derived from a siliceous argillaceous sediment or from an altered granitic rock.

Specimen We7 (Pollock Hills, south-western corner Webb Sheet area): *Coarse sericitic quartz sandstone (quartz greywacke).*

Hand specimen: A friable, massive, fine- to coarse-grained sandstone with a thin film of cream to yellowish material between the quartz grains.

Thin section (Slide 6402): The dominant mineral is quartz (93 %); its grainsize ranges from 0.08 to 1.5 mm., and its grain-shape from angular to rounded. There is a marked gap between grains whose average size is about 1 mm. and others measuring about 0.25 mm. Nearly all the quartz grains show strain-shadows, and several are bordered by an optically continuous shell of secondary silica. A few fragments of quartzite and/or vein quartz are present. The interstitial material (5 %) consists of sericite and probably a little very fine quartz.

Accessory minerals are leucoxene, clay, and rare tourmaline. The clay occurs in only one small area in the slide.

Specimen Ry13 (Corroboree Valley): *Claystone.*

Hand specimen: A very pale greenish buff, poorly laminated claystone containing a few thin veinlets of secondary silica. The weathered surfaces are iron-stained, and in places iron staining has penetrated into the body of the rock.

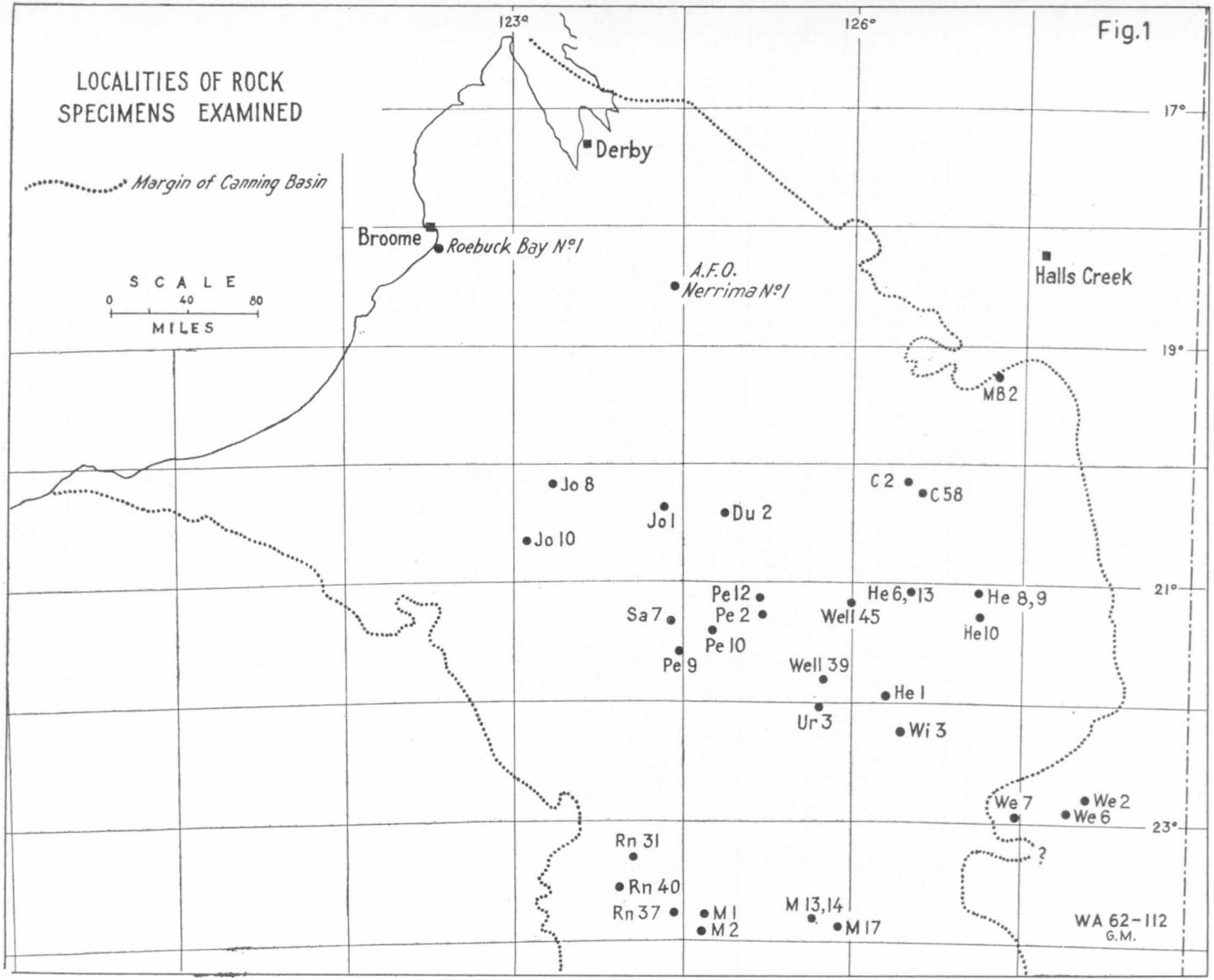
Fig.1
LOCALITIES OF ROCK SPECIMENS EXAMINED
Margin of Canning Basin
SCALE
0 40 80
MILES
123°
126°
17°
19°
21°
23°
Derby
Broome
Roebuck Bay No. 1
A.F.O. Nerrima No. 1
Halls Creek
MB 2
Jo 8
Jo 1
Du 2
Jo 10
C 2
C 58
Pe 12
Pe 2
Sa 7
Pe 10
Pe 9
He 6, 13
Well 45
He 8, 9
He 10
Well 39
He 1
Ur 3
Wi 3
We 7
We 2
We 6
Rn 31
Rn 40
Rn 37
M 1
M 2
M 13, 14
M 17
WA 62-112
G.M.

Fig. 1.

Thin section (Slide 6403): The rock is very fine-grained (less than 0.005 mm.), and as a consequence mineral identification is difficult. Minerals present are probable kaolinite, sericite, and (?) chlorite. They may be authigenic products derived from original argillaceous material. No orientation of particles was noted. A few spherules or part-spherules of (?) kaolinite are present.

? Ordovician

Specimen MB58 (Cummins Range): *Medium-grained silicified greywacke.*

Hand specimen: A hard, medium-grained sandstone with no visible bedding. Grains of feldspar can be distinguished by their cleavage and/or pink colour. Quartz appears to be the most abundant mineral.

Thin section (Slide 5180): The rock is medium-grained (0.2—0.5 mm.). Grain-shapes range from angular to subrounded. The minerals present are quartz (55%), feldspar (25%), sericite (5%), and rare muscovite, tourmaline, and zircon. Lithic fragments make up 15% of the rock, and consist of probable groundmass material from acid igneous rocks, quartz siltstone, arkosic siltstone, micropegmatite, and rare quartz-sericite schist. Irregular marginal growths of authigenic silica mask the original shapes of some of the quartz grains. The feldspars represented are orthoclase, microcline, and sodic plagioclase. Some of the feldspar grains have been partly kaolinized; some grains of orthoclase are lightly stained with iron oxide, and this probably accounts for their pink colour as seen in hand specimen. Sericite and authigenic silica fill the interstices.

? Noonkanbah Formation

Specimen He9 (Thornton Flat): *Fontainebleau siltstone.*

Hand specimen: A light brown, calcareous siltstone with prominent, fine cross-bedding accentuated by preferential weathering along very fine, dark bands. The presence of carbonate was confirmed by a test with dilute HCl.

Thin section (Slide 6404): The minerals present are quartz (45%), calcareous cement (40%), feldspar (5%), iron oxide (5%), leuxocene, biotite, muscovite, books of kaolin, tourmaline, zircon, and rare chlorite. The quartz has a fairly even grainsize (0.04—0.06 mm.), and nearly all grains are angular. The cement is calcite, which has grown as relatively large (0.5± mm.) irregular crystals enclosing many silt grains (Fontainebleau texture). The cement was probably a calcareous mud before it recrystallized. The iron minerals appear as red and black grains, which may form the very fine, black bands seen in hand specimen. Most of the mica is associated with these bands. Because of fine grainsize the varieties of feldspar present are hard to determine; however, they appear to be orthoclase, microcline, and sodic plagioclase.

Balgo Member

Specimen He8 (½ mile north of Thornton Flat): *Very fine-grained, feldspathic quartz sandstone.*

Hand specimen: A hard, pale pinkish buff, fine-grained, cross-bedded sandstone. Bedding is revealed on the weathered surface by preferential etching of two or three thin layers which are rich in muscovite. The exposed parts of the rock are iron-stained.

Thin section (Slide 6405): Grainsize is uneven, and averages about 0.06 mm.; grain-shape is angular to subangular. The minerals present are quartz (70%), argillaceous material (20%), feldspar (8%), and accessory iron oxide and leucoxene (1%), muscovite, zircon, tourmaline, and very rare rutile. The quartz grains are angular to splintery. The argillaceous material occurs mostly as distinct, irregularly-shaped bodies, about the same size as the quartz grains, and most of it appears to have partly or wholly replaced feldspar; some of the bodies may, however, be clay pellets. The fresher grains of feldspar can be identified as microcline, orthoclase, perthite, and sodic plagioclase. Several of the zircon grains are euhedral and zoned. Pleochroism in the tourmaline is of two kinds—sky blue to colourless and olive-green to colourless.

Balgo or Condren Member

Specimen He13 (Forebank Hills): *Porous, ferruginous sandy claystone.*

Hand specimen: A porous, yellow-brown, cross-bedded, sandy argillite. Some bands appear more porous than others; this may be due to variations in clay content. Muscovite flakes are oriented parallel to the bedding.

Thin section (Slide 6406): The minerals present are iron-stained argillaceous material (50%), quartz (40%), muscovite (1%), and very rare tourmaline and zircon. Pore space makes up about 9%. The average grainsize of the quartz is 0.06—0.15 mm., and the grains are angular. The argillaceous matrix is mostly very fine-grained, but a few accordion-like books of diagenetic kaolinite have been developed. The pale brown colour of the books is due to light staining by iron oxide.

Condren Member

Specimen He6 Forebank Hills ('three white hills' of Carnegie): *Argillaceous siltstone.*

Hand specimen: A fine-grained, very pale yellowish grey, silty rock containing a discontinuous ferruginous band measuring 1 mm.—5 mm. in width. The rock breaks along the bedding, which is poorly developed and is marked by fine mica flakes.

Thin section (Slide 6407): The minerals present are quartz (50%), argillaceous material (45%), black iron-ore (1%), muscovite (1%), tourmaline, and zircon. Lithic fragments, mainly chert, make up 1%. The grainsize of the quartz ranges from 0.02—0.05 mm., with exceptional grains up to 0.2 mm. The quartz grains are angular; some are shard-like, and many are splintery, suggesting that there may have been some tuffaceous contribution. The argillaceous material forming the matrix has been authigenically altered to form fine aggregates of clay minerals and occasional books of kaolinite.

The muscovite flakes are mostly oriented parallel to the bedding; they are much more plentiful in some layers than in others.

The ferruginous band consists of argillaceous material containing books of kaolinite (50%), quartz (30%), and ferruginous clay containing granules of iron oxide (20%).

Noonkanbah Formation

Specimen 5C7 (AFO Nerrima No. 1 Bore, 932 feet): *Fine-grained, feldspathic quartz sandstone.*

Hand specimen: A light grey, fine-grained, micaceous sandstone. Several concentrations of fine-grained pyrite, measuring up to 3 mm. x 2 mm., are visible, and small specks of pyrite are scattered throughout the core. Bedding-direction is indicated by muscovite flakes that lie at right angles to the length of the core.

Thin section (Slide 5181): The rock is uniformly fine-grained (0.14—0.21 mm.), and most grains are subangular. The minerals present are quartz (80%), feldspar (12%), lithic fragments (3%), muscovite (1%), chlorite (1%), pyrite (1%), leucoxene, biotite, and tourmaline. The subangular shapes of the quartz grains have commonly been accentuated by authigenic outgrowths of silica; this silica is probably the main cementing agent. Feldspars comprise orthoclase, microcline, rare sodic plagioclase, and very rare perthite; partial kaolinization is more advanced in the orthoclase than in the other varieties. The lithic fragments consist of fine-grained sedimentary rocks. Pyrite occurs as irregular grains of varying size scattered throughout the slide.

Poole Sandstone

Specimen 5C8 (AFO Nerrima No. 1 Bore, 1160 feet): *Very chloritic, feldspathic sandstone.*

Hand specimen: The bore core is a fine-grained, somewhat porous, greyish-green, chloritic sandstone with chlorite surrounding every grain. Mica flakes and discontinuous bands of dark minerals reveal the presence of cross-bedding.

Thin section (Slide 5182): Grainsize is somewhat uneven, and averages 0.1 mm. The minerals present are quartz (60%), feldspar (20%), chlorite (12%), bleached biotite (3%), muscovite (2%), kaolinite (2%), leucoxene, iron oxide, rare zircon, and rare tourmaline. The quartz grains are subangular to angular and even splintery. Recognizable feldspars are orthoclase, microcline, and sodic plagioclase; some of the plagioclase is kaolinized. The chlorite, a medium-green variety, has extremely low birefringence, and forms a shell about 0.01 mm. wide round every grain, and also occurs in pockets between the grains. Several bands contain slight concentrations of leucoxene, (?)ilmenite, and zircon; these evidently correspond to the dark bands noted in the hand specimen.

GRANT FORMATION (NEAR BASE)

Specimen 131C7 (AFO Nerrima No. 1 Bore, Core 16, 7687 feet): *Calcareous greywacke.*

Hand specimen: The bore core, from a depth of 7687 feet in No. 1 Bore, is a hard, medium-grained, calcareous greywacke, containing fragments of limestone, sandstone, and some igneous material. One exceptionally large fragment had the dimensions 2.3 mm. x 1.2 mm.

Thin section (Slide 5184): The dominant mineral present is quartz (60%); its grainsize ranges from 0.2 to 0.8 mm., and the shape of most grains has been changed from rounded to subangular by outgrowths of authigenic silica. This silica is the main cement. Feldspar (5%) was identified as orthoclase, microcline, microcline-perthite, and plagioclase; its grainsize is similar to that of quartz, and the grains are subrounded. Calcite (10%) is irregularly distributed as a cement, and has clearly crystallized during diagenesis. A few grains of pyrite and a single grain of tourmaline, with pleochroism from colourless to blue-black, were noted. Lithic fragments (20%) consist of trachyte, limestone, sandy limestone, fine-grained sandstone, chloritic siltstone, and cherty material.

GRANT FORMATION

Specimen 131C5 (Roebuck Bay No. 1 Bore, Core 36, 2941-2951 feet): *Medium to fine lithic, feldspathic sandstone.*

Hand specimen: This part of the bore core is a light grey, friable, medium to fine sandstone without bedding.

Thin section (Slide 5183): The grainsize ranges from fine to medium (0.1—0.5 mm.), and the grain-shape ranges from subangular to rounded. The dominant mineral is clear quartz (75%); several grains show irregular outgrowths of authigenic silica, and a few 'rutilated' grains were noted. The feldspar (10%) consists of orthoclase, microcline, plagioclase, and perthite; some grains are partly kaolinized and sericitized. Accessories are clots of diagenetically reconstituted clay, fibrous-radiating (?)zeolite, garnet, biotite, apatite, leucoxene, zircon, and tourmaline. Lithic fragments (10%) consist of fine-grained sedimentary rocks, felsite and/or chert, granite, and (?)trachyte.

UNDIFFERENTIATED PERMIAN

Specimen Pe2a (Thompson Hills): *Coarse sericite sandstone or coarse quartz greywacke.*

Hand specimen: A massive, pale buff sandy rock consisting of coarse to fine quartz grains embedded in an argillaceous or sericitic matrix.

Thin section (Slide 6408): This slide resembles slide We7, but is less even-grained and contains a higher proportion of materials other than quartz. The rock consists of subangular to subrounded grains of quartz and quartzite (75%), and accessory leucoxene (3%), muscovite, tourmaline, and rare zircon embedded in a matrix of sericite (20%). The quartz grains range in size from at least 1.25 cm. to 0.15 mm.; nearly all of them show strain shadows, and a few represent strongly sheared quartzite or, more probably, vein quartz.

Specimen Pe2b (Thompson Hills): *Fine greywacke-conglomerate.*

Hand specimen: A pale buff massive sandy and argillaceous rock containing coarse to fine subrounded quartz grains and scattered rock fragments.

Thin section (Slide 6409): In thin section the rock is found to consist of subangular to subrounded quartz grains (43%), and very fine sandy and silty claystone (20%) embedded in a reconstituted, pale brown argillaceous matrix (35%), which has slightly embayed and replaced some of the quartz grains. The size of the quartz grains ranges from 1.5 mm. to silt size, and the largest rock fragments measure over 1 cm. As the clay component in the rock fragments is identical with that in the host rock, it is probable that the age of the fragments may be almost the same as that of the host rock, in which they may have been incorporated through the action of turbidity currents.

Accessory minerals (2%) are leucoxene, tourmaline, and zircon.

Specimen Pe2c (Slide 6410): Is essentially similar to specimen Pe2B, and is a *fine greywacke conglomerate.*

Specimen Pe12 (10 miles west-north-west of Thompson Hills): *Poorly sorted, fine to coarse, argillaceous and opaline quartz sandstone.*

Hand specimen: A fairly friable massive coarse-grained argillaceous sandstone. The weathered surfaces are iron-stained, and this staining has penetrated the body of the rock giving it a mottled yellow to red-brown colour.

Thin section (Slide 6411): The minerals present are quartz (70%), argillaceous material (12%), probable opal (10%), iron oxide and leucoxene (3%), and rare tourmaline. The remaining 5% is pore space. Two size ranges are apparent in the quartz—0.5—1.25 mm. and 0.04—0.2 mm.—and the grain-shape is subangular to rounded. Wavy extinction is present in some of the larger quartz grains; a few composite quartz grains may have been derived from quartzitic or vein material. The argillaceous material, together with the finer quartz grains, forms the matrix; in parts it has been authigenically recrystallized to kaolin-illite-iron oxide mixtures. The opal is colourless; it surrounds both fine and coarse quartz grains, and has a refractive index of about 1.455 and very low double refraction. In addition to surrounding quartz grains, it lines and partly fills pore spaces, or it may entirely fill what has clearly been a pore space.

Specimen Ry17 (Contention Heights): *Medium-grained argillaceous sandstone.*

Hand specimen: A porous, medium-grained, reddish-brown, quartz sandstone.

Thin section (Slide 6412): The dominant mineral is quartz (55%); its grainsize is medium (0.2—0.6 mm., average 0.4 mm.), and its grain-shape is subangular to subrounded. Most grains are replaced along fractures by material of the matrix. Wavy extinction was observed in some quartz grains, and one or two grains of rutilated quartz are present. The matrix (30%) consists mainly of light red-brown and light brown material which is of a mixture of illite, kaolin, and iron oxide; it contains some books of kaolin and rare books of illite in places. The red-brown material is seen to have an irregularly spherulitic and flamboyant structure when observed between crossed polarizers. The matrix has reached its present condition by reconstitution of original argillaceous and ferruginous material during weathering and/or diagenesis.

Muscovite and rare tourmaline and zircon are the accessory minerals. Pore space accounts for 15% of the area of the slide.

Specimen Rn31 (28 miles north-north-west of Bejah Hill): *Poorly sorted argillaceous sandstone.*

Hand specimen: A massive, grey-white, medium-grained, argillaceous sandstone. The weathered surfaces are iron-stained, and in places the rock beneath has been discoloured.

Thin section (Slide 5187): The minerals present are quartz (70%), clayey matrix (30%), accessory iron oxide, and rare tourmaline, zircon, and leucoxene. The grainsize of the quartz ranges from fine to coarse (0.2—1 mm.). Many grains have been marginally corroded and internally replaced along fractures by the matrix material, and some of the original rounded shapes have become highly irregular. Several grains of rutilated quartz are present.

Diagenetic changes have resulted in complete reconstitution of the matrix. Curved and spherical growth-lines are visible in ordinary light, and between crossed polarizers a confused picture of flaring, mutually interfering, spherulitic structures is visible.

Thin shells and small pockets of opal and of a mineral possibly belonging to the apatite group are visible in parts of the slide.

Specimen Rn40 (22 miles north-west of Bejah Hill): *Poorly sorted argillaceous sandstone.*

Hand specimen: A massive, hard, fine- to coarse-grained, buff to brown, quartz sandstone. The weathered surfaces are iron-stained. For a depth of about ¼″ from exposed surfaces the rock is hard and glassy through silicification. Further inwards it is porous, and consists of glassy, angular quartz grains embedded in a fine-grained matrix; the thin section is cut from this part.

Thin section (Slide 5189): The dominant mineral is quartz (75%), of angular to subrounded shape and of very variable grainsize—generally within the range 0.015 to 1 mm., though a few grains are larger than 1 mm. The quartz is embedded in a light brown, argillaceous matrix (24%) whose grain-size has become coarser during diagenesis and/or weathering; the matrix has a refractive index less than that of balsam and a low double refraction.

Many quartz grains have been marginally corroded and extensively replaced, probably along fractures, by the material of the matrix. Several grains of rutilated quartz and at least one quartz grain showing an optically continuous shell of authigenic silica are visible. Accessory minerals are red and black iron oxides, leucoxene, and rare zircon, rutile, and tourmaline.

Thin (0.01—0.02 mm.) layers of opal line cavities and ramify through the matrix in some parts of the slide.

Specimen He10 (3 miles south of Farewell Lakes): *Micaceous and argillaceous siltstone.*

Hand specimen: A pale buff, fine-grained, argillaceous siltstone. No bedding laminations are present, although minute mica flakes are undoubtedly parallel to the bedding direction. The weathered surface is iron-stained, and in places the rock beneath has been discoloured.

Thin section (Slide 6413): The minerals present are quartz (60%), argillaceous material (33%), muscovite (5%), iron oxide (1%), and rare zircon and tourmaline. The quartz is very fine-grained (0.01—0.04 mm.) and angular. Argillaceous matter forms the matrix; it is finely crystalline, and in places books of kaolinite have developed. Most of the flakes of muscovite lie parallel to each other.

Specimen Jo1 (Traves Cliffs): *Ferruginous argillaceous siltstone.*

Hand specimen: A slightly porous, iron-stained, argillaceous siltstone. Bedding is rendered visible by variations in clay and iron oxide content on freshly broken surfaces, and by selective weathering on exposed surfaces.

Thin section (Slide 6414): The minerals present are quartz (60%), argillaceous material (34%), hydrated iron oxide (5%), muscovite (1%), and rare tourmaline and zircon. The grainsize of the quartz is fairly uniform (0.02—0.06 mm.), and its grain-shape is angular. The argillaceous matrix is mainly fine grained, but it has been authigenically reconstituted; in places books of kaolin are recognizable.

Iron oxide colours part of the argillaceous material. The muscovite is mostly oriented parallel to the bedding, but many flakes lie in random directions.

Godfrey Beds

Specimen C2a (Catspaw Hills, Cornish Sheet area): *Very fine quartz greywacke.*

Hand specimen: A buff-coloured, slightly friable, fine-grained sandstone with a number of fine black specks scattered along a 1 cm. band. Mica flakes are oriented parallel to poorly defined bedding.

Thin section (Slide 5185): The specimen is fine-grained and has a fairly even grainsize (0.1 mm.), though a few larger grains are up to 0.4 mm. across. The grains are subangular to angular. The minerals present are quartz (75%), clay (10%), feldspar (5%), red and black iron oxides and leucoxene (3%), biotite and muscovite (1%), and rare tourmaline and zircon. Lithic fragments make up 5% of the specimen; they consist of quartzite and fine-grained sandstone. A number of quartz grains show growths of authigenic silica along their margins, and some formerly rounded grains have developed angular outlines in this way. Feldspars present are orthoclase, microcline, and sodic plagioclase. The clay minerals are either pale buff and very fine-grained, or recrystallized to book-like forms.

Specimen C58 (Godfrey Tank area, Cornish Sheet area): *Fine, feldspathic, argillaceous sandstone.*

Hand specimen: A grey-white, fine-grained, argillaceous sandstone. The bedding is very poorly developed, and is probably crossed. Minute mica flakes indicate the bedding. Weathered surfaces of the rock are iron-stained.

Thin section (Slide 5185): The rock consists essentially of quartz (60%), clay (25%), and feldspar (10%). Most grains of quartz and feldspar are angular, and generally range from 0.065 mm. to 0.25 mm.; a few are as large as 0.4 mm. Accessory minerals are muscovite (1%), iron oxide, leucoxene, zircon, brown tourmaline, and red rutile. Lithic fragments make up 3% of the rock, and consist of quartzite, sericite schist, and acid volcanic or hypabyssal rock. A few quartz grains show authigenic silica additions along their edges. The feldspar is microcline and rare sodic plagioclase. The matrix consists of clay; most of it is ultra fine-grained, but a little has recrystallized to accordion-like masses, presumably of kaolinite; silica makes up the rest of the matrix.

Kidson Beds

Specimen Ur3 (Reeves Knoll): *Argillaceous quartz sandstone.*

Hand specimen: A porous, friable, light reddish brown, medium-grained quartz sandstone containing occasional larger grains up to 7 mm. diameter. No bedding is visible.

Thin section (Slide 6415): The dominant mineral is quartz (60%); its grainsize ranges from 0.14 mm. to 0.8 mm., but most grains measure less than 0.5 mm. Grain-shape ranges from subangular to well rounded. A few composite quartz grains appear to be derived from either granite or quartzite. Several grains of chert are also present. A few quartz grains show authigenic outgrowths of silica. Accessory constituents are muscovite, rare leucoxene and black iron oxide, and very rare zircon. Pore space amounts to about 25%.

The matrix (10%) consists mainly of red-brown, crudely spherulitic shells of a mixture of kaolin, sericite, and iron oxide coating the quartz grains in such a way as to leave abundant pore spaces. Some pockets of iron-stained kaolin are scattered through the rock. These materials must have been developed through the reconstitution of an originally structureless argillaceous base, and it seems probable that a good deal of it has been removed by weathering, thus accounting for the high porosity of this rock.

Anketell Formation

Specimen Jo10 (15 miles south of Turkey Place): *Ferruginous argillaceous siltstone with thin bands of ferruginous claystone and ferruginous silty claystone.*

Hand specimen: A dark red-brown cross-bedded ferruginous siltstone containing bands of purplish brown claystone 3 to 5 mm. wide and 2—2.5 cm. apart; it seems likely that the banding is seasonal. Graded bedding is visible in one claystone band, but this band appears not to be represented in the thin section available.

Thin section (Slide 6416): The siltstone is seen to consist of angular grains of quartz (50%), argillaceous material (30%), hydrated iron oxide (20%), accessory muscovite, and rare tourmaline and zircon. The average size of the quartz grains is about 0.05 mm. The argillaceous material is a brownish-orange clay-illite-iron oxide mixture with refractive index greater than that of balsam.

The claystone band in the thin section is seen to be a composite one, in which a layer of ferruginous silty claystone with prominent muscovite flakes lies between two bands of ferruginous claystone. The argillaceous material in the silty claystone has been reconstituted into books commonly measuring 0.05 to 0.1 mm. across. The refractive index of the clay in the books and in the claystone proper is less than that of balsam.

Bejah Beds

Specimen M1 (Traeger Range): *Porous reconstituted radiolarite.*

Hand specimen: The rock consists of a very porous, light-weight, siliceous substance which gives a hollow ring when struck, and is possibly a radiolarite. Less porous or non-porous clots measuring up to 5 mm. x 2 mm. are prominent. The rock is pale brown; the less porous patches are greyish puce.

Thin section (Slide 5171): The rock consists mainly of a highly porous framework of opal containing numerous specks of hematite. The average diameter of the pores is about 0.15 mm. A few angular grains of quartz, from 0.1 mm. to less than 0.005 mm. across, are visible. Traces of sericite are also present. The hematite appears translucent red between crossed nicols and brick-red in reflected light. The clots of non-porous or less porous opal are generally darker than the highly cellular opal, and contain a few well-preserved radiolaria which were identified by Dr Irene Crespin as *Lithocyclia exilis* Hinde. According to Dr Crespin this species indicates the topmost part of the Lower Cretaceous.

Specimen M1A (Traeger Range): *Reconstituted radiolarite.*

Hand specimen: The rock is very pale buff (almost white), ultra-fine-grained, very compact, hard, and smooth-surfaced, and has a conchoidal fracture.

Thin section (Slide 5172): No crystalline minerals except silt-sized, angular grains of quartz and a few flakes of sericite could be identified. The fineness of the grain and the chemical analysis indicate that the rock consists very largely of opal. The general appearance of the slide is that of an ultra-fine-grained, pale-grey, isotropic material, whose refractive index is well below that of balsam. A few remains of radiolaria can be seen in the thinnest parts of the slide.

Specimen M2 (8 miles north of Woolnough Hills): *Poorly sorted argillaceous quartz sandstone.*

Hand specimen: A pale grey, poorly sorted sandstone with a fairly low argillaceous content; it is massive, and has an uneven fracture. The rock is slightly porous; irregular pores up to 1 mm. in diameter are visible.

Thin section (Slide 5177): The dominant mineral is quartz (85 %); many grains are irregularly fractured and angular; a few are well rounded. Some grains are crowded with fluid inclusions. Two size-ranges are apparent in the quartz—0.5 mm. to 1 mm., and 0.1 mm. to 0.25 mm. Some grains have been partly replaced by the material of the matrix, particularly along fractures. Three grains of rutilated quartz are present; most or all of the rutile has been changed to leucoxene. Argillaceous material (15 %) occurs interstitially; it has been completely reconstituted, and crudely developed spherulitic structures may be seen in places. A few scattered grains of leucoxene, tourmaline, zircon, and iron oxide are present. The tourmaline is pleochroic from colourless to blue-green.

Specimen M13 (22 miles north-west of Nipper Pinnacle): *Reconstituted silty radiolarite.*

Hand specimen: The rock is off-white, slightly porous, apparently very fine-grained, light, and not bedded. It has a subconchoidal fracture, and an argillaceous odour when breathed upon.

Thin section (Slide 5178): Angular quartz grains, with average diameter 0.06 mm., and many ultra-fine grains (about 0.005 mm. across) are embedded in a greyish-buff, isotropic, opaline base. The total quartz content is about 5 %. A number of muscovite flakes and one grain of zircon are visible. Circular areas of opal that contain few or no inclusions, and measure up to 0.15 mm. in diameter, are almost certainly 'ghost-like' remains of radiolaria whose skeletal pattern has almost everywhere been completely destroyed. Only very rarely has external ornamentation been preserved. Several tests were determined by Dr I. Crespin as possibly *Lithocyclia exilis* Hinde and *Cenosphaera* sp.

A chemical analysis by S. Baker showed that the rock contains 86.06 % silica. It is a *reconstituted silty radiolarite* or, less specifically, a *silty porcellanite.*

Specimen M14 (22 miles north-west of Nipper Pinnacle): *Reconstituted sandy radiolarite.*

Hand specimen: A reddish-buff, fine-grained, slightly porous sandstone. Variation in iron content accentuates the poor cross-bedding. Flakes of muscovite lie parallel to the bedding planes.

Thin section (Slide 5179): The rock has a somwehat porous framework of opal (58 %), which contains small amounts of argillaceous matter and probable hematite; the opal encloses abundant (35 %) angular quartz grains, whose grainsize ranges from 0.05 mm. to 0.13 mm. Several complete radiolaria were determined by Dr I. Crespin as *Lithocyclia exilis* Hinde, and (?)*Cenosphaera* sp. Most tests have probably been dissolved and redeposited as formless opal. Argillaceous matter (5 %) is found in blebs of different sizes throughout the rock; its particle size is less than 0.005 mm. Accessory minerals are leucoxene, muscovite, zircon, and tourmaline, some pleochroic from colourless to greenish-blue, and some from grey-blue to black.

Specimen M17b (9 miles north-north-west of Nipper Pinnacle): *Ferruginous argillaceous siltstone.*

Hand specimen: A fine-grained, light red-brown, slightly mottled, ferruginous siltstone. Variations in iron content appear as broad concretionary marking. Most of the rock is fissile but one surface is lumpy, and indicates that part of the rock is a mudstone rather than a siltstone.

Thin section (Slide 5173): The principal minerals present are argillaceous material (40 %) and quartz (40 %), which is partly masked by interstitial material; most grains are 0.02 mm. or less across. Flakes of muscovite (5 %) and minor chlorite are oriented roughly parallel, and determine the direction in which the rock breaks. The argillaceous matrix is impregnated with abundant (15 %) minute particles of iron oxide, probably hematite. Abundant small areas about 1 mm. across stand out because they contain less hematite than the surrounding rock.

Specimen M17c (9 miles north-north-west of Nipper Pinnacle): *Ferruginous argillaceous siltstone.*

Hand specimen: The rock is a ferruginous siltstone with fine irregular bands of argillaceous material subparallel to the bedding. In places the bands appear almost vein-like. Numerous micaceous flakes lie parallel to the bedding. The rock is moderately porous; many of the pores are elongated.

Thin section (Slide 5174): The dominant mineral is quartz (48%); the grains are angular and average 0.05 mm. across. Muscovite flakes (2%) commonly lie subparallel to the bedding but many have a random disposition. The matrix consists of argillaceous material (30%), which has been diagenetically reconstituted and stained golden brown by hydrated iron oxide. Hydrated iron oxide (25%) is also present as distinct dark clots and minute specks. Tourmaline is a rare accessory. Pore spaces make up about 3% of the rock.

Specimen M17d (9 miles north-north-west of Nipper Pinnacle). *Micaceous argillaceous siltstone.*

Hand specimen: A pinkish-white, medium-grained siltstone; oriented mica flakes are the only indication of bedding. The weathered surface is stained with iron, and in places the rock beneath has been discoloured. A red- and brown-stained clot measuring 2.5 cm. x 1.5 cm. is possibly attributable to the weathering of a pyritic part of the rock.

Thin section (Slide 5175): Quartz (75%) is the dominant mineral; the grains are angular to splintery and of uneven size (0.007 mm. to 0.05 mm.); isolated grains measure up to 0.6 mm. The matrix (20%) is argillaceous, and in places the fine particles have crystallized more coarsely to concertina-like masses of kaolinite. Flakes of muscovite and chlorite make up about 3% of the rock; most of them are oriented parallel to the bedding, but many also lie in random directions. Tourmaline grains are rare; several show pleochroism from colourless to blue. Other accessories are leucoxene and very rare zircon and rutile.

Specimen M17e (9 miles north-north-west of Nipper Pinnacle): *Alunite-rock.*

Hand specimen: The rock is white and ultra fine-grained. It has a subconchoidal fracture, and the weathered surfaces are iron stained.

Thin section (Slide 5176): The rock is ultra-fine-grained (0.002—0.001 mm.). The only minerals that could be identified were an occasional quartz grain and muscovite flake. The slide is virtually colourless, and between crossed nicols turns dark grey to greyish white; true interference colours are not seen because numerous grains occur within the thickness of the slide.

A chemical analysis (Lab. No. 59/683), made by S. Baker, showed that the major constituents are sulphate, aluminium, water, and potassium. The analysis and an X-ray powder photograph made by W. Roberts indicate that the rock is essentially *alunite.*

Specimen Rn37 (21 miles east-south-east of Bejah Hill): *Reconstituted radiolarite.*

Hand specimen: The specimen is off-white, hard, and ultra-fine-grained, and shows no sign of bedding. It is smooth-surfaced and has a conchoidal fracture. The weathered surfaces are iron-stained.

Thin section (Slide 5188): The rock consists of a fine-grained greyish-buff, structureless, isotropic substance, probably opal, containing a few percent of silt-sized quartz grains and muscovite flakes. Some of the latter are oriented, presumably parallel to bedding. Several radiolaria were determined by Dr I. Crespin as *Lithocyclia exilis* Hinde, and *Cenosphaera* sp. A few probable radiolaria are represented by round holes or spherical 'ghosts' in the opaline material.

S. Baker found that the rock contains 89.36% silica.

UNDIFFERENTIATED MESOZOIC

Specimen Pe10 (20 miles west-south-west of Thompson Hills): *Very fine quartz greywacke.*

Hand specimen: A somewhat friable, fine-grained, pale buff, micaceous argillaceous sandstone. The weathered surfaces are iron-stained. The muscovite appears to be oriented parallel to the bedding which is poorly defined by two faint black layers.

Thin section (Slide 6417): The minerals present are quartz (85%), argillaceous matter (10%), iron oxide and sphene (2%), muscovite, chert, tourmaline, biotite, and zircon. The grainsize of the quartz ranges from very fine to fine (0.04 mm. to 0.16 mm.), and averages about 0.1 mm.; its grain-shape is angular to round. Rutilated quartz grains are rare. The argillaceous material is pale buff in transmitted light. Black iron oxide and sphene occur in a band which contains zircon and tourmaline as well.

Specimen Jo8 (Battlement Rocks): *Medium quartz greywacke.*

Hand specimen: A pale buff, somewhat friable, medium-grained, porous, cross-bedded quartz greywacke. A few grains measure up to 3 mm. Muscovite flakes are prominent, though not abundant, on the bedding planes. The weathered surfaces are iron-stained, and some staining penetrates the body of the rock.

Thin section (Slide 6418): The dominant mineral is quartz (80%). Its grainsize ranges from 0.15 to 0.55 mm., but the average is about 0.4 mm. The grain-shape is predominantly angular. Several grains have wavy extinction. The matrix consists of argillaceous material (15%), and is mainly fine-grained; in places it has been authigenically altered to kaolinite aggregates and books. Muscovite makes up about 3% of the rock; it has no preferred orientation.

Specimen Sa7 (6 miles south-west of Bremner Peak): *Micaceous argillaceous siltstone.*

Hand specimen: A pink and pale buff, medium-grained, micaceous siltstone. Variations in iron staining clearly mark the bedding, which is further emphasized by minute mica flakes.

Thin section (Slide 6419): The dominant mineral is quartz (55%). The grains are angular and of uneven size (0.01—0.06 mm.), and the finer ones are partly marked by interstitial material. Argillaceous matter (40%) forms the matrix, and in places the fine particles have crystallized to form accordion-like masses of kaolinite. Flakes of muscovite make up about 4% of the specimen; most of them are oriented parallel to the bedding, though a few lie in random directions. Accessory minerals are leucoxene, iron oxide, tourmaline, zircon, and very rare rutile.

Specimen Du2 (Newbery Peaks): *Fine micaceous and argillaceous sandstone.*

Hand specimen: A fine-grained, light reddish-brown, argillaceous sandstone. Poor bedding laminations are marked by variations in the amount and colour of clay. Flakes of muscovite are oriented parallel to the bedding.

Thin section (Slide 6420): The minerals present are quartz (55%), argillaceous material (35%), muscovite (5%), iron oxide (1%), and rare chert and tourmaline. The grainsize of the quartz ranges from 0.06 mm. to 0.24 mm., and its grain-shape is subangular to subrounded. The argillaceous material forming the matrix has largely been authigenically altered to aggregates, books and partial spherules. Thin layers of a red-brown mixture of kaolin, illite, and iron oxide have developed around a large percentage of the quartz grains. The muscovite flakes average 0.2—0.5 mm. in length, and are mostly oriented parallel to the bedding.

Specimen Pe9 (45 miles west-south-west of Thompson Hills): *Porous fine-grained argillaceous sandstone.*

Hand specimen: A light red-brown, fine-grained, porous quartz sandstone. Bedding is indicated by small variations in colour and by flakes of muscovite.

Thin section (Slide 6421): The grainsize is fairly uniform, and ranges from 0.06 mm. to 0.16 mm. The rock consists of quartz (75%), argillaceous material (17%), and accessory iron oxide, muscovite, leucoxene, tourmaline, and rare zircon. Pore space makes up the remaining 8%. The quartz grains are subangular to subrounded. The argillaceous material has been authigenically altered to a red-brown illite-kaolinite-iron oxide mixture which occurs as a narrow (0.004 mm. to 0.15 mm.) shells round the quartz grains, and also penetrates and partly replaces many of them. Pockets of the same material lying between the grains of quartz show a distorted spherulitic structure, and are commonly made up of two or more mutually interfering spherules or part-spherules.

Undifferentiated Mesozoic or Permian

Specimen Wi3 (Redknap Mount): *Medium argillaceous sandstone.*

Hand specimen: A buff and brownish orange, medium-grained moderately porous sandstone.

Thin section (Slide 6422): The thin section represents the buff coloured part of the rock, which is seen to consist of quartz (75%), argillaceous matrix (15%), and rare tourmaline, rutile, and zircon. Pore spaces occupy about 10% of the area of the slide.

The argillaceous matrix shows the spherulitic structure so commonly noted in the sandstone of the Canning Basin; its refractive index is less than that of balsam. Its colour is an uneven murky brown; basically the colour is light buff, but varying concentrations of dust-like dark specks give rise to different intensities of brown colour.

The quartz grains occupy three size ranges; some measure about 0.8 mm., and are subangular to subrounded; others are subrounded to rounded, and measure about 0.35 mm.; the remainder are angular and their size is about 0.05 mm. The quartz in these grainsize categories is distributed as follows: 0.8 mm.—20%; 0.35 mm. and 0.05 mm.—each 40%.

RECENT

Specimen He1 (35 miles south-east of Well 40): *Nodular limestone.*

Hand specimen: The rock consists of limestone nodules set in a fine-grained, quartz-carbonate matrix. The nodules, though pitted on their weathered surfaces, are more resistant to weathering than is the matrix, which may contain some argillaceous impurities. The nodules are of irregular shape and size (2—25 mm.) and it is possible that they are fragments of a pre-existing limestone. Both nodules and matrix effervesced with 1 : 10 HCl.

Thin section (Slide 6423): The specimen consists of 55% matrix and 45% nodular limestone. The nodules are composed of calcilutite enclosing scattered grains of quartz (0.1 mm. to 0.3 mm. diameter). The calcite in the matrix is also extremely fine-grained, but contains argillaceous and some ferruginous impurities and numerous quartz grains. Tourmaline is a rare accessory. The quartz grains range in size from 0.06 to 0.14 mm., and in shape from angular to rounded. The ferruginous impurities in the matrix give rise to a mottled appearance, as they are not evenly distributed; they are also concentrated in a zone 0.1 mm. to 1 mm. wide round the fragments of limestone. Some recrystallization has taken place both in the fragments and in the matrix.

? RECENT

Specimen Well 39B (2 miles south of Lake Tobin): *Medium argillaceous opaline sandstone.*

Hand specimen: A mottled light red-brown and cream, massive, porous, poorly cemented, medium-grained, sandy and argillaceous rock which, under the microscope (Slide 6424), is seen to consist of subangular to subrounded grains of quartz (55%) and concretions of opal in a matrix consisting of reconstituted argillaceous material and opal.

The quartz grains are angular, subangular, subrounded, and rounded, and are very poorly sorted; their grainsize ranges from 0.02 mm. to 1 mm. A few quartz grains are sagenitic. The materials of the matrix are very unevenly distributed.

The matrix in some parts of the rock consists predominantly or entirely of massive or cellular opal, and in others it consists predominantly or entirely of reconstituted argillaceous material. The argillaceous material occurs either as a coating to the grains, or, more rarely, it may entirely fill the spaces between the grains. Its colour ranges from buff to red-brown, depending on the iron content, and its refractive index may be either above or below that of balsam. In one place plant cells are preserved in opal. The opaline matrix is either clear or charged with finely divided argillaceous material which has not been reconstituted. Opal appears to be the more abundant constituent of the matrix. The cream-coloured parts of the hand specimen represent the purer opaline material.

Accessory constitutents are iron oxide (mostly hematite) granules, tourmaline, and zircon.

Specimen Well 45: *Fine argillaceous sandstone.*

Hand specimen: The specimen is a porous, light red-brown, argillaceous sandstone, with a number of discontinuous clay lenses about 1 mm. thick. The direction of bedding is marked by clay lenses and by reflections from subparallel flakes of muscovite. Several pale buff pockets of probable opaline material are present; the largest measures about 3 cm.

Thin section (Slide 6425): The rock is seen to consist of subangular to angular grains of quartz (55%) and flakes of muscovite (2%) embedded in an argillaceous matrix (23%). Pore spaces make up about 20% of the area of the slide. The quartz grains are of fairly even size (0.15 mm.), and many are bordered by a narrow shell of secondary silica in optical continuity with the original detrital grain. Rutile needles are present in a few quartz grains, and grains of chert are sparsely distributed through the slide.

Zircon and tourmaline are rare accessories.

The matrix consists mainly of brownish orange clay-illite-iron oxide mixture showing the distorted spherulitic structure characteristic of this material. With it, especially in a more argillaceous layer, are associated large and small concertina-like books of pale buff to colourless kaolin, coarser flakes of illite, and a little fine-grained argillaceous material. The matrix as now constituted has probably been formed by diagenesis and weathering from original fine-grained mixed clay-iron oxide material.

APPENDIX 3

OSTRACOD ASSEMBLAGES NEAR THE UPPER DEVONIAN-LOWER CARBONIFEROUS BOUNDARY IN THE FITZROY AND BONAPARTE GULF BASINS

by

P. J. JONES

The stratigraphical distribution of ostracod assemblages found in samples from the outcropping Upper Devonian and Lower Carboniferous rocks of the Fitzroy and Bonaparte Gulf Basins can be used to date parts of the subsurface sections of the bores BMR 2 Laurel Downs, Sisters No. 1, Frome Rocks No. 2, and Meda No. 1. Further collecting remains to be done, especially from the lower part of the Laurel Formation, and from the Upper Devonian rocks deposited before the *Avonia proteus* zone (Veevers, 1959a).

To recognize the first appearance of topmost Upper Devonian rocks in bores in the Fitzroy Basin, it is essential to study the distribution of ostracod species in a reference surface section which is known to pass through the Upper Devonian-Lower Carboniferous boundary. At present, no continuous surface section of both Upper Devonian and Lower Carboniferous rocks is known in the Fitzroy Basin; the nearest section which satisfies this condition is in the Bonaparte Gulf Basin, where the Upper Devonian Burt Range Limestone passes conformably into the Lower Carboniferous Enga Sandstone, which is conformably succeeded by the Septimus Limestone (Traves, 1955).

About sixty samples collected from the Burt Range Limestone and the Septimus Limestone have been submitted for micropalaeontological examination to the Bureau of Mineral Resources through the courtesy of Mr E. P. Utting, Chief Geologist of Westralian Oil Limited. Of these samples, about one-third have yielded a rich ostracod fauna, which can be resolved into two assemblages; this fauna is now being described. No ostracods have been recorded from the Enga Sandstone.

Many surface samples have been collected by geologists of the Bureau of Mineral Resources from the Fitzroy Basin; they include samples from the top part of the Laurel Formation (upper Tournaisian), and from the Fairfield Beds (*A. proteus* zone). Each of these formations has its own particular ostracod assemblage, and the assemblage from the Fairfield Beds is slightly older than the one from the middle part of the Burt Range Limestone, in the Bonaparte Gulf Basin.

Therefore, to date, three successive assemblages of ostracods are known to exist near the Upper Devonian-Lower Carboniferous boundary in North-Western Australia; they cannot be accurately defined until the ranges of all the species have been determined, which may lead to a finer division than the one tentatively proposed here. In ascending order of age, the three assemblages are as follows:

(i) *Assemblage A*

Assemblage A occurs in the *A. proteus* zone of the Fitzroy Basin, in the Fairfield Beds. It contains species belonging to the genera *Aparchites*, *Cavellina*, *Glyptopleura*, *Knoxiella*, and *Knoxites*, all of which are common. *Paraparchites* is present, and *Bairdia* is very rare.

(ii) *Assemblage B*

Assemblage B occurs in the middle part of the Burt Range limestone of the Bonaparte Gulf Basin, and has been recently found in bore BMR 2, Laurel Downs, of the Fitzroy Basin (see below). It contains species belonging to the genera *Bairdia*, *Bairdiacypris*, *Cavellina*, *Coryellina*, *Knoxiella*, *Paraparchites* and *Silenites*. *Aparchites* is absent. It has very few species in common with Assemblage A, but many in common with the younger Assemblage C. Assemblage B can be characterized by some species which appear to be restricted to it, e.g., species belonging to the genera *Aparchitellina*, *Bairdiacypris*, and *Coryellina*.

(iii) *Assemblage C*

Assemblage C occurs in the upper part of the Septimus Limestone and in the uppermost beds of the Burt Range Limestone of the Bonaparte Gulf Basin, and in the Laurel Formation of the Fitzroy Basin. It contains many species in common with Assemblage B (e.g., species belonging to the genera *Bairdia*, *Cavellina*, *Knoxiella*, *Paraparchites*, and *Silenites*), with additional species appearing for the first time (e.g., species belonging to the genera *Acratia*, *Cyathus*, *Evlanovia*, *Glyptopleurites*, *Graphiadactyllis*, *Mennerites*, and *Microcheilinella*).

A fourth assemblage also occurs in the Bonaparte Gulf Basin, in Lower Carboniferous shaly beds younger than the Septimus Limestone, but this will not be dealt with here.

Ages of the ostracod assemblages

The dating of the assemblages depends upon the stratigraphical control afforded by the macro-fossils, especially the brachiopods.

(i) *Assemblage A*

The Fairfield Beds were referred to as the '*Productella* limestone' by Teichert (1949), who regarded them as late Famennian. Veevers (1959a) included the Fairfield Beds in the zone of *Avonia proteus*.

(ii) *Assemblage B*

Teichert (Matheson & Teichert, 1948) correlated the lower fossiliferous beds of the Burt Range 'Series' with his '*Productella* limestone'. He also regarded the remainder of the 'series' as very late Devonian, but this can only be proved if clymenids actually occur in these beds. As short-ranging clymenids have not been found, the middle and upper parts of the Burt Range Limestone cannot be correlated with the standard German Upper Devonian succession. Therefore, at the moment, I prefer to use the term 'passage-beds' to show that they can be referred to either the Famennian or the Tournaisian stage, or both.

(iii) *Assemblage C*

Öpik (in Noakes, Öpik & Crespin, 1952), regarded the presence of *Leptaena analoga* Phillips in the Septimus Limestone as indicating a definite Lower Carboniferous age, and the presence of *Productus* (*Marginirugus*) as indicating an age equivalent to that of the Warsaw and Keokuk formations in the Mississippi Valley. This is supported by Thomas (1959a), who has studied more recent collections of brachiopods from the Septimus Limestone; he regarded the presence of *Spirifer* cf. *tornacensis* as indicating late Tournaisian.

The uppermost beds of the Burt Range Limestone may be transitional between the Upper Devonian and the Lower Carboniferous, as they have yielded cf. *Avonia proteus* (Veevers, 1959b), which indicates Upper Devonian, and also *Leptaena analoga* Phillips (Thomas, 1959a), which indicates Lower Carboniferous. Therefore, the uppermost beds of the Burt Range Limestone may possibly be equivalent to the Zone d'Etroeungt of France and Belgium. The ostracod species found in the top of the Burt Range Limestone are also found in the Septimus Limestone, so they have been included in Assemblage C.

In the Fitzroy Basin, the upper beds of the Laurel Formation contain a rich fauna of brachiopods, which Thomas (1959b) regarded as late Tournaisian. The suggestion of a hiatus between the Laurel Formation and the Fairfield Beds (Thomas, 1959b) remains to be tested by further work. At present, no stratigraphically useful fossils have been found in the lower beds of the Laurel Formation, the base of which has not been seen in contact with the underlying Upper Devonian formations.

The relationships between the ostracod assemblages and their stratigraphical distribution is shown in Figure 1.

Ostracod assemblages in subsurface samples

It is now possible to correlate parts of the subsurface sections of the bores Frome Rocks No. 2, BMR 2 Laurel Downs, Sisters No. 1, and Meda No. 1, by applying some of the provisional results obtained from an examination of the distribution of ostracod species in surface formations of known ages.

Assemblage A. At 3557 feet in Frome Rocks No. 2, the base of the Grant Formation rests on a thick sequence of richly fossiliferous calcarenites and siltstones which continues down to 6264 feet.

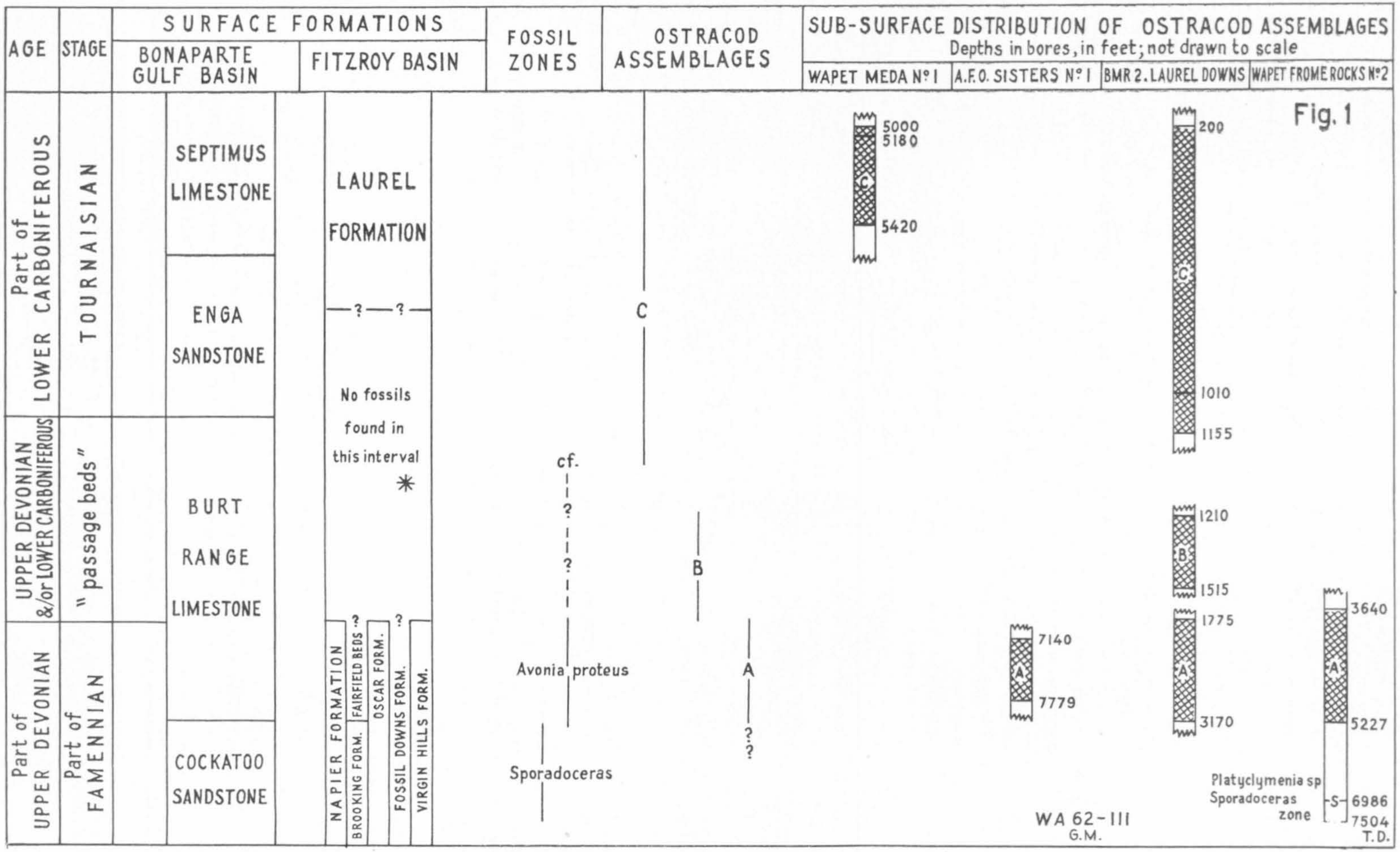

Fig. 1.—Distribution of ostracod assemblages.

* This gap does not necessarily represent a hiatus, but simply denotes:

(i) the absence of recorded index fossils in the lower part of the Laurel Formation, and

(ii) the absence of ostracod Assemblage B in the Upper Devonian formations.

Assemblage A first appears in cuttings at 3640 feet, which indicates the presence of Upper Devonian rocks, probably the *A. proteus* zone. Cores 10 and 11 (3746-3754 feet) were cut from a grey ostracod limestone, which can be roughly correlated with the ostracod limestone found in BMR 2, in which Assemblage A first appears in core 18 (1775-1785 feet). A species of *Bairdia* common to Assemblages B and C makes its only appearance in Frome Rocks No. 2 at 3640 feet, which suggests a horizon slightly higher than 1775 feet in BMR 2. The last indication of the presence of Assemblage A in Frome Rocks No. 2 occurs in core 17 (5220-5227 feet), which is without doubt still in the *A. proteus* zone, as the first indication of the presence of the *Sporadoceras* zone does not occur until the depth of 6986 feet is reached. At this depth, in core 23 (6986-6993 feet), a clymenid was found, which Dr B. F. Glenister identified as *Platyclymenia*, a genus restricted to the *Platyclymenia* 'Stufe' of the German succession—approximately equal to the *Sporadoceras* zone and part of the *A. proteus* zone of the Upper Devonian of the Fitzroy Basin. In BMR 2, the lower limit of Assemblage A is difficult to determine, as below core 36 (3160-3170 feet) ostracods are few and badly preserved in cores, but well-preserved in cuttings. Therefore, the lower limit of Assemblage A is at least as deep as 3170 feet, with a possibility of occurring at the bottom of the bore at 4000 feet. At present, it is not known if Assemblage A enters into rocks older than the *A. proteus* zone in the lowest beds in BMR 2.

In Sisters No. 1 the first indication of Assemblage A occurs in cuttings at least at 7140 feet. As it does not occur in cuttings at 7000 feet, cuttings between these depths have still to be examined to accurately fix the upper limit of Assemblage A. This assemblage occurs down to at least core 10 (7769-7779 feet); the rocks between 7140 and 7779 feet therefore can probably be referred to the *A. proteus* zone. Ostracods were not found in the deeper cores (cores 12, 8896-8902 feet, and core 14, 9721-9728 feet).

In Meda No. 1, Assemblage A is absent, and the first definitely Upper Devonian rocks are encountered in core 13 (6686-6696 feet), from which Dr Glenister found the conodont species *Palmatolepsis* (*Manticolepsis*) *triangularis* (Sanneman), which he regards as indicating the presence of the *Manticoceras* zone.

Assemblage B. At present, Assemblage B has not been found in the surface rocks of the Fitzroy Basin, which is negative evidence, compatible with the suggestion of Thomas (1957, 1959) that there is probably an unconformity between the Laurel Formation and the Fairfield Beds. Of course, in subsurface sections in the deeper parts of the basin, the Lower Carboniferous and Upper Devonian rocks are probably conformable.

Assemblage B has only been found in one bore, BMR 2 Laurel Downs. In BMR 2, no ostracods have been recovered in the cores taken from between core 10 (1000-1010 feet) and core 18 (1775-1785 feet); a rich ostracod fauna has been collected, however, from cuttings taken between these depths. As the ostracods found in the cuttings could have been recirculated in the drilling mud, their stratigraphical value is reduced when the lower limit of an assemblage is required. The first appearance (downwards) of a species or assemblage can be taken as a reliable indication of its true upper limit in the bore. The first indication of Assemblage B is found in cuttings at 1210 feet, based on the first appearance of *Bairdiacypris* sp., which so far has only been found in this assemblage. Another index form of Assemblage B is found in cuttings at 1440 feet, and is referred to *Aparchitellina*. The lower limit of Assemblage B may be taken at 1515 feet, the depth at which *Bairdia* sp. makes its first appearance. This species is also found at 1530 feet, but below this depth no ostracods are found until 1710 feet. The absence of any trace of previous animal life between 1530 feet and 1710 feet is probably due to an unfavourable environment at the time of the deposition of the dolomite sequence (1600-1670 feet), which, therefore, is probably primary, and not of diagenetic origin.

In Sisters No. 1, ostracods are found above the upper limit of Assemblage A at 7140 feet, in cuttings at 6435 feet and between 6770 and 6945 feet, but they are not well-preserved, and cannot be referred to any ostracod assemblage known at present. The lowest definite occurrence of Lower Carboniferous rocks is in core 8 (6083-6093 feet), in which Dr Dorothy Hill identified the tetracoral *Zaphrentites* sp. nov. cf. *delanouei*, which she regarded as indicating basal Carboniferous (early Tournaisian). Mr W. G. Hill (1957) in the final report on Sisters No. 1 regards the boundary between the Lower Carboniferous and the Upper Devonian rocks as relatively indistinct. (The sequence, in fact, appears to be conformable.) He estimated that Devonian rocks first appear at approximately 6190 feet. As the first definite indication of Upper Devonian rocks occurs at 7140 feet, with the presence of ostracod Assemblage A, the boundary must occur somewhere between 6093 feet and 7140 feet. It is not impossible that the ostracods found within this interval may represent a facies fauna equivalent to Assemblage B, but at present this assumption would be purely speculative.

Assemblage B has not been recognized in the bores Meda No. 1 and Frome Rocks No. 2.

Assemblage C. Assemblage C is present in BMR 2 Laurel Downs, in cuttings between the depths of 200 and 1155 feet, and in cores between 250 and 1010 feet. In Meda No. 1, the ostracods found in core 9 (5239-5245 feet) and in cuttings between the depths of 5180 and 5420 feet may also be referred to this assemblage.

Assemblage C has not been recognized in Frome Rocks No. 2 and Sisters No. 1.

Conclusions

Assemblage A indicates the presence of late Famennian rocks of the *Avonia proteus* zone in the following bores:

Frome Rocks No. 2	3640—5227 feet
Sisters No. 1	7140—7779 feet
BMR 2 Laurel Downs	1775—3170 feet or ? 4000 feet

Assemblage B is only found in BMR 2 Laurel Downs, between 1210 and 1515 feet, and indicates the presence of 'passage-beds' between late Tournaisian sediments and that part of the *A. proteus* zone which crops out at the surface in the Fitzroy Basin. This suggests that in BMR 2, sedimentation was continuous from at least 1515 feet to the top of the Laurel Formation, thus repeating a sequence of events similar to that known to exist in the Bonaparte Gulf Basin. If the supposed presence of *Avonia proteus* in the uppermost beds of the Burt Range Limestone is later confirmed by well-preserved material (Veevers, 1959b), then Assemblage B may be referred to the upper part of the *A. proteus* zone.

The mutual relationships between Assemblages A and B are not clearly known, because hitherto they have not been found in the same surface section in the same basin. Assemblage A occurs in exposures of the Fairfield Beds in the Fitzroy Basin, whereas Assemblage B occurs in a section of the Burt Range Limestone in the Bonaparte Gulf Basin. BMR 2 Laurel Downs is the only bore that demonstrates that Assemblage B is younger than Assemblage A, but here the relationship is still uncertain, as it is obscured by an environment unfavourable for ostracod life—the deposition of dolomite. Therefore, in BMR 2, it is uncertain whether or not there is a hiatus between Assemblages A and B; but if so, it must be very short.

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Appendix 4

MESOZOIC AND PERMIAN FOSSILS FROM THE CANNING BASIN

by

J. M. Dickins

Introduction

The Permian fossils (except those from locality T16) collected by Bureau field parties in the Canning Basin in 1955 and 1956 were considered in a previous report (Dickins, 1958, unpubl.), which is to be published as an appendix to Casey & Wells (1961). The fossils considered below were collected by B. H. Stinear and A. T. Wells from Helen Hills (T16, Cuncudgerie Sandstone) and by Wapet field parties in 1954 and 1955. The latter are indicated by Wapet field numbers and the specimens have been lodged in the collections of the Bureau of Mineral Resources, Canberra, A.C.T. The localities have been marked by Wapet on copies of their unpublished maps (Sheet 'E', C-1805; Sheet 'F', C-1806; and C-1072-G-1 Sheets 1, 2 and 3) held in the Bureau, Canberra, and the latitudes and longitudes recorded have been taken from these maps. They must be regarded as approximate, except where otherwise indicated, as they are based on an uncorrected grid.

The fossils are considered under the subheadings Mesozoic, Mesozoic or Permian, and Permian. Under these subheadings the localities are listed in alphabetical and numerical order, as it has not been practicable to group them according to their stratigraphical position.

In most samples the fossils identified are pelecypods and gastropods, but in some samples brachiopods and other forms have been listed.

Stratigraphical Subdivisions of the Liveringa Formation

Guppy, Lindner, Rattigan & Casey (1958, p. 51) consider that three 'lithostratigraphical' units can be recognized in the Liveringa Formation of the Fitzroy Basin; the lowermost unit they named the Lightjack Member and the uppermost the Hardman Member. They did not name the middle member. The Lightjack and Hardman Members possess different marine faunas which are readily recognizable, and according to Thomas & Dickins (1954) are of a different age; the fauna of the Lightjack Member is Lower Permian (Artinskian to Kungurian), and that of the Hardman Upper Permian (probably Tartarian).

Although McWhae, Playford, Lindner, Glenister & Balme (1958, p. 57) apparently include only the marine beds in the Lightjack Member, Guppy et al. include in addition, at the top, plant-bearing sandstones.

In the north-eastern Canning Basin Casey & Wells (1961) also recognize three subdivisions in the Liveringa Formation: the Balgo, Condren, and Hardman Members. The Balgo Member is the equivalent of the Lightjack Member in the restricted sense of McWhae et al. and contains the same marine fauna; the Condren Sandstone Member overlies the Balgo Member and contains plant fossils; the Hardman Member is represented by a single fossiliferous locality.

In this report it is proposed to use 'Lower Liveringa beds' (or 'Lower Liveringa') in the sense of Thomas & Dickins (1954, pp. 220, 221) and Dickins (1956, p. 25) to indicate the lower marine fossiliferous beds of the formation identified by stratigraphical relationship, fauna, and lithology, and comprising the Lightjack Member in the restricted sense and the Balgo Member. 'Upper Liveringa beds' ('Upper Liveringa') is used for the beds with the Hardman fauna.

The Lower Liveringa beds can be distinguished from the Upper Liveringa especially by the presence of the following molluscs:

Pelecypoda

Astartila fletcheri Dickins, 1956

Stutchburia muderongensis Dickins, 1956

Atomodesma exarata Beyrich, 1864

Oriocrassatella stokesi Etheridge Jnr., 1907

Gastropoda

Mourlonia? sp. nov.

The Upper Liveringa beds are characterized by the following:

Pelecypoda

Sanguinolitidae gen. et sp. nov.

Atomodesma cf. *semiplicata* Reed, 1944

Schizodus cf. *obscurus* (Sowerby), 1821

Oriocrassatella sp. nov. ('*Procrassatella*' type)

Astartella sp. nov.

Aviculopecten sp. nov.

Pseudomonotis sp. nov. (affins. *P. deplanata* Waagen, 1881)

Gastropoda

Mogulia sp.

Pleurotomariidae gen. et sp. nov.

In addition to the molluscs the two subdivisions have distinctive brachiopod faunas.

The Lower and Upper Liveringa are recognizable over long distances in the Canning Basin and in the sense used represent 'stages'. The middle part of the Liveringa is characterized by an absence of marine fossils and the presence of plant beds. It thus appears that a subdivision of the Liveringa based on both lithological and biological data could be more useful for regional work than units defined only by lithology. In this connexion it is of considerable interest that the 'upper stage' and probably the 'middle' and 'lower stages' of the Liveringa are recognizable by their fauna and flora in the Bonaparte Gulf Basin.

Identifications

Mesozoic

C2a (Godfrey Beds). Lat. 20° 15′ S, Long. 126° 35′ E (Corrected grid).

A single species of pelecypods is present, which can be identified as *Etea*? sp. The genus *Etea* occurs in the Lower Cretaceous rocks of North America.

L10. Lat. 18° 45′, Long. 121° 57′.

Doubtful animal track.

L24. (Frezier Sandstone) 2½ miles south of La Grange Telegraph Station.

Pseudavicula papyracea Etheridge Jnr., 1907.

This species indicates a Lower Cretaceous (probably Aptian) age.

M16. Lat. 19° 30′, Long. 123° 11′.

Meleagrinella maccoyelloides Brunnschweiler, 1960 (previously referred to as *Maccoyella* sp.).

Quenstedtia sp.

Elsewhere, both these species occur in the Alexander Formation.

M18. Lat. 19° 28′, Long. 123° 28′.

Meleagrinella maccoyelloides Brunnschweiler.

M19. Lat. 19° 28′, Long. 123° 28′.

?*Meleagrinella maccoyelloides* Brunnschweiler. M16, M18, and M19 are similar lithologically.

P2. Lat. 20° 1′, Long. 119° 53′. In creek 11½ miles north of Mount Clarkson Bore.

Plant fragments.

Unidentifiable fragment, apparently part of a living chamber of an ammonite.

Foot of Mount Clarkson.

Pseudavicula? sp. ind.

Unidentifiable pelecypods.

Creek 5 miles north-east of Mount Clarkson Bore.

Unidentifiable shell impressions.

Mesozoic or Permian

M59 Gl. Lat. 19° 4′, Long. 125° 7′.

Oriocrassatella? sp. ind.

These shells cannot be positively identified; they could be poorly preserved *Oriocrassatella* and they are not like any of the Mesozoic shells which are found in the area. The presence of *Oriocrassatella* would indicate that the rocks at this locality were of Permian age but, because of poor preservation, no certainty is possible.

N1. Lat. 18° 53′, Long. 125° 13′.
Wood impressions.

N158. Lat. 18° 46′, Long. 125° 15′.
Unidentifiable organic remains.

Permian

B1. Lat. 19° 14′, Long. 126° 6′.

Atomodesma sp. ind.
Aviculopectinidae gen. et sp. ind.
Bellerophontidae gen. et sp. ind.
Warthia cf. *micromphala* (Morris), 1845.

These fossils do not allow differentiation within the Permian.

B51. Lat. 19° 16′, Long. 125° 57′.

Stutchburia sp. ind.
Astartella sp.

This sample is probably from the Upper Liveringa as *Astartella* sp. has been recorded only from these beds. Some corroborative evidence, however, would be desirable.

M2N1. Lat. 19° 12′, Long. 125° 32′.

Pelecypoda.

Sanguinolitidae gen. et sp. nov. (this species is restricted to Upper Liveringa).
Pseudomonotis sp. nov. (related to *P. kazanensis* Waagen, 1881 and *P. deplanata* Waagen, 1881 from the Middle and Upper Productus Limestone of India. Restricted to Upper Liveringa).
Aviculopecten sp. nov. (undulating ribbing restricted to Upper Liveringa).

Gastropoda.

Pleurotomariidae gen. et sp. indet.

Brachiopoda.

Cleiothyridina sp.

This fauna is from the Upper Liveringa beds.

M3. Lat. 19° 12′, Long. 125° 32′.

Pelecypoda.

Astartila? sp. nov. (large form with a very prominent beak).
Atomodesma cf. *mytiloides* Beyrich, 1864 (this form is elongated backwards and can perhaps be separated on this basis from *A. mytiloides*).
Volsellina? sp. nov. (= *Modiola* sp. in Guppy et al., 1958, p. 54).
Pseudomonotis sp. nov. (as in M2N1).
Aviculopecten sp. nov.?

Gastropoda.

Bellerophon sp.
Bellerophontidae gen. et sp. indet.
Pleurotomariidae gen. et sp. indet.

Other fossils.

Bryozoan and brachiopod fragments.

Upper Liveringa.

M4. Lat. 19° 12′, Long. 125° 33′.

Pelecypoda.

Nuculanidae gen. et sp. ind.
Astartila? sp. nov.
Sanguinolitidae gen. et sp. nov.
Stutchburia sp. nov. (short and squat).
Schizodus sp. nov.
Oriocrassatella sp. nov. ('*Procrassatella*' type found in Upper Permian).
Astartella sp. nov.
Pseudomonotis sp. nov.
Aviculopecten sp. nov.
Streblopteria? sp. (a small form; more inflated than species in Lower Permian beds, '*Streblochondria* sp.' of Guppy et al., 1958, p. 54).
Pelecypoda gen. et sp. nov. (triangular form with radiating teeth).

Gastropoda.

'*Bucanopsis*' sp. nov.
Pleurotomariidae gen., sp. nov.

Brachiopoda.

Streptorhynchus sp.
Strophalosia sp.
Waagenoconcha? sp. ind.

Upper Liveringa beds.

M5. Lat. 19° 17′, Long. 125° 26′.

Stutchburia sp. ind.
Atomodesma exarata Beyrich, 1864.
Warthia cf. *micromphala* (Morris), 1845.
Pleurotomariidae gen. et sp. ind.

The occurrence of *A. exarata* indicates that this locality is in the Lower Liveringa beds.

M5E. Same locality as M5.

Stutchburia sp. ind.
Warthia cf. *micromphala* (Morris).

Fossils not very useful for age determination; could be Lower Liveringa.

M7E1. Lat. 19° 14′, Long. 125° 55′.

Pelecypoda.

Nuculana? sp.
Astartila sp. nov.
Stutchburia sp. ind.
'*Allorisma*' sp.
Atomodesma sp. ind.
Schizodus sp.
Oriocrassatella sp. nov.
Astartella sp. nov.

Gastropoda.

Warthia cf. *micromphala* (Morris).
Pleurotomariidae gen. et sp. nov. (this genus and species is restricted to Upper Liveringa).

Other fossils.

Aulosteges? sp.
Straight nautiloid.

Astartella sp. nov., *Oriocrassatella* sp. nov., and Pleurotomariidae gen. et sp. nov. indicate that this fauna is from the Upper Liveringa beds.

M8. Lat. 19° 8′, Long. 126° 1′ (35 feet from top of Saddle Back Hill).

Bellerophontidae gen. et sp.

Fossils not of value for identifying the stratigraphical subdivision. Lithology like that of Lower Liveringa beds.

M50. Lat. 18° 59′, Long. 125° 49′.

This sample contains no molluscs but the occurrence of *Strophalosia kimberleyensis* Prendergast, 1943 indicates that it is from the Noonkanbah Formation.

In the Canning Basin *S. kimberleyensis* occurs only in the top part of the Noonkanbah Formation and in the Carnarvon Basin only in the Wandagee and Norton Formations.

M51. Lat. 19° 8′, Long. 125° 57′.

Indeterminate shell fragments.

M55A1. Section at Lat. 18° 59′, Long. 125° 0′.

Pelecypoda.

'*Heteropecten*' sp. ind.

Indeterminate fragments.

Brachiopoda.

Strophalosia kimberleyensis Prendergast, 1943.

Noonkanbah Formation.

M55A2. Same Latitude and Longitude as M55A1.

Brachiopoda.

Taeniothaerus sp. (similar to species described by Coleman (1957) from Wandagee Formation of Carnarvon Basin).

Permorthotetes guppyi Thomas, 1958.

'*Martiniopsis*' sp.

Neospirifer sp.

Upper Noonkanbah or Lower Liveringa. G. A. Thomas (pers. comm.) suggests that this fauna may be the same as that found at the base of the Liveringa Formation at the Shore Range Trig.

M55A3. Location as for M55A1.

Brachiopoda.

Neospirifer cf. *byroensis* Glauert, 1912.

N. byroensis appears to be a long-ranging species and at present is of little value for correlation within the Permian.

M55B1. Section at Lat. 18° 59′, Long. 125° 0′.

Pelecypoda.

Astartila sp. ind.

Leiopteria? sp. ind.

Oriocrassatella stokesi Etheridge Jnr., 1907.

Gastropoda.

Mourlonia? sp. nov.

Bellerophon sp. ind.

Mourlonia? sp. nov. and *Oriocrassatella stokesi* suggest that this sample is from the Lower Liveringa.

M56. Lat. 19° 0′, Long. 125° 1′.

Gastropoda.

Mourlonia? sp. nov.

Bellerophontidae gen. et sp. ind.

This, like the previous sample, is probably Lower Liveringa, particularly if the lithology is taken into account.

M58. Lat. 19° 5′, Long. 125° 6′.

Brachiopoda.

Strophalosia sp.

Streptorhynchus sp.

Cleiothyridina sp.

G. A. Thomas (pers. comm.) considers that these brachiopods indicate Upper Liveringa.

M62. Lat. 19° 14′, Long. 125° 20′.

Gastropoda.

Pleurotomariidae gen. et sp. ind.

Warthia cf. *micromphala* (Morris), 1845.

Scaphopoda.

Gen. et sp.

The fossils are not definitive but the lithology suggests Lower Liveringa.

M66. Lat. 19° 2′, Long. 125° 13′.

Pelecypoda.

Astartila sp. ind.

Atomodesma exarata Beyrich, 1864.

Gastropoda.

Warthia cf. *micromphala* (Morris), 1845.

A. exarata indicates that this sample is from the Lower Liveringa.

M67. Lat. 19° 4′, Long. 125° 22′.

Pelecypoda.

Megadesmus? sp. nov.

Stutchburia sp. ind.

Gastropoda.

Warthia cf. *micromphala* (Morris), 1845.

The fossils are not definitive but the lithology suggests Lower Liveringa.

M68A. Lat. 19° 5′, Long. 125° 27′.

Indeterminate shell fragments.

M68B. Castle Rock, Lat. and Long. as for M68A.

Pelecypoda.

Astartila fletcheri Dickins, 1956.

Stutchburia muderongensis Dickins, 1956.

Atomodesma exarata Beyrich.

Indeterminate gastropods.

The three pelecypods are characteristic of the Lower Liveringa.

M69. Lat. 19° 3′, Long. 125° 31′.

Pelecypoda.

Megadesmus sp. nov.

Stutchburia muderongesis Dickins.

Atomodesma exarata Beyrich.

Gastropoda.

Warthia cf. *micromphala* (Morris), 1845.

T16. Lat. 22° 45′, Long. 123° 25′ (Helen Hill, Canning Stock Route, 2½ miles north-north-west of Well 27—Cuncudgerie Sandstone).

Pelecypoda.

Myonia? sp. nov.

Indeterminate fragments.

Myonia? sp. nov. is closely related to or conspecific with a form that occurs in the Nura Nura Member of the Poole Sandstone, and thus provides additional evidence for the correlation of the marine beds of the Cuncudgerie Sandstone with the Nura Nura Member (*see* Dickins & Thomas, appendix B *in* Traves, Casey & Wells, 1956, p. 51). G. A. Thomas (pers. comm.) has identified the brachiopods *Linoproductus* sp. nov. and *Pseudosyrinx* sp. nov. from this sample, and these identifications confirm the correlation with the Nura Nura Member.

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Appendix 5

MICROPLANKTON FROM BMR 4 AND 4A (WALLAL) BOREHOLES

by

P. R. Evans

A preliminary study of the micro-organic content of all suitable cores from BMR 4 and 4A bores was made in 1958, from which it was deduced that the sediments between 399 feet and 1515 feet of the combined borehole sections were of Upper Jurassic age, perhaps Lower Cretaceous in part.

This age determination is based on the presence of *Gonvaulax jurassica* Deflandre, 1938, *Scrinodinium crystallinum* (Defl.), 1938 and *Nannoceratopsis pellucida* Defl., 1938, all of which have been described from European Oxfordian and Kimmeridgian beds, and *Cannosphaeropsis aemula* (Defl.), 1938 which has been found in the Kimmeridgian and Lower Cretaceous (Deflandre, 1938, 1941; Downie, 1957). Unfortunately microplankton from Tithonian beds have not yet been described, so that the exact life-ranges of these species are not known.

Within Australia, these species and others common in the Wallal assemblage, such as *Dingodinium jurassicum* Cookson & Eisenack, 1958, *Wanaea clathrata* C. & E., 1958 and *Broomea ramosa* C. & E., 1958, have been described from the Dingo Claystone of the Carnarvon Basin, where they are associated with Kimmeridgian ammonites (Arkell, 1956, unpubl.) and Jurassic pelecypods (Cox, 1956, unpubl.), spores (Balme, 1957) and foraminifera (Crespin & Belford, 1955 & 1956, unpubl.). The foraminifera alone indicated a Lower Cretaceous age for a portion of the Dingo Claystone; the various fossil horizons indicate that the Cape Range microplankton, and, in consequence, the Wallal assemblage, may extend into the Cretaceous. This assemblage cannot be younger than Aptian because a different and distinctive microplankton suite occurs in Aptian deposits of the Carnarvon Basin and elsewhere in Australia.

Similar assemblages have also been described (Cookson & Eisenack, 1960) from bores at Broome, where they are associated with an Oxfordian-Kimmeridgian macrofauna (Teichert, 1940), and in the Wapet Wallal corehole. Internal subdivisions of the BMR 4 assemblages correspond approximately to the divisions suggested by Cookson & Eisenack: an upper division, represented by cores 4 (399-400 feet) and 5 (500-510 feet), contains the elements of the 'Upper Jarlemai Siltstone' microfauna of the Wallal corehole.This assemblage differs from, and is stratigraphically above, those which are associated elsewhere with Oxfordian and Kimmeridgian macrofaunas, and Cookson & Eisenack suggested that it is (?) Lower Tithonian. However, as the absolute ranges of the species on which this is based have not been established, the possible age of the beds between 399 and 1515 feet in BMR 4 and 4A lies within the interval Upper Jurassic to Lower Cretaceous.

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APPENDIX 6

PLANT FOSSILS FROM THE CANNING BASIN, WESTERN AUSTRALIA

by

MARY E. WHITE

INTRODUCTION

Plant fossils were collected by Bureau of Mineral Resources field parties from 42 localities in the Canning Basin, and by geologists of West Australian Petroleum Pty Ltd from two localities. Solution of some problems of stratigraphy has been based on the identification of floral units. Rock outcrop is largely confined to the margins of the basin; although weathering is deep, the plant fossils are mostly well preserved. Three boreholes drilled in the area intersected plant-bearing beds and assisted in elucidation of the stratigraphy. Floral assemblages in field collections and in borehole samples range in age from Upper Devonian to Cretaceous, with only a Carboniferous flora absent.

Upper Devonian/Lower Carboniferous age is represented by *Leptophloeum australe* (M'Coy), which is a most characteristic plant of that horizon throughout Australia. A Lycopod stem possibly referable to the Devonian genus *Protolepidodendron* occurs in the Upper Carboniferous rocks of the Grant Range Bore. Permian assemblages are of two types: associations of *Noeggerathiopsis* and *Samaropsis* at some localities; and at others a typically Lower Gondwana flora of *Glossopteris*, *Gangamopteris*, and *Vertebraria*. The Triassic floras are of two types: a typically Middle Triassic *Dicroidium* flora such as occurs in the Molteno Beds in South Africa and the Ipswich Series in Queensland, and a younger flora with stronger Jurassic affinity. A flora of Upper Jurassic/Lower Cretaceous type occurs in the Callawa Formation, and the Broome Sandstone contains a flora more Cretaceous than Jurassic in affinities.

The plant fossil localities are shown in Figure 1. The table has been compiled to give details of locality, collection data, floral lists, age determinations on floral identifications, and the formation to which the rocks at each locality are assigned by Veevers & Wells.

In the descriptions of the collections which follow, the specimens are referred to by collection numbers of two types. Those illustrated in this paper are registered under Commonwealth Palaeontological Collection Numbers (CPC) and are indexed separately in the collection housed in the Bureau of Mineral Resources, Canberra. Specimens not illustrated are indexed under 'F' numbers; usually one number refers to all the specimens from one locality.

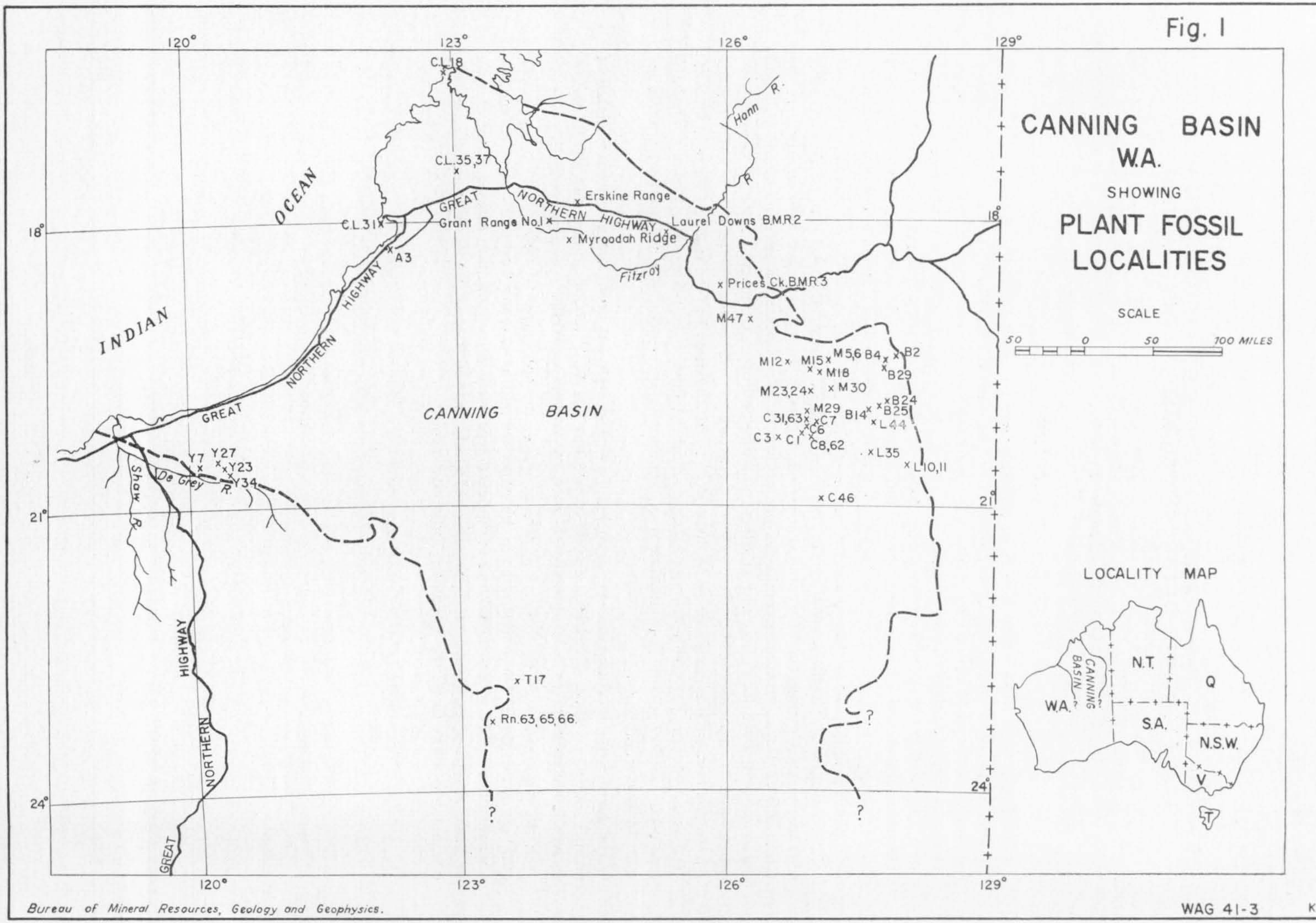
Fig. I
CANNING BASIN
W.A.
SHOWING
PLANT FOSSIL
LOCALITIES
SCALE
50 0 50 100 MILES
LOCALITY MAP
N.T.
Q
W.A.
CANNING BASIN
S.A.
N.S.W.
V
T
INDIAN OCEAN
GREAT NORTHERN HIGHWAY
CANNING BASIN
C.L.18
C.L.35,37
C.L.31
Erskine Range
Grant Range No.1
Laurel Downs B.M.R.2
Myroodah Ridge
A3
Fitzroy
Prices Ck. B.M.R.3
Hann R.
M47
M12
M15
M5,6
B4
B2
M18
B29
M23,24
M30
M29
B14
B24
B25
C31,63
C7
C6
L44
C3
C1
C8,62
L35
L10,11
C46
Y7
Y27
Y23
Y34
De Grey R.
Shaw R.
T17
Rn.63,65,66.
Bureau of Mineral Resources, Geology and Geophysics.
WAG 41-3
K.C

Fig. 1.

LOCALITY	LOCATION	COLLECTOR	PLANT FOSSILS IDENTIFIED	AGE INDICATED BY FLORA	FORMATION (Veevers & Wells)
Laurel Downs Stratigraphical Bore BMR 2	Lat. 18° 7′S Long. 125° 20′E	Core sample at 2498 feet. S. D. Henderson, 1956	*Leptophloeum australe* (M'Coy)	Upper Devonian or Lower Carboniferous	....
B 4	Billiluna 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	*Leptophloeum australe* (M'Coy)	,,	....
Grant Range Bore No. 1	Lat. 18° 1′S Long. 124°E	Core sample between 12,175′ & 12,180′	*Protolepidodendron* sp. ?	....	Anderson Formation
B 29	Billiluna 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	....	....	....
B 2	,,	,,	....	....	....
Prices Creek water Bore for BMR 3 Bore	13 miles N. of Christmas Creek Homestead. Lat. 18° 42′S Long. 125° 53′E	Core sample at 61-62′. S. D. Henderson, 1956	*Noeggerathiopsis hislopi* (Bunb.) *Samaropsis* sp.	Permian	Grant Formation
B 24	Billiluna 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	*Vertebraria indica* Royle	,,	Grant Formation
B 25	,,	,,	*Noeggerathiopsis hislopi* (Bunb.) *Samaropsis* sp.	,,	Grant Formation
B 14	,,	,,	....	....	....
L 10	Lucas 4-mile Sheet	,,	*Phyllotheca* sp. ?	....	Condren Member (Liveringa Formation)
L 11	,,	,,	*Glossopteris* sp.	Permian	,,
L 44	,,	,,	*Glossopteris indica* Sch. *Glossopteris communis* Feist. *Vertebraria australis* M'Coy *Gangamopteris cyclopteroides* Feist.	,,	,,
M 5	Mt Bannerman 4-mile Sheet	,,	*Glossopteris indica* Sch. *Carpolithus* sp.	,,	,,

LOCALITY	LOCATION	COLLECTOR	PLANT FOSSILS IDENTIFIED	AGE INDICATED BY FLORA	FORMATION (Veevers & Wells)
M 6	Mt Bannerman 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	?*Lycopodiopsis pedroanus* Carr	Permian	Condren Member (Liveringa Formation)
M 18	,,	,,	*Glossopteris indica* Sch. *Gangamopteris cyclopteroides* Feist.	,,	,,
M 24	,,	,,	*Samaropsis moravica* (Helmhacher) *Samaropsis milleri* Feist. *Samaropsis* sp. *Glossopteris* scale leaves Equisetalean stem fragments	,,	,,
M 30	,,	,,	*Gangamopteris cyclopteroides* Feist. *Glossopteris indica* Sch. *Glossopteris communis* Feist.	,,	,,
M 47	,,	,,	*Gangamopteris cyclopteroides* Feist. *Glossopteris indica* Sch. *Glossopteris communis* Feist. *Glossopteris* scale leaves	,,	,,
C 46	Cornish 4-mile Sheet	,,	*Glossopteris indica* Sch. *Schizoneura* ? sp.	,,	,,
'Myroodah Ridge'		West Australian Petroleum Pty Ltd	*Samaropsis milleri* Feist. Equisetalean stems	,,	Liveringa Formation
M 12	Mt Bannerman 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	. . . .	. . . .	Blina Shale
M 15	,,	,,	*Araucarites* sp.	Triassic or Jurassic	,,
M 23	,,	,,	Equisetalean stems Cycad pith casts: *Artisia alternans* Lignier?	. . . .	Condren Member (Liveringa Formation)
L 35	Lucas 4-mile Sheet	,,	*Araucarites cutchensis* Feist.	. . . .	,,
'Erskine Sandstone'		West Australian Petroleum Pty Ltd	Equisetalean stems ? Cycad pith casts *Artisia alternans* Lignier	Triassic or Jurassic	Erskine Sandstone

LOCALITY	LOCATION	COLLECTOR	PLANT FOSSILS IDENTIFIED	AGE INDICATED BY FLORA	FORMATION (Veevers & Wells)
C 1	Cornish 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	*Schizoneura* sp. ?	....	Culvida Sandstone
C 6	"	"	....	....	"
C 8	"	"	*Dicroidium odontopteroides* (Morr.) Gothan *Taeniopteris* sp. *Equisetites* sp. nov.	Middle Triassic	"
C 31	"	"	*Equisetites woodsi* Jones & de Jersey *Dicroidium odontopteroides* (Morr.) Gothan *Yabiella* ? *Equisetites* sp. nov.	"	"
C 62	Cornish 4-mile Sheet	J. N. Casey & A. T. Wells, 1956	*Dicroidium odontopteroides* (Morr.) Gothan *Lycopodites* sp. *Linguifolium* sp. *Linguifolium denmeadi* Jones & de Jersey *Ginkgoites antarctica* Saporta *Danaeopsis hughesi* Feist. *Baiera* sp.	"	"
M 29	Mt Bannerman 4-mile Sheet	"	*Stenopteris elongata* Carr. *Dicroidium feichmanteli* (John) Gothan *Danaeopsis hughesi* Feist. *Equisetites* stems and leaf sheaths *Cycadolepis* sp. *Lepidopteris stormbergensis* (Sew.) nov. com. *Eury-Cycadolepis*	"	"
C 63	Cornish 4-mile Sheet	"	....	....	"

LOCALITY	LOCATION	COLLECTOR	PLANT FOSSILS IDENTIFIED	AGE INDICATED BY FLORA	FORMATION (Veevers & Wells)
Rn 63	Cronin Hills (Runton 4-mile Sheet area) 23° 15′S, 123° 20′E	A. T. Wells & B. H. Stinear, 1956	*Stenopteris tripinnata* Walk. *Linguifolium denmeadi* Jones & de Jersey *Elatocladus planus* (Feist.) *Ptilophyllum pecten* (Phillips) *Hausmannia* sp. *Taeniopteris* sp. *Carpolithus circularis*	Upper Triassic or Jurassic	Cronin Sandstone
Rn 65	,,	,,	*Ptilophyllum pecten* (Phillips) *Elatocladus planus* (Feist.)	,,	,,
Rn 66	,,	,,	*Elatocladus planus* (Feist.) *Ptilophyllum pecten* (Phillips) *Taeniopteris elongata* Walk. *Cycadolepis* sp.	,,	,,
T 17	Tabletop 4-mile Sheet	,,	....	....	....
A 3	2 miles North of Goldwyer Well; 24 miles south of Broome	D. J. Guppy, 1948	*Cladophlebis* sp. *Taeniopteris howardensis* Walk. *Cladophlebis albertsi* (Dunk.) *Dichopteris delicatula* Sew. *Dictyophyllum davidi* Walk. *Pterophyllum* sp. *Sphenopteris superba* Shirley *Nilssonia schaumbergensis* Dunk *Ptilophyllum pecten* (Phillips)	Upper Jurassic or Lower Cretaceous	Broome Sandstone
CL 18	Cape Leveque	,,	*Cladophlebis albertsi* (Dunk)	,,	Leveque Sandstone
CL 31	Top of cliff section, at Entrance Point, Roebuck Bay, Broome	,,	*Otozamites bengalensis* O. & M.	Jurassic or Lower Cretaceous	Broome Sandstone
CL 35	Top of section, Hill A, 15 miles N.W. of Nillibubbaca Well on Broome-Derby Road, 67 mls from Broome	,,	*Ptilophyllum pecten* (Phillips)	,,	Jowlaenga Sandstone

LOCALITY	LOCATION	COLLECTOR	PLANT FOSSILS IDENTIFIED	AGE INDICATED BY FLORA	FORMATION (Veevers & Wells)
Lighthouse Permit area, Broome	Lighthouse cliffs, Broome	R. O. Brunnschweiler, 1949	*Ptilophyllum pecten* (Phillips) *Cladophlebis australis* (Morr.) *Brachyphyllum mamillare* L. & H. *Bucklandia* sp. *Zamites* sp. *Hausmannia* sp.	Upper Jurassic or Lower Cretaceous	Broome Sandstone
Y 23	14 miles N.W. of Callawa Homestead, Yarrie 4-mile Sheet	D. M. Traves & J. N. Casey, 1954	'*Neorhacopteris minuta*' *Pachypteris* sp. *Ginkgoites digitata* Brongn. *Cladophlebis australis* Morr. *Brachyphyllum mamillare* L. & H.	,,	Callawa Formation
Y 34	10 miles N.W. of Callawa Homestead, Yarrie 4-mile Sheet	,,	*Pagiophyllum peregrinum* Sch. *Brachyphyllum* foliage *Ruffordia mortoni* Walk.	,,	,,
Y 7	13½ miles W. of N. of Yarrie Homestead, Yarrie 4-mile Sheet	,,	*Pachypteris* sp. *Cladophlebis australis* Morr. *Brachyphyllum mamillare* L. & H. '*Neorhacopteris minuta*'	,,	,,
Y 27	15 miles E. of N. of Yarrie Homestead, Yarrie 4-mile Sheet	,,	....	....	....

DESCRIPTIONS OF COLLECTIONS

North-east Canning Basin

Locality B4, Specimen CPC 2835

Plate 1, Figure 1 shows an impression of a stem with a regular pattern of leaf bases which are rhombic with leaf trace scars in the upper angles. It is an impression of a slightly decorticated stem of *Leptophloeum australe* (M'Coy) which is a most characteristic plant of Upper Devonian—Lower Carboniferous horizons in Australia.

Localities B29 and B2, Specimens F 21586 and F 21582

Several indeterminate wood and stem impressions occur in these specimens.

Locality B24, Specimens F 21584

One determinate fossil is referred to *Vertebraria* sp. cf. *V. indica* Royle. It resembles examples of *V. indica* from the Lower Gondwanas in the Raniganj field (Feistmantel, 1880-1881, Plate XIIa).

Locality B25, Specimens F 21585

The plant remains in these specimens are largely fragmentary and indeterminate. Two identifications can be made:

(a) A seed of *Samaropsis* type occurs in one specimen. The seed is oval, approximately 1 cm. long, with a maximum width of 8 mm. The apex is divided and there is a median ridge with faint vein-like striations on either side.

(b) A fragment of leaf of *Noeggerathiopsis hislopi* (Bunb).

An association of *Samaropsis* and *Noeggerathiopsis* indicates a Permian age for the specimens.

Locality B14, Specimens F 21583

The stem impressions in this coarse-grained sandstone are too poorly preserved for identification.

Locality L10, Specimens F 21581

An Equisetalean stem cast 1.75 cm. wide, with three nodes at 1.5—2 cm. intervals and with 14 vertical ridges, is referred to *Phyllotheca* cf. *P. australis* Brongn. The preservation is poor, and Equisetalean fossils of this sort without any evidence of leaf sheaths or fructifications could be referred to several genera. No age determination is possible.

Locality L11, Specimens F 21587

A layer of shale in these specimens is highly fossiliferous but powdery; iron-rich material has largely obliterated details. Some fragments of leaves show venation of the *Glossopteris* type, and there is one *Glossopteris* scale leaf.

Locality L44, Specimens F 21591

An association of *Glossopteris indica* Sch., *Glossopteris communis* Feist., *Vertebraria australis* M'Coy, and *Gangamopteris cyclopteroides* Feist. is present. Plate 1, Figure 2 shows *Glossopteris indica* Sch. (CPC 2848). Plate 1, Figure 3, of *Glossopteris communis* (CPC 2849), shows the lower portion of an unusual leaf in which the midrib is very broad. Plate 1, Figure 4 shows *Vertebraria australis* (CPC 2850). *Vertebraria* is believed to be part of the rhizome of Glossopteroid plants and is usually associated with *Glossopteris* leaves.

This is a Lower Gondwana assemblage, indicating a Permian age.

Locality M5, Specimens F 21588

Poorly preserved leaves of *Glossopteris indica* type and a seed referable to *Carpolithus* are the only determinate plant remains.

Locality M6, Specimens F 21589

Two impressions of small areas of Lycopod stems with horizontally extended leaf cushions are present. They are assigned tentatively to *Lycopodiopsis pedroanus* Carr., a Lower Permian Lycopod which is associated with the *Glossopteris* flora in South Africa, Brazil, and Western Australia (Poole Range, Edwards, 1952).

Locality M18, Specimens F 21590

Poorly preserved and largely indeterminate leaves similar to *Glossopteris indica* and *Gangamopteris cyclopteroides* occur in these specimens, denoting a Permian age.

Locality M24, Specimens F 21593

Winged seeds of the *Samaropsis* type occur plentifully in a band. These appear to be three distinct species:

(a) The smallest variety (A in Text-figure 2) has a circular wing with a slight point above, and is emarginate below. The seed portion is diamond-shaped with a circular inclusion and is situated slightly below the centre point of the wing. This seed is similar to *Samaropsis moravica* (Helmhacher) which is a very common Permian and Upper Carboniferous variety in Europe.

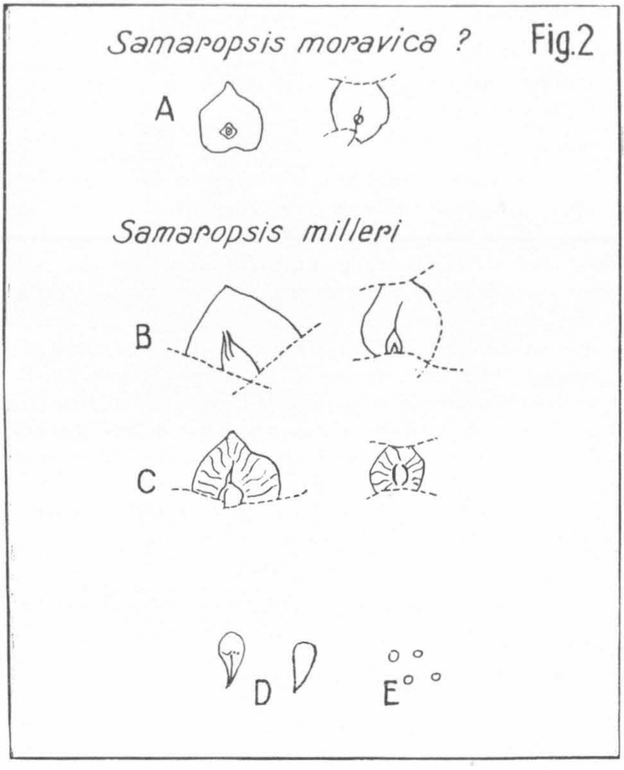

Fig. 2.—Seeds, etc. from Locality M24. X1.

(b) Larger winged seeds (B in Text-figure 2) are probably referable to *Samaropsis milleri* Feist.

(c) A third type of winged seed has marked radiating striations on the wings and has not been identified (C in Text-fig. 2).

Small scale leaves (D in Text-figure 2) may be of *Glossopteris*. There are also small Equisetalean stems and numerous linear impressions which may be rootlets.

Numerous small, spherical bodies (E in Text-figure 2) occur in some of the specimens, notably CPC 2856. Their average diameter is 1 mm. and they are not well enough preserved to be identified. They may be seeds, or could possibly be freshwater ostracods (P. J. Jones, pers. comm.).

The plant assemblage at locality M24 is of Permian age.

Locality M30, Specimens F 21594

Well preserved leaves of *Gangamopteris cyclopteroides* Feist. are associated with *Glossopteris indica* Sch. and *Glossopteris communis* Feist., denoting a Permian age. Plate 1, Figure 5 shows *Gangamopteris cyclopteroides* Feist. (CPC 2857).

Locality M47, Specimens F 21595

Gangamopteris cyclopteroides Feist., *Glossopteris indica* Sch., *Glossopteris communis* Feist., and *Glossopteris* scale leaves denote a Permian age.

Locality C46, Specimens F 21599

Fragments of leaves of *Glossopteris indica* Sch. are associated with stem fragments probably referable to *Schizoneura.*

Locality M12, Specimens F 21602

Indeterminate stems are present.

Locality M15, Specimens F 21603

Plate 2, Figure 1 shows a cone scale referred to *Araucarites* sp. (CPC 2861). There are also indeterminate rootlet impressions.

Locality M23, Specimens F 21592

These specimens contain interesting plant fossils in an excellent state of preservation. Equisetalean stems are present alone or associated with wide, wrinkled stems.

The Equisetalean stems, Plate 2, Figure 2 (CPC 2852) are of the *Schizoneura* type with no alternation of ridges at nodes. There are no leaf sheaths or fertile organs and no identification can be made. The genera *Phyllotheca*, *Schizoneura*, and *Equisetites* are all very similar in the appearance of their stem casts.

The transversely wrinkled stems seen in Plate 2, Figure 3 (CPC 2854) have a strong resemblance to Lycopod stems, especially to a stem impression referred to *Lycopodiopsis* by Edwards (1952). It is possible that they should be referred to the Triassic Lycopod genus *Pleuromeia*, which also has wrinkled stems. However, Dr A. B. Walkom, whose opinion was sought, does not think these stems can be referred to *Pleuromeia.* He regards the impressions as pith casts of a Cycad and says they are similar to specimens examined by him from Jurassic strata in Western Australia, where they were associated with typically Jurassic plants. He refers the stems to *Artisia alternans* Lignier, although none of Lignier's examples are as wide as the present stems.

Locality L35, Specimens F 21601

Triangular cone scales similar to *Araucarites cutchensis* Feist. are illustrated in Plate 2, Figure 4.

Locality C1, Specimens F 21596

Equisetalean stems similar to *Schizoneura* sp. are present.

Locality C6, Specimens F 21597

Indeterminate plant fragments.

Locality C7, Specimens F 21598

Indeterminate.

Locality C8, Specimens F 21605

A few fragments of fronds of *Dicroidium odontopteroides* (Morr.) Gothan, are associated with small portions of leaves of *Taeniopteris* sp.

The majority of the plant remains, however, appear to belong to a single species of *Equisetites.* They are all fragments of a small herbaceous Equisetalean in a highly fertile state (Plate 2, Figs. 5, 6, and Plate 3, CPC 2871).

Stem impressions range from 3—10 mm. in width and many show strong vertical ribbing; there is no indication of noding of the stems. A few have no vertical ribbing and have a ribbon-like appearance with slightly undulating margins. These look like linear leaves and some have a median groove like a midrib. Many small cones, 2—5 mm. across, are present, both attached to stems and separate.

Complete examples show oval cone scales. Some of the cone impressions have a central hollow where part of the cone has broken off. Text-figure 3 shows an example in which two cones are borne laterally on the stem in the axes of needle-like bracts or leaf sheath segments.

This appears to be an unrecorded species of *Equisetites*.

The age of the flora at Locality C8 and at Localities C31, C62, and M29, which follow, is Triassic. The floral assemblage is similar to that of the Molteno Beds in South Africa and of the Ipswich Series in Queensland. The presence of *Dicroidium* is regarded by Townrow (1957) as indicating a Middle Triassic age, and not a Rhaetic age as previously believed. *Dicroidium* does persist into Lower Jurassic strata, but with a flora somewhat different from the Molteno and present flora.

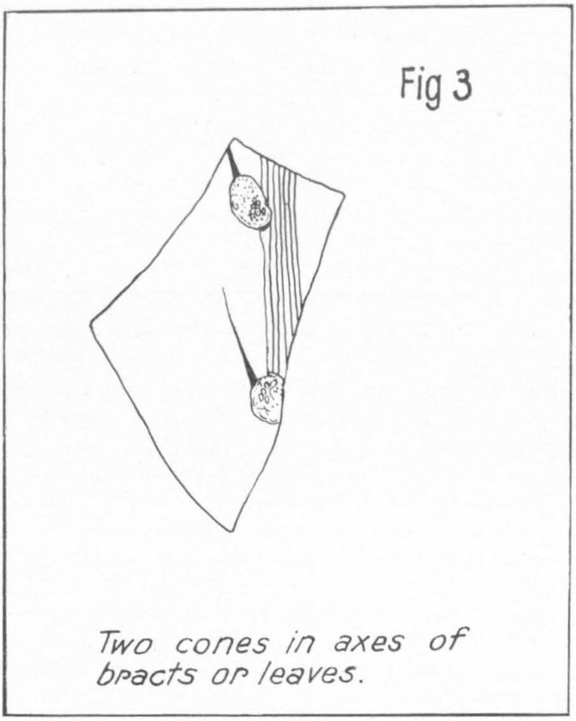

Fig. 3.—*Equisetites* sp. nov. CPC 2871a. ×2.

Locality C31, Specimens F 21606

The following species occur at this locality:

Equisetalean cones. Plate 3, Figure 2 (CPC 2872) shows a cone similar to figures of *Equisetites woodsi* Jones & de Jersey, from the Jurassic in Queensland.

Equisetalean stem fragments.

Fragments of *Dicroidium* and *Yabiella*?.

Small Equisetalean cones as from Locality C8, referred to *Equisetites* sp. nov.

Locality C62, Specimens F 21607

The following identifications have been made:

Dicroidium odontopteroides (Morr.) Gothan. Plate 3, Figure 3 shows CPC 2874.

An impression of a small cone is referred to the genus *Lycopodites*. 'A' in Plate 1, Figure 15 (CPC 2869) shows this cone. No minute detail is preserved.

Linguifolium sp. A terminal portion of a leaf with undulating margins and venation of the *Linguifolium* type is seen at 'B' in Plate 3, Figure 4. It is probably referable to *L. denmeadi*.

Linguifolium denmeadi Jones & de Jersey.

A leaf of *Ginkgoites antarctica* Saporta is seen in Plate 3, Figure 5 (CPC 2876).

Pinnules of a frond of *Danaeopsis hughesi* Feist. occur in CPC 2877.

Indistinct impressions of fronds with contorted laminal segments occur in CPC 2878. These are probably referable to *Baiera* sp.

Locality M29, Specimens F 21604

The following have been identified:

Small portions of a frond of *Stenopteris elongata* Carr. which is a fern with Middle Triassic-Jurassic range. It occurs in the Ipswich and Walloon Series in Queensland.

Large fronds, in an excellent state of preservation, of *Dicroidium feistmanteli* (Johnston) Gothan. Plate 4, Figure 1 shows CPC 2863.

Leaves of a frond of *Danaeopsis hughesi* Feist. Plate 3, Figure 6 shows CPC 2864.

Casts and impressions of *Equisetalean stems*. Some of these are large, with a flattened diameter of about three inches. The ribs do not alternate at the nodes. Plate 4, Figures 2 and 3, show two examples of these stems (CPC 2865). They are referred to *Equisetites* sp. on the evidence of the cones and leaf sheaths associated with them.

Equisetalean cones. Plate 4, Figure 4 (CPC 2866, Magn. X3) shows a cone which is referred to *Equisetites woodsi* J. & de J. Similar cones occur in the Brighton Beds in Queensland.

Equisetalean leaf sheaths. Small fragments of leaf sheaths occur associated with the stems and cones.

Cycadolepis sp. These thin, bract-like leaves have wrinkled during preservation.

Fronds of the fern *Callipteridium stormbergense* Sew. are present in CPC 2869. Plates 4 and 5, Figures 5 and 1, show four fronds and a section of the rachis bearing pinnules. The venation is of *Cladophlebis* type as far as can be seen. Mr J. A. Townrow of Reading University has recently published a revision of the genus *Lepidopteris*, to which he refers the South African type specimens of *Callipteridium stormbergensis* Sew. Plates 4 and 5, Figures 5 and 1 were sent to him for his opinion and he agrees with the determination of the specimens as *Lepidopteris stormbergensis* (Sew.) nov. comb.

An obscure form similar to the problematical '*Eury-Cycadolepis*' from the Wealden Beds in England occurs in specimen CPC 2870. Plate 5, Figure 2 shows two woody organs with what appears to be a cork layer exposed by partial decortication. It is not possible to form any conclusions on the nature of these organs, but they seem most likely to be woody bract structures attached to a stem.

Locality C63, Specimens F 21619

Specimens from this locality show indeterminate stem impressions, some possibly with *Equisetalean* affinities, and no age determination is possible.

Locality Rn63, Specimens F 21609

The following have been identified:

A frond of the fern *Stenopteris tripinnata* (Walk.), Plate 4, Figure 6 (CPC 2840). This fern occurs in the Ipswich Series in Queensland.

Numerous single leaves of *Linguifolium denmeadi* Jones & de Jersey. The type specimen for this species occurred in the Ipswich Series in Queensland. Plate 5, Figure 3 shows CPC 2841.

Fragments of *Elatocladus planus* (Feist.). Coniferous fronds of this sort are common in Late Triassic and Jurassic strata.

Fragments of *Ptilophyllum pecten* (Phillips). This type of frond is very common in Late Triassic and Jurassic strata and in the Lower Cretaceous Rajmahal Series in India.

Portion of leaves of *Hausmannia* sp.

Fragment of *Taeniopteris* sp.

Casts of small round seeds of the *Carpolithus circularis* type.

The age of the flora at Rn63 appears to be Late Triassic or Jurassic.

Locality Rn65, Specimens F 21610

The plant remains are mainly indeterminate but small bits of *Ptilophyllum pecten* (Phillips) and *Elatocladus planus* (Feist.) are present.

Locality Rn66, Specimens F 21611

Plate 6, Figures 1 and 2 of CPC 2842 and CPC 2843 shows the assemblage at this locality.

The following plants can be identified:

Very large numbers of fronds and detached fragments of *Elatocladus planus* (Feist.).

Fronds of *Ptilophyllum pecten* (Phillips).

Portions of leaves of *Taeniopteris* cf. *T. elongata* Walk.

Bennetitalean flower bracts and squamae. *Cycadolepis* sp.

Casts of small round seeds.

There are Annelid tracks among the plant remains in these specimens.

The age of the flora from Rn66 could be Late Triassic, Jurassic, or Lower Cretaceous.

Locality T17, Specimen F 21612

Indeterminate plant fragments.

CALLAWA FORMATION, CANNING BASIN

Locality Y23

Specimens F 21181 and F 21181a

Four impressions of terminal sections of delicate fern fronds are present. Plate 5, Figure 4 (CPC 3749) shows one of the larger examples, the others being less complete and of narrower fronds. This fern shows striking similarity of form to the Palaeozoic genus *Rhacopteris*, and to *Rhacopteris ovata* M'Coy in particular, although the size is in no way comparable. (Figures of *Rhacopteris ovata* showing the similarity are seen in Plate 25 of 'The Carboniferous Flora of Peru' by W. J. Jongmans, 1954.)

There is no indication of the form of complete fronds and none are fertile. With such fragmentary evidence the plant can be assigned only doubtfully to the Filicales. It might have affinity with *Phyllocladiopsis heterophylla* Fontaine. Dr A. B. Walkom considers that there is insufficient material to warrant the erection of a new genus at this stage. But as the fronds do not fit satisfactorily into existing Jurassic genera it is proposed to call it by the descriptive name '*Neorhacopteris minuta*', until such time as more is known of its habit and affinities.

Specimen F 21182

An indistinct impression of part of a leaf of *Ginkgoites digitata* Brongn. is associated with small sterile fronds of *Cladophlebis australis* (Morr.), a small, narrow stem of *Brachyphyllum mamillare* L. & H. and a fragment of *Pachypteris.*

Ginkgoites digitata is of very common occurrence in Jurassic strata and has a practically world-wide distribution.

Locality Y34

Specimens F 21183 and F 21183a

Stem impressions referable to *Pagiophyllum peregrinum* Schimp. are seen in Plate 5, Figure 5 (CPC 3750). The surface of each stem impression is deeply pitted in a regular pattern corresponding to the overlapping scale-like leaves of the original plant, seen here in cast form. Associated with these larger stems are very narrow small stems of *Brachyphyllum mamillare* L. & H. and fragments of Conifer foliage of the *Voltzia* type. There are also small round seeds which may be of Cycads.

The genera *Pagiophyllum*, *Brachyphyllum*, and *Voltzia* are not natural groups but are useful descriptive terms for types of branches, stems and leaves of conifer affinity. In this case it seems likely that the large stems, small stems, and leaf fragments are parts of the same plant species. All are widespread Jurassic types, ranging through Cretaceous to Tertiary.

Specimen F 21184a

A terminal portion of a frond of the fern *Ruffordia mortoni* Walk. Plate 5, Figure 6 (CPC 3751) is associated with conifer stem and leaf fragments as seen in F 21183a.

Specimen F 21184b

Part of a frond of the fern *Ruffordia mortoni* Walk. In CPC 3752 shows the well separated, multi-lobed pinnules of the species (Plate 5, Figure 7). There is also a very small frond of '*Neorhacopteris minuta*'.

Ruffordia mortoni Walk. was described from Cape York Peninsula (Walkom, 1928) from a Cretaceous horizon. It is a species similar to a Wealden species of *Ruffordia* in Europe and a Cretaceous species in America. It is similar to the very common Jurassic fern *Coniopteris hymenophylloides* var. *australica* Sew. especially in the appearance of terminal sections of fronds.

Specimen F 21184c contains a very small frond of '*Neorhacopteris minuta*'.

Locality Y7

Specimen F 21185 (CPC 3753)

Fronds of *Pachypteris* sp. are associated with fertile pinnules of *Cladophlebs austiralis* (Morr.), small stems of *Brachyphyllum*, and a fragment of stem with ring markings on the surface. This stem is seen in Plate 6, Figure 3. It is probably a pith cast. There is also a delicate frond approximately an inch long and an eighth of an inch wide, of unknown affinity, which seems to have trifoliate leaves (Plate 6, Figure 4).

The fern fronds referred to *Pachypteris* sp. are seen in Plate 6, Figure 5. They are similar to species from the Late Triassic and Jurassic in South Africa and Europe.

Specimen F 21186. Small stems of *Brachyphyllum mamillare* L. & H. are associated with fertile pinnules of *Cladophlebis australis* (Morr.), pinnules of '*Neorhacopteris minuta*', and a small bilocular seed.

Specimen F 21187. Plate 7, Figure 1 of CPC 3754 shows sterile fronds of *Cladophlebis australis* (Morr.), which is a very common Jurassic plant in Australia. It is rare in Middle Triassic, common in Upper Triassic, very common in Jurassic, and persists into Lower Cretaceous in the Styx River Series in Queensland.

Specimen F 21187a. Plate 7, Figure 6 (CPC 3755) shows portion of a fertile frond of *Cladophlebis australis* (Morr.). The sori are in two rows parallel to the midrib on each pinnule, near the margins. Preservation is poor and no minute detail is visible, but the specimen is similar to fertile examples illustrated by Walkom (1917), by which the frond is referred to the *Osmundaceae*.

Specimens F 21188. The remaining specimens from locality Y7 contain elements of the same flora as seen in the described specimens.

Locality T27

The plant fragments in these specimens are indeterminate.

DAMPIER PENINSULA

Locality A3

Specimen F 21507 contains a poorly preserved frond of *Cladophlebis* sp.

Specimen F 21508, a poorly preserved leaf, is referred doubtfully to *Taeniopteris howardensis* Walk. This species is recorded by Walkom from the Burrum Series in Queensland.

Specimen F 21509 is a sterile frond of *Cladophlebis albertsi* (Dunk).

Specimen F 21510. Plate 7, Figure 3 shows portion of a fine fern frond (CPC 3756). Preservation is poor and no details of venation are visible, but its appearance strongly suggests its identity with the Wealden frond *Dichopteris delicatula* Sew.

Specimen F 21511 shows a poorly preserved frond of *Dictyophyllum* type similar to *D. davidi* Walk. which occurs in the Walloon Series in Queensland.

Specimen F 21512. A small portion of a frond is referred to *Pterophyllum* sp.

Specimen F 21513. A terminal portion of a fern frond is referred to *Sphenopteris superba* Shirley. Preservation is poor.

Specimen F 21514. Plate 7, Figure 4 (CPC 3757) shows a well-preserved small Cycad frond with slight irregularity in the sizes of the divisions of the lamina. Whether this frond should be referred to *Pterophyllum* (*Anomozamites*), on the basis of the irregular segmentation, or to *Nilssonia* is not clear. The attachment of the segments appears to be lateral, indicating *Pterophyllum*, but if this is an upper surface impression, the lower view could be different and the specimen referable to *Nilssonia.* It resembles *Nilssonia schaumbergensis* Dunk. recorded by Walkom from the Burrum Series in Queensland, where it is associated with *Taeniopteris howardensis* as in this collection.

Specimen F 21516 contains a single badly preserved frond of *Ptilophyllum pecten* (Phillips).

Locality CL18

Specimen F 21517. CPC 3758

Plate 1, Figure 2 shows portion of a fertile frond of *Cladophlebis albertsi* (Dunk). Each pinnule has two sori, one on each side of the midrib, close to the rachis. Each sorus is a raised ring which appears to have nine or ten 'teeth' on its inner margin, radiating from the centre of the sorus. The sorus on the lower left pinnule shows the 'teeth' clearly. The 'teeth' are presumably individual sporangia.

It is at once apparent that the nature of the sorus precludes the fern from the *Osmundaceae*, to which *Cladophlebis australis* and other known fertile specimens of *Cladophlebis* are assigned. Affinity is indicated with the Matonineae and with the genus *Laccopteris* in particular. (A figure of the sorus of *Laccopteris polypodioides* (Brongn) seen on p. 359 of *Fossil Plants*, II, Seward, 1910, shows the similarity.)

The arrangement of two sori to each pinnule instead of many sori in two parallel rows on each pinnule is different from any described species of *Laccopteris.*

On the evidence of the sori borne on this frond, which was referred to *Cladophlebis albertsi* (Dunk.) on vegetative form, it is necessary to reclassify the frond and to refer it to *Laccopteris* sp. nov.? The sterile specimen in F 21509 is similarly reclassified as it shows no difference in leaf form from the fertile specimen.

Specimen F 21518

Casts of small, indeterminate stems are present.

Locality CL31

Specimen F 21519

Plate 7, Figure 5 (CPC 3759) shows an impression of a frond of *Otozamites bengalensis* O. & M. No minute detail is visible. The genus *Otozamites* attains its widest distribution in the Jurassic Period, but is fairly abundant both in Late Triassic and Lower Cretaceous. *O. bengalensis* is recorded in Australia from Jurassic strata only and Walkom has stressed that the only species occurring in Cretaceous beds is very different from *O. bengalensis*. However, the reclassification of the Rajmahal Series of India as Lower Cretaceous (Arkell, 1956) calls for a review of the so-called Jurassic occurrences where the determination of age was based on the flora only, and undoubted Lower Cretaceous occurrences seem likely.

Locality CL35

Specimen F 16738. A poorly preserved frond of *Ptilophyllum pecten* (Phillips) is present.

LOCALITY IN LIGHTHOUSE CLIFFS, BROOME

Specimen F 21503. Plate 8, Figure 1 shows a frond of *Ptilophyllum pecten* (Phill.) associated with *Cladophlebis australis* (Morr.) (CPC 3760). A small stem of *Brachyphyllum mamillare* L. & H. is also present. All three species are common in Jurassic and Lower Cretaceous strata in Australia.

Specimen F 21504. Plate 8, Figure 2 (CPC 3761) shows a portion of a stem with prominent leaf bases. This stem is referred to *Bucklandia* sp. Stems of this sort have frequently been recorded in association with *Ptilophyllum pecten* in Australia and elsewhere.

Specimen F 21505. Plate 8, Figure 3 (CPC 3762) shows a fragment of a small frond of *Zamites* type. Such fronds range from Rhaetic to Lower Cretaceous.

Specimen F 21506. Plate 8, Figure 4 (CPC 3763) shows portion of a leaf of a fern of the family *Dipteridinae*. It is referred to the genus *Hausmannia*. The shape of the leaf fragment suggests the orbicular form of the whole leaf. The venation of radiating veins which branch dichotomously, and fine veins at right angles to the main branches, is consistent with characteristics of *Hausmannia*. The species is similar to *H. buchii* (Andrae) which has been recorded from the Walloon Series in Queensland and from Jurassic strata in Europe. There are similar Lower Cretaceous forms in Europe and no positive species identification can be made in this instance.

MYROODAH RIDGE

Specimens F 21190. These specimens contain casts of indeterminate plant stems with no preservation of internal tissues. Very similar stem casts occur in specimens collected by Casey & Wells from Locality M12 on the Mount Bannerman Sheet, referred to the Blina Shale.

Specimens F 21191. These specimens contain:

Small Equisetalean stems.

Small circular bodies which may be seeds or freshwater ostracods.

Thin wing-like impressions with a median fold, which may be winged seeds similar to *Samaropsis milleri* Feist.

A similar fossil assemblage was found at Locality M24 (Casey & Wells) in Liveringa (Condren) Sandstone of Permian age.

ERSKINE RANGE

Specimens F 21192. Equisetalean stems are associated with wrinkled stems believed to be pith casts of a Cycad and referred to *Artisia alternans* Lignier. Similar fossils occur at Locality M23 (Casey & Wells) on the Mount Bannerman Sheet. (Walkom reports similar pith casts in Jurassic assemblages from other localities in Western Australia. No age determination for the Erskine Sandstone is possible on the botanical evidence alone.)

STRATIGRAPHICAL BORE BMR 2, LAUREL DOWNS

Plant fossils occur in the Laurel Downs Bore at two horizons:

1. The core samples at 2212-2212½ feet show superficially indeterminate fossil stems or roots with a flattened diameter of between 2 and 5 mm. Some of the fossils are in the form of impressions with a coaly film on the surface, and others are partially petrified. There are numerous linear impressions which might be rootlets or linear leaves.

Plate 9, Figure 2 shows the face of a core sample at this level in which two partially petrified stems or roots are present (CPC 3764). One of these was sectioned for microscopic examination. A map of a transverse section is seen in Plate 9, Figure 2. There is a central vascular cylinder without medulla, with a ring of small vascular bundles on its outer margin. No tissues external to the stele are preserved. The arrangement of the stele is similar to that in a young Lepidodendroid stem, but it is also similar to the arrangement in a Stigmarian rootlet. There is insufficient evidence for identification.

2. The core samples at 2498 feet contain two very clear impressions of *Leptophloeum australe* (M'Coy) (CPC 3765). Plate 9, Figure 3 shows one of these impressions. The rhombic leaf bases have leaf trace scars in their upper angles. *Leptophloeum australe* (M'Coy) is of very common occurrence in beds of Upper Devonian/Lower Carboniferous age in Australia. The species was formed by the merging of *Lepidodendron nothum* Unger and *Lepidodendron australe* M'Coy by Feistmantel in 1890. It is regarded as being closely related to *Leptophloeum rhombicum* Dawson of Devonian strata in N.E. America.

GRANT RANGE NO. 1 BORE

Grant Range No. 1 Bore was drilled by West Australian Petroleum Pty Ltd to a total depth of 12,915 feet. The bore started in Lower Permian Grant Formation. Upper Carboniferous sandstone, shale and siltstone was penetrated between 7900 and 12,915 feet.

Plant fossils in core 85, between 12,175 and 12,180 feet, were submitted for examination. The fossils (CPC 3766) consist of a number of stem impressions varying from 3 to 7 mm. in width. Some of the impressions show no diagnostic features, but several have minute surface markings. Plate 10, Figure 1 shows portion of a stem in which the surface of the impression was covered by a thin film of calcite (Figure 2). Removal of the film gave a fresh surface on which markings were more uniformly shown. Figure 3 shows a stem in which small areas only show surface features. Minute circular depressions or pits, some with faint impressions of leaf bases around them, and a pattern of ridges show Lycopod affinity. The specimens show general similarity to '*Bothrodendron minutifolium* Boulay'. The straight vertical lines of leaf bases suggest the Devonian genus *Protolepidodendron*, but in the absence of further evidence from better preserved specimens, no close identification can be made. Juvenile stems of *Lepidodendron* and *Lycopodiopsis* show similar features.

WATER BORE FOR BMR 3, PRICES CREEK

A bore drilled to 108 feet to supply BMR 3 Stratigraphical Bore with water passed through Grant Formation consisting of fine grey sandstone rich in plant remains between 60 and 70 feet. The sample under consideration is from a $2\frac{1}{2}''$ diameter core taken at 61 to 62 feet.

The plant material consists of carbonized impressions of stems, rootlets, leaves and seeds. The stem impressions are of a pith cast type and vary in width from $\frac{1}{4}''$ to $1\frac{1}{2}''$. They are indeterminate. Numerous linear impressions, probably rootlets, occur throughout the cores and are concentrated in zones. The leaf impressions are referable to *Noeggerathiopsis hislopi* (Bunb.) (Plate 10, Figures 2 and 3, CPC 3767). The leaves are associated with seeds of *Samaropsis* type (Figure 3).

Noeggerathiopsis occurs associated with *Samaropsis* in Permian strata in South Africa, India, South America and Australia. In the Northern Hemisphere its counterpart is the Permian *Cordaites-Samaropsis* association.

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PLATE 1.

FIG. 1.—*Leptophloeum australe* (M'Coy) Natural size. CPC 2835. Locality B 4.
FIG. 2.—*Glossopteris indica* Sch. Natural size. CPC 2848. Locality L 44.
FIG. 3.—*Glossopteris communis* Feist. Natural size. CPC 2849. Locality L 44.
FIG. 4.—*Vertebraria australis* M'Coy. Natural size. CPC 2850. Locality L 44.
FIG. 5.—*Gangamopteris cyclopteroides* Feist. Natural size. CPC 2857. Locality M 30.

PLATE 2.

FIG. 1.—*Araucarites* sp. Natural size. CPC 2861. Locality M 15.
FIG. 2.—Equisetalean stems. Half natural size. CPC 2852. Locality M 23.
FIG. 3.—Cycad Pith Casts with Equisetalean stems. Natural size. CPC 2854. Locality M 23.
FIG. 4.—*Araucarites cutchensis* Feist. Natural size. CPC 2860. Locality L 35.
FIGS. 5, 6.—*Equisetites*, sp. nov. Fertile Equisetalean. Magnification ×2. CPC 2871. Locality C 8.

PLATE 3.

FIG. 1.—*Equisetites*, sp. nov. Fertile Equisetalean. Magnification ×2. CPC 2871. Locality C 8.
FIG. 2.—*Equisetites woodsi* Jones & de Jersey Cone. Magnification ×3. CPC 2872. Locality C 31.
FIG. 3.—*Dicroidium odontopteroides* (Morr.) Gothan. Magnification ×3. CPC 2874. Locality C 62.
FIG. 4.—*Lycopodites* sp. Cone at A. *Linguifolium* sp. leaf at B. Natural size. CPC 2869. Locality C 62.
FIG. 5.—*Ginkgoites antarctica* Saporta. Natural size. CPC 2876. Locality C 62.
FIG. 6.—*Danaeopsis hughesi* Feist. Natural size. CPC 2864. Locality M 29.

PLATE 4.

FIG. 1.—*Dicroidium feistmanteli* (Johnston) Gothan. Natural size. CPC 2863. Locality M 29.
FIGS. 2, 3.—Equisetalean stem. Natural size. CPC 2865. Locality M 29.
FIG. 4.—*Equisetites woodsi* Jones & de Jersey. Magnification ×3. CPC 2866. Locality M 29.
FIG. 5.—*Lepidopteris stormbergensis* (Sew.) nov. com. Natural size. CPC 2869. Locality M 29.
FIG. 6.—*Stenopteris tripinnata* Walk. Natural size. CPC 2840. Locality Rn 63.

PLATE 5.

FIG. 1.—*Lepidopteris stormbergensis* (Sew.) nov. com. Natural size. CPC 2869. Locality M 29.
FIG. 2.—'*Eurycycadolepis*'. Natural size. CPC 2870. Locality M 23.
FIG. 3.—*Linguifolium denmeadi* Jones & de Jersey. Natural size. CPC 2841. Locality Rn 63.
FIG. 4.—'*Neorhacopteris minuta*' Magnification ×2. CPC 3749. Locality Y 23.
FIG. 5.—*Pagiophyllum peregrinum* Sch. Natural size. CPC 3750. Locality Y 34.
FIG. 6.—*Ruffordia mortoni* Walk. Natural size. CPC 3751. Locality Y 34.
FIG. 7.—*Ruffordia mortoni* Walk. Natural size. CPC 3752. Locality Y 34.

PLATE 6.

FIG. 1.—A. *Elatocladus plana* (Feist.). B. *Taeniopteris* cf. *T. elongata* Walk. D. *Ptilophyllum pecten* (Phillips). E. Annelid track. Natural size. CPC 2842. Locality Rn 66.
FIG. 2.—A. *Elatocladus plana* (Feist). B. *Taeniopteris* cf. *T. elongata* Walk. C. *Cycadolepis*. Bennetitalean flower bract. Natural size. CPC 2843. Locality Rn 66.
FIG. 3.—Stem with ring markings. Magnification ×2. CPC 3753. Locality Y 7.
FIG. 4.—Fine Frond. Magnification ×3. CPC 3753. Locality Y 7.
FIG. 5.—*Pachypteris* sp. Magnification ×2. CPC 3753. Locality Y 7.

PLATE 7.

FIG. 1.—*Cladophlebis australis* (Morr.) Sterile fronds. Natural size. CPC 3754. Locality Y 7.

FIG. 2.—*Cladophlebis albertsi* Dunk. = *Laccopteris* sp. nov.? Fertile pinnules. Magnification ×5. CPC 3758. Locality CL 18.

FIG. 3.—*Dichopteris delicatula* Sew. Magnification ×2. CPC 3756. Locality A 3.

FIG. 4.—*Nilssonia schaumbergensis* Dunk. Natural size. CPC 3757. Locality A 3.

FIG. 5.—*Otozamites bengalensis* O. & M. Natural size. CPC 3759. Locality CL 31.

FIG. 6.—*Cladophlebis australis* (Morr.) Fertile pinnules. Magnification ×2. CPC 3755. Locality Y 7.

PLATE 8.

FIG. 1.—*Ptilophyllum pecten* (Phillips). *Cladophlebis australis* (Morr.) Natural size. CPC 3760. Lighthouse cliffs Locality.

FIG. 2.—*Bucklandia* sp. Magnification × 2. CPC 3761. Locality Lighthouse cliffs.

FIG. 3.—*Zamites* sp. Natural size. CPC 3762. Locality Lighthouse cliffs.

FIG. 4.—*Hausmannia* cf. *H. buchii* Andrae. Magnification × 2. CPC 3763. Locality Lighthouse cliffs.

PLATE 9.

FIG. 1.—Map of Transverse Section of section of petrified stem.

FIG. 2.—Core Sample at 2212-2212.5 feet, BMR 2 Laurel Downs. Petrified thin stems. CPC 3764.

FIG. 3.—Core Sample at 2498 feet, BMR 2 Laurel Downs. *Leptophloeum australe* (M'Coy). CPC 3765.

PLATE 10.

FIG. 1.—Lepidodendroid Stems from core 85, (12,175 to 12,180 feet), Grant Range No. 1.

FIG. 2.—*Noeggerathiopsis hislopi* (Bunb.). Natural size. CPC 3767. Core Sample between 61 and 62 feet, Prices Creek Water Bore.

FIG. 3.—Seeds of *Samaropsis* sp. and venation of *Noeggerathiopsis hislopi* (Bunb.). Magnification ×4. CPC 3767. Core Sample between 61 and 62 feet, Prices Creek Water Bore.

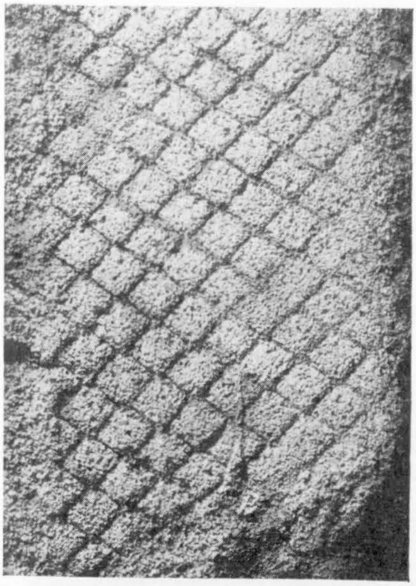


Fig 1

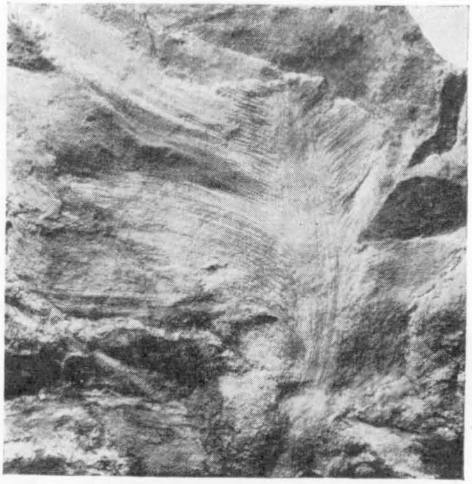


Fig 3

Fig 2

Fig 4

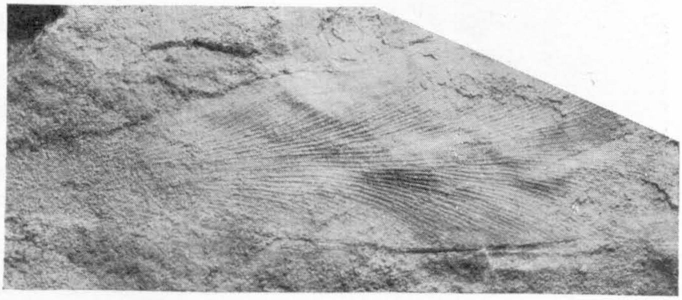


Fig 5

Fig 1

Fig 3

Fig 2
(Approx ½ nat. scale)

Fig 6

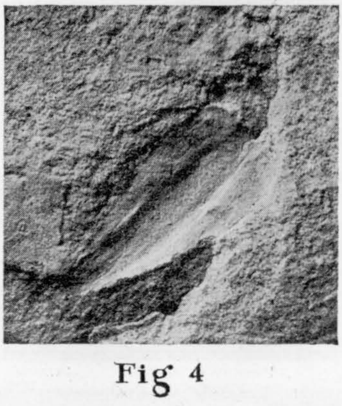


Fig 4

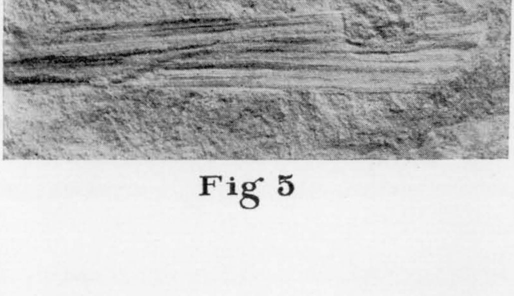


Fig 5

Plate 3

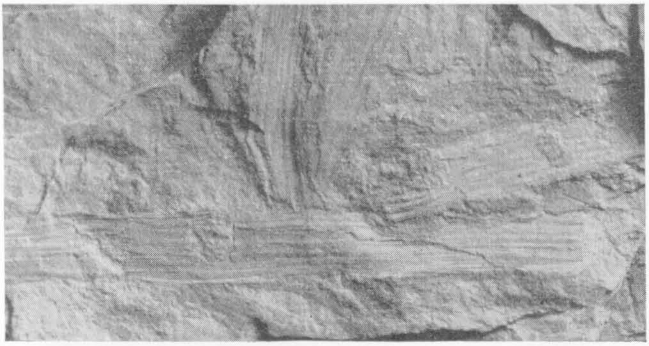


Fig 1 (× 2)

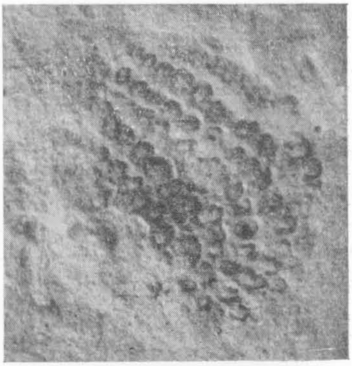


Fig 2 (× 3)

Fig 3 (× 3)

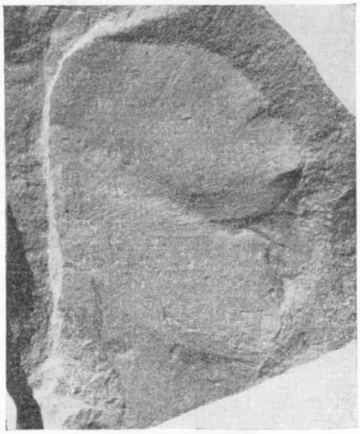


Fig 5

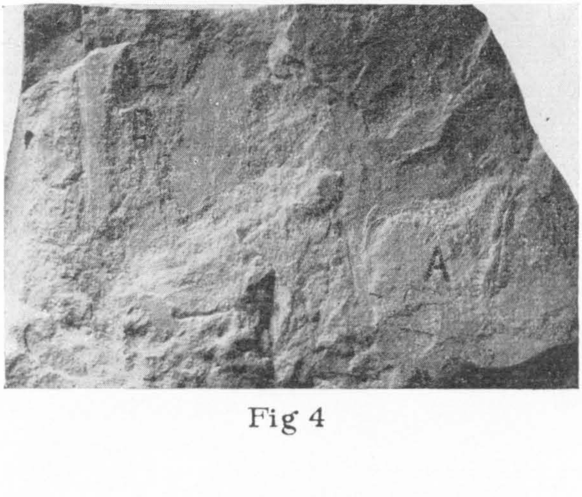


Fig 4

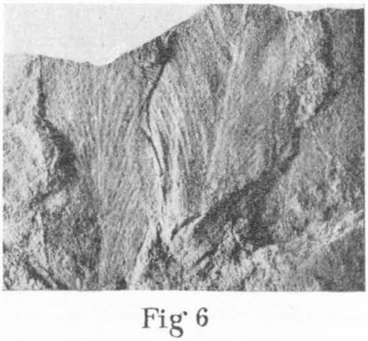


Fig 6

Plate 4

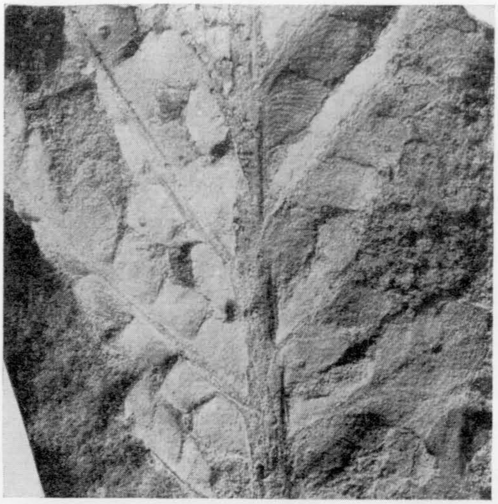


Fig 1

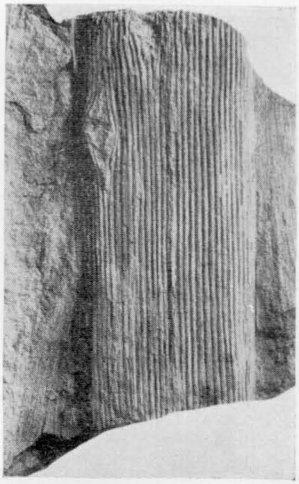


Fig 2

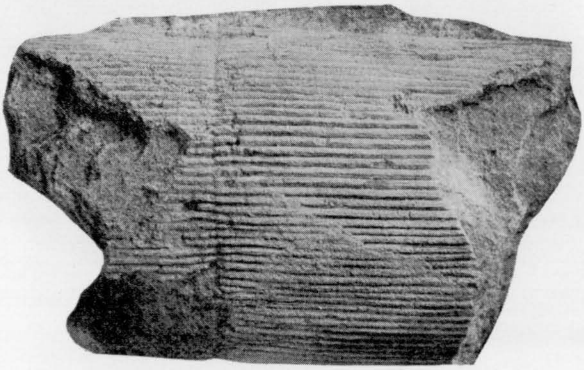


Fig 3

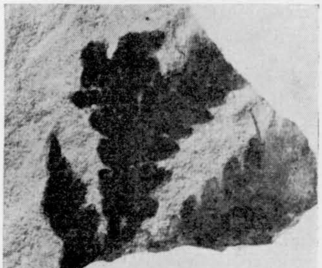


Fig 5

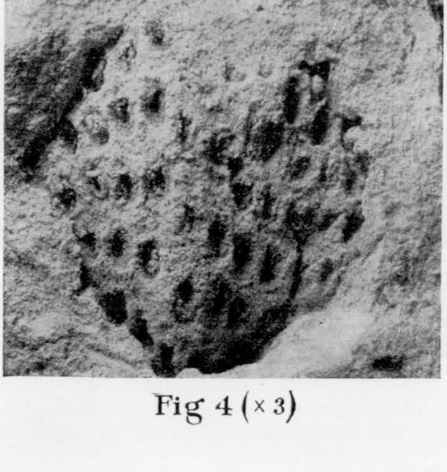


Fig 4 (× 3)

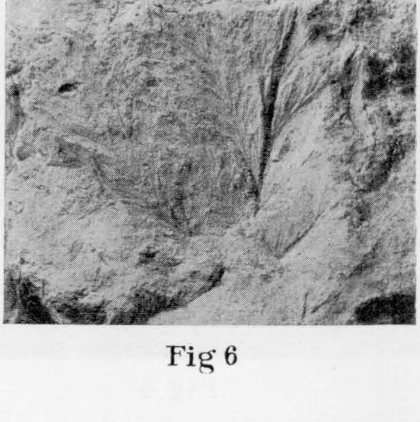


Fig 6

Plate 5

Fig 1

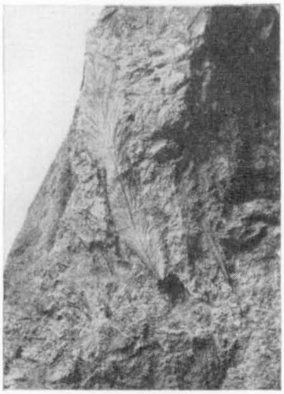


Fig 3

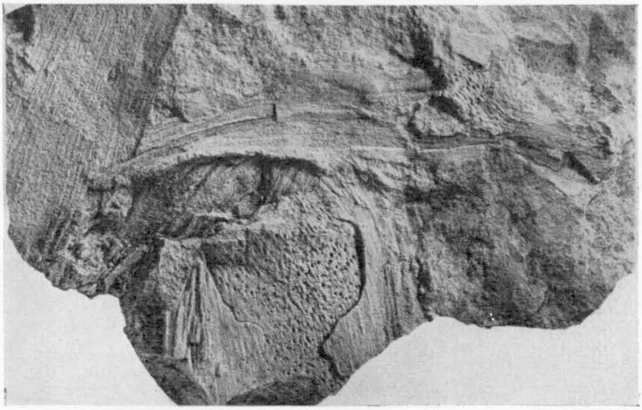


Fig 2

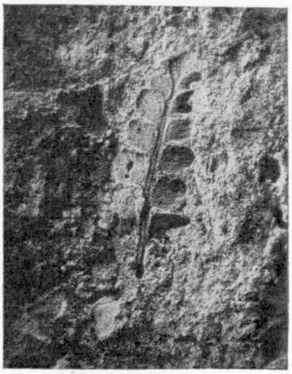


Fig 4

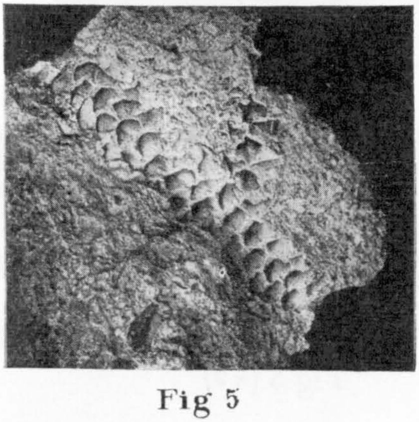


Fig 5

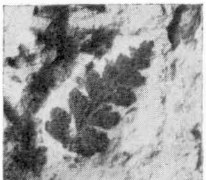


Fig 6

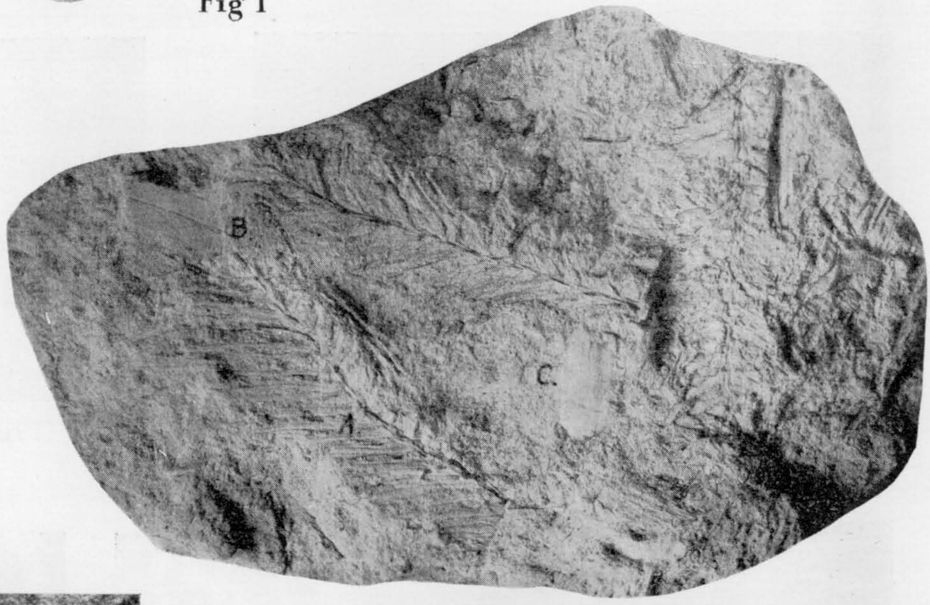
Fig 7

Plate 6

Fig 1

Fig 4 (×3)

Fig 2



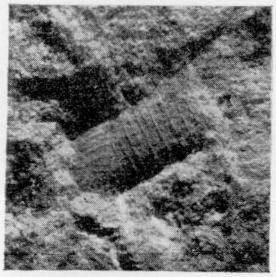


Fig 3

Fig 5 (× 2)

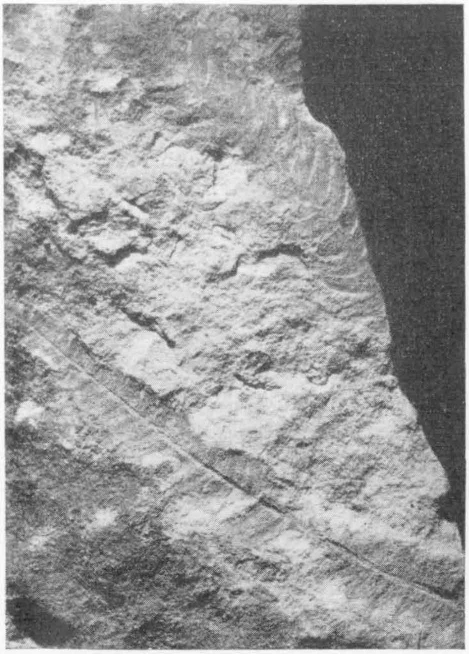


Fig 1

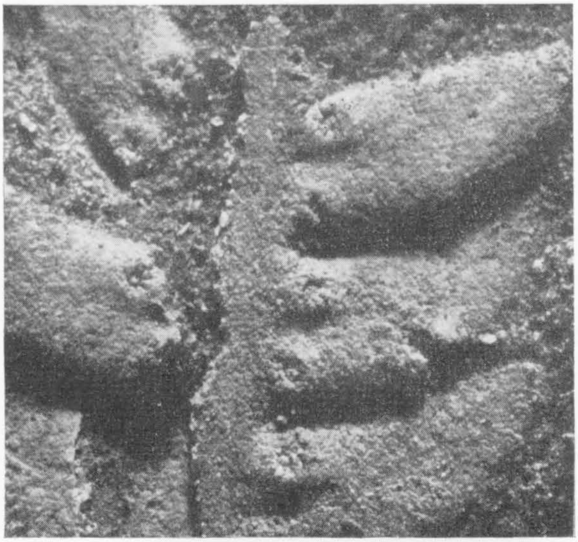


Fig 2 (× 5)

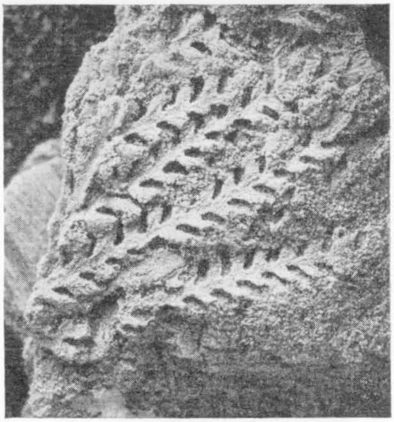


Fig 3 (× 2)

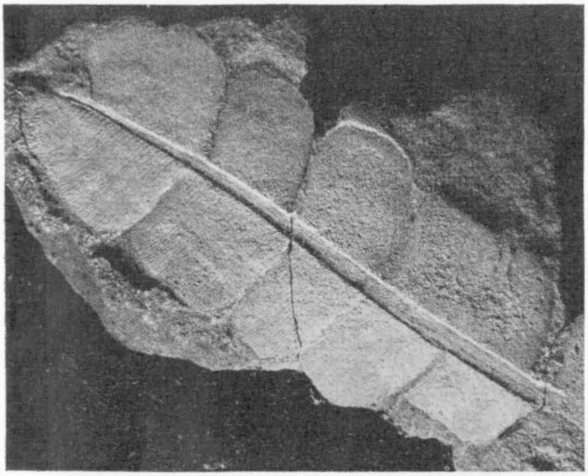


Fig 4

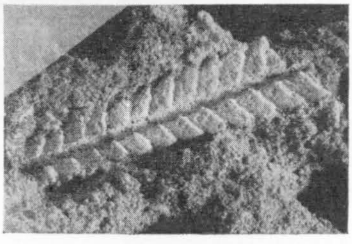


Fig 5

Fig 6 (× 2)

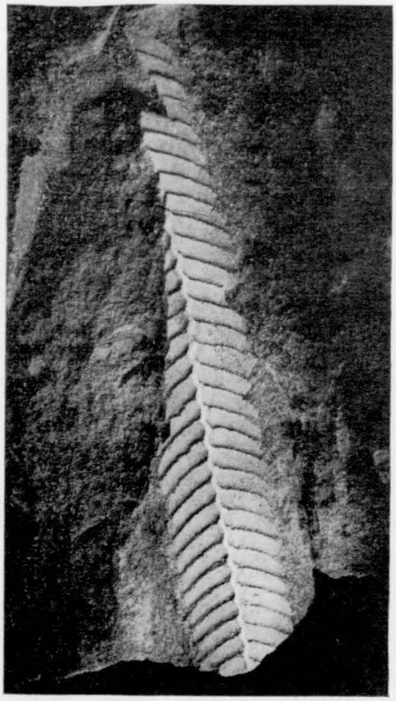


Fig 1

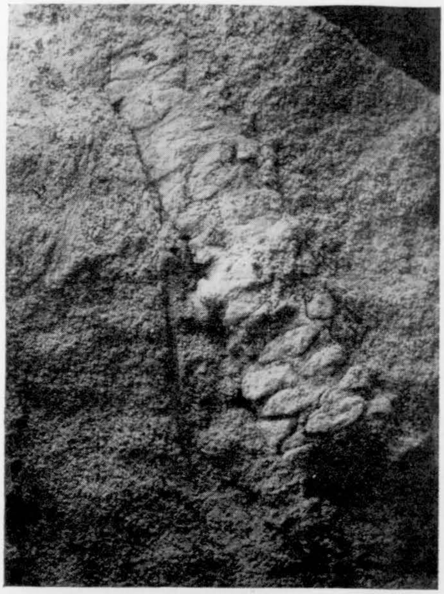


Fig 2 (×2)

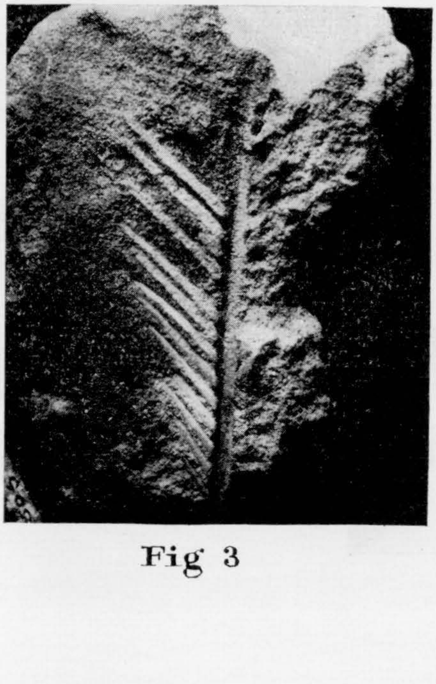


Fig 3

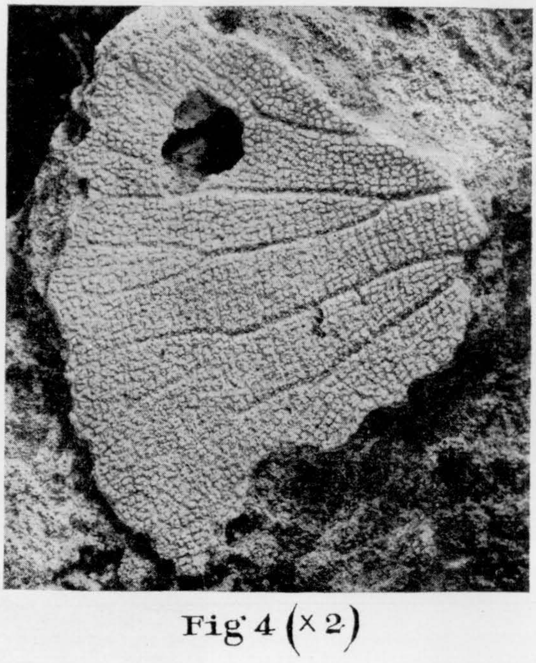
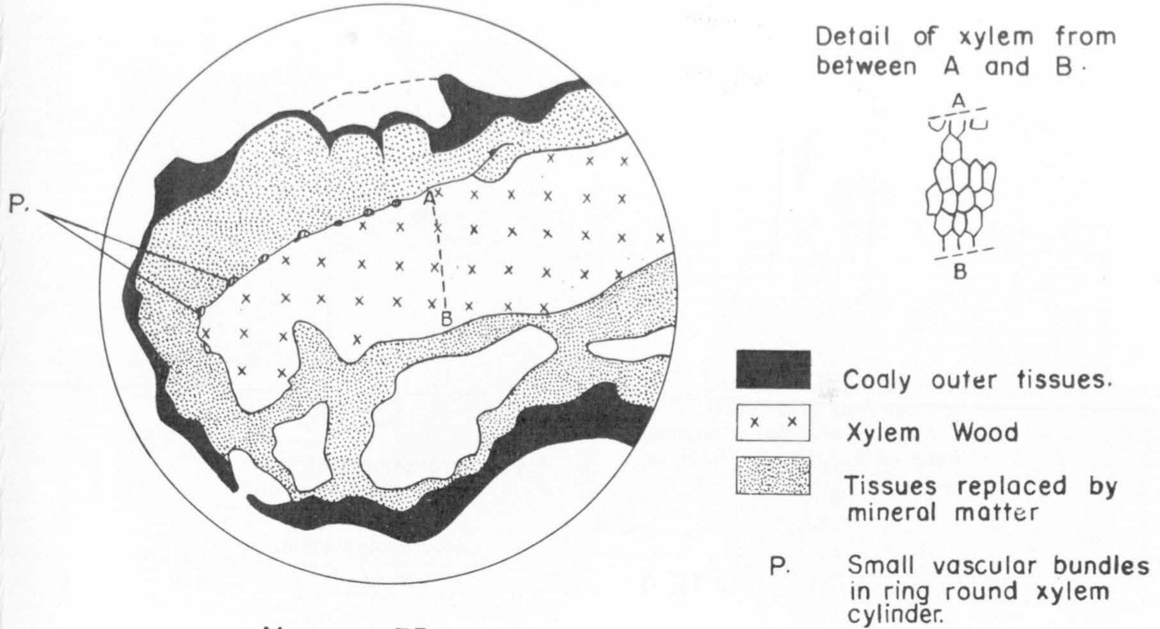


Fig 4 (×2)

MAP OF SECTION OF STEM



Magn. x 75 approx.

Fig 1

Fig 2

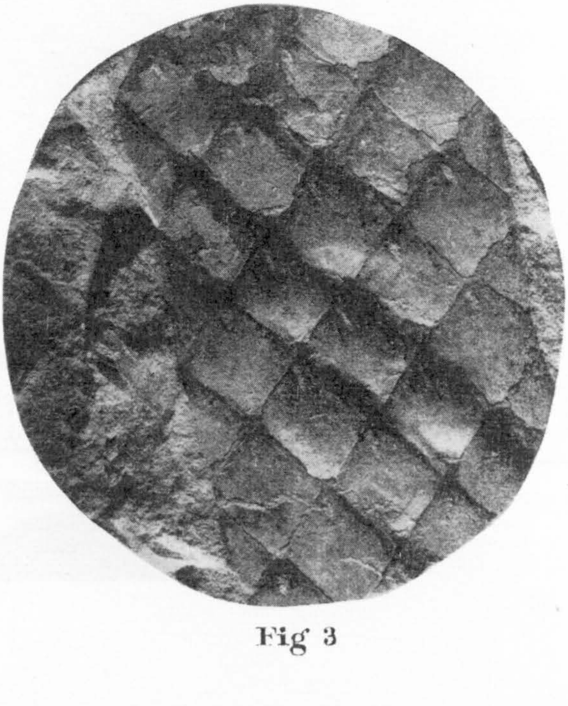


Fig 3

LEPIDODENDROID STEMS

from core 85, (12,175 to 12,180 feet)

GRANT RANGE No.1 BORE

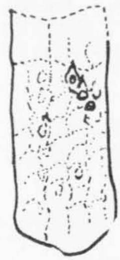


Fig.1. Faint reticulation showing vertical lines of depressions and spiral horizontal arrangement. Form of 3 leaf bases clear in one region.

X 2

Fig 2 Arrangement of leaf scars pits and small ridges on irregularly decorticated stem.

X 2

Fig 1

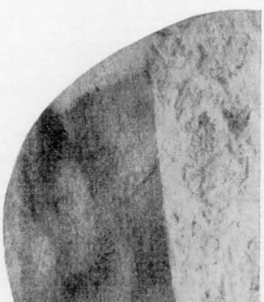


Fig 2

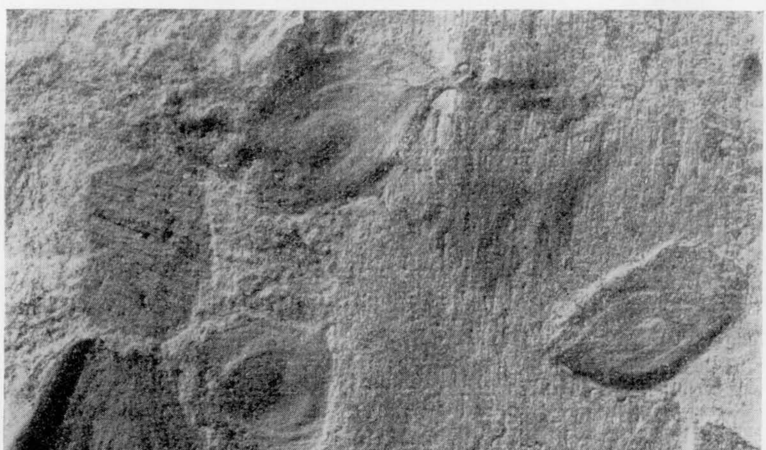


Fig 3 (x 4)

INDEX

(for Index of Bores see below, p. 323)

INDEX OF DEEP BORES IN THE CANNING BASIN