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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Stratigraphy of the Georgina Basin

BY

K. G. SMITH

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DIRECTOR: N. H. FISHER

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SUMMARY

The Georgina Basin is a large Palaeozoic sedimentary basin extending from northwestern Queensland into the Northern Territory. Field parties from the Bureau of Mineral Resources mapped some of the Queensland part of the basin in the early 1950s, and the remainder in the period 1957-65; officers of the Geological Survey of Queensland participated in most of the Queensland surveys. Since 1957, petroleum exploration companies have made geological, gravity, aeromagnetic, and seismic surveys in selected areas, and the Bureau of Mineral Resources has carried out aeromagnetic and reconnaissance gravity surveys over most of the basin, and seismic surveys in Queensland and in small areas in the Northern Territory. Sixteen petroleum exploration wells have been drilled, but no commercial deposits of oil or gas were found; three deep stratigraphic holes were drilled by the Bureau, which also drilled an aggregate of about 3000 m in shallow scout holes.

The Georgina Basin covers an area of about 325,000 sq km and extends in a belt trending northwest from latitude 25°S in northwestern Queensland to about latitude 18°S in the Northern Territory. The basin is about 1000 km long and about 500 km wide. The southwestern, western, northern, and eastern margins are defined by Precambrian outcrops, but the northwestern and southwestern margins are concealed by Mesozoic sediments. The position of the northwestern margin has not been resolved, but the southeastern margin has been defined approximately by gravity, seismic, and aeromagnetic surveys and by limited stratigraphic drilling.

The basin contains Cambrian and Ordovician marine sediments, and Devonian or Siluro-Devonian freshwater sequences. Middle Cambrian sediments are widespread, but Upper Cambrian, Ordovician, and Devonian rocks are restricted to the southern part of the basin. There are no known Palaeozoic intrusive rocks, and there is no evidence of metamorphism.

Early Middle Cambrian sedimentary rocks are regarded as the basal units of the Georgina Basin succession, but in many places around the margins and within the basin they are underlain, unconformably or disconformably, by several thousand metres of unmetamorphosed sedimentary rocks of late Precambrian or Lower Cambrian age. Since thse older rocks are either non-magnetic or have low magnetic susceptibility, the sedimentary section above magnetic basement includes them in some areas. Economic basement lies above magnetic basement because the petroleum prospects of the pre-Middle Cambrian sediments are not highly regarded.

Most of the northern half of the basin is covered by a thin blanket of marine Middle Cambrian sediments consisting of shale, limestone, dolomite, and minor sandstone. Some of the sediments are richly fossiliferous and may be potential source rocks for petroleum; many of the carbonate rocks are vuggy and cavernous and yield large quantities of water. The thickness seldom exceeds 350 m, but ranges up to 550 m. The Middle Cambrian sequence has been strongly faulted along the northern margin of the basin, but elsewhere there is no evidence of structural deformation. The Lake Nash Anticline in the northern part of the basin is attributed to deposition over a Precambrian ridge. Most of the sediments in the Northern Territory part of the basin are of early Middle Cambrian age, and a complete sequence of Middle Cambrian rocks is known only in the Camooweal-Undilla area of Queensland.

In the southern half of the basin, the thickest exposures of the Cambrian and Ordovician marine sequences are in the Huckitta, Tobermory-Glenormiston, and Boulia areas, where measured sequences range from 1200 to 1800 m.

In the Huckitta and Tobermory-Glenormiston areas the sediments were deformed in Carboniferous(?) time during the Alice Springs Orogeny, but in the Boulia area, which was not affected by this orogeny, the main tectonic events occurred in Lower Ordovician time, with a mild recurrence of faulting near the end of the Lower Cretaceous.

INTRODUCTION

The Georgina Basin is a large Palaeozoic sedimentary basin trending northwest from western Queensland into the Northern Territory. The basal beds are of lower Middle Cambrian age (see p. 26), and the basin contains Cambrian and Ordovician marine sediments and Devonian or Siluro-Devonian freshwater sequences. Precambrian rocks crop out along the southwestern, western, northern, and eastern margins of the basin (Fig. 20), but the northwestern margin is obscured by Mesozoic sediments which conceal a probable connexion with the Daly River Basin; the southeastern margin is concealed by Mesozoic sediments of the Great Artesian Basin, but the extent of the Palaeozoic sediments has been outlined by geophysical surveys and some drilling. In the west, the probable connexion with the Palaeozoic Wiso Basin is concealed by Quaternary sand.

The detailed stratigraphy and lithology of all the mapped formations in the Georgina Basin are described in the second part of this Bulletin, along with descriptions of the marginal and cover rocks. In the first part of the Bulletin the regional stratigraphy and structure within the preserved margins of the basin are outlined, together with notes on the geology of the southeastern extension of the basin.

Location

The outlines of the Georgina Basin, including its probable subsurface extension in the southeast, are shown in Figure 1. No accurate assessment has been made of the area occupied by Palaeozoic sediments in the southeastern extension of the basin.

There are no large towns within the Georgina Basin, but Camooweal (population 251)* and Urandangi (population about 30) are small local centres. The main commercial centres surrounding and serving the area are Mount Isa (population 13,338), Cloncurry (2438), Boulia (300), and Dajarra (184) in Queensland, and Alice Springs (4638) and Tennant Creek (837) in the Northern Territory.

Development

Some of the Georgina Basin is uninhabited desert, but most of the land is divided into large cattle and sheep stations of which some exceed 2500 sq km in area. Most run beef cattle on open ranges, but sheep are raised on a few of the stations in the Northern Territory and on several in Queensland. A few roadhouses cater for tourists, who pass along the major highways in large numbers in the winter months.

Access and Communications

Road and air transport links traffic to railheads beyond the boundaries of the basin. The railway line from South Australia terminates at Alice Springs; and another line links Larrimah (about 150 km north of the northwestern margin of the basin) with Darwin. Mount Isa and Dajarra are railheads for freight and passengers to eastern Queensland.

The main roads serving the area are the sealed Stuart Highway connecting Alice Springs with Darwin, 1540 km to the north, the sealed Barkly Highway which links Tennant Creek with Mount Isa, a distance of 675 km, and an unsealed road (now being sealed) linking Boulia with Winton, 350 km to the east. These roads and the main secondary roads in the area are shown in Figure 1; all the

* Population figures are taken from 1961 Commonwealth Census, except for Urandangi, whose population of less than 50 is not published.

Figure 1. Location and access

INTRODUCTION

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* Population figures are taken from 1961 Commonwealth Census, except for Urandangi, whose population of less than 50 is not published.

TABLE 1: MEAN MONTHLY MAXIMUM AND MINIMUM TEMPERATURES

Locality	(°F)	*Jan.*	*Feb.*	*March*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Average Per Year*
Alice Springs	max.	95.3	94.7	90.1	81.3	73.3	67.1	66.9	72.5	80.1	87.6	91.7	94.7	82.9
	min.	69.8	68.3	62.8	53.8	46.0	41.2	38.9	43.2	49.2	58.5	64.0	68.2	55.3
Tennant Creek	max.	98.5	96.8	94.5	88.8	81.7	76.0	75.4	81.3	88.6	95.1	98.3	99.8	89.6
	min	75.9	74.5	72.1	66.1	59.0	53.3	51.1	54.2	60.7	67.9	72.7	75.5	65.2
Camooweal	max.	97.9	96.2	94.6	90.8	83.8	78.6	78.2	83.0	89.6	96.0	98.8	99.3	90.6
	min.	75.2	74.0	70.3	63.5	55.5	49.8	47.5	51.2	58.6	66.5	71.7	74.8	63.2
Urandangi	max.	100.9	99.5	96.3	90.5	82.1	76.1	75.4	80.9	88.2	95.2	99.8	101.5	90.5
	min.	74.7	73.8	68.4	58.5	52.7	47.8	45.2	47.7	54.8	63.4	69.0	73.7	60.8
Boulia	max.	101.8	99.1	96.2	88.1	80.9	73.8	72.8	78.4	86.2	93.2	97.8	100.8	89.1
	min.	76.0	74.8	71.0	61.9	53.5	48.1	45.8	46.8	55.6	63.2	69.7	73.7	61.7

TABLE 2: MEAN MONTHLY RAINFALL

Locality	*No. of Years*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Average Per Year (in.)*
Alice Springs	30	1.74	1.32	1.09	0.39	0.60	0.52	0.29	0.31	0.28	0.71	1.15	1.53	9.93
Tennant Creek	30	4.04	3.54	2.08	0.35	0.21	0.35	0.25	0.06	0.11	0.40	1.07	1.39	13.85
Newcastle Waters	13	5.14	3.33	1.88	0.83	0.74	0.01	0.15	0.02	0.09	1.37	1.15	3.13	17.84
Wonarah	13	3.06	2.21	0.81	0.44	1.08	0.29	0.20	0.03	0.11	0.59	0.67	2.12	11.62
Brunette Downs	11	4.13	3.53	1.04	0.52	0.98	0.05	0.03	0.02	0.02	0.59	0.57	2.52	14.00
Anthony Lagoon	13	6.40	4.09	1.55	0.41	1.23	0.03	0.09	0.01	0.14	0.47	1.49	3.61	19.42
Camooweal	13	3.80	3.72	2.46	0.76	0.96	0.19	0.15	0.02	0.10	0.62	1.05	2.42	16.24
Lake Nash	13	2.50	2.89	1.79	0.35	1.10	0.46	0.51	0.06	0.13	0.50	0.43	1.21	11.96
Urandangi	30	2.05	2.26	0.96	0.29	0.50	0.51	0.43	0.12	0.25	0.47	0.83	0.97	9.64
Boulia	56	1.69	1.98	1.53	0.99	0.42	0.53	0.32	0.26	0.29	0.53	0.90	1.30	10.34
Chatsworth	28	2.49	2.85	1.63	0.52	0.60	0.69	0.42	0.08	0.26	0.57	0.85	1.52	12.48
Glenormiston	44	1.10	1.70	0.97	0.20	0.31	0.41	0.28	0.12	0.21	0.47	0.45	1.17	7.44

Earth tanks and dams lose up to half of their water by evaporation during the summer. The pastoral industry therefore depends on supplies of groundwater, and most of the stations operate numerous bores for stock and domestic purposes. For the watering of cattle, the minimum requirement is one bore to 250 sq km, but on many properties there are more.

Vegetation

The wide range of rainfall, type of soil, and local drainage patterns produce many variations in vegetation, but in general the northern fringe of the basin, where rainfall exceeds 15 inches (380 mm), is characterized by *Eucalyptus* spp., and the remainder by *Acacia* spp. (Perry, 1960). In the south, eucalypts are found mainly along the banks of major streams.

In the *Acacia* zone, the most abundant tree is mulga (*Acacia aneura*), but gidyea, ironwood, witchetty bush (all *Acacia* spp.), supplejack (*Ventilago viminalis*), and whitewood (*Atalaya hemiglanca*) are fairly common; all are drought-resisting species which seldom grow more than 6 m high. The main drought-resisting shrubs in the southern part of the basin are saltbush (*Atriplex* spp.) and southern bluebush (*Kochia* spp.), which have nutritive value for stock. Most of the southern part of the basin is covered by various species of sclerophyllous grasses, which form large hummocks and are collectively known as spinifex; they grow on sand plains, dune fields, and on most of the stony hills.

Several perennial drought-evading species of grasses flourish on the treeless plains of the Barkly Tableland and extend southeast down the plains of the Georgina River (Perry & Christian, 1948); the best known species is Mitchell grass (*Astreleba* spp.), which grows in tussocks, but Flinders grass (*Iseilema* spp.) is also common. Both provide nutritive food for cattle, and are commonly the only grasses available.

HISTORY OF GEOLOGICAL INVESTIGATIONS

Only recently has the Palaeozoic geology of the Georgina Basin been systematically studied; but earlier observations by explorers, surveyors, and geologists provide a good deal of information.

The early explorers—Gregory (1861), Burke & Wills (Jackson, 1862), Landsborough (1862), and McKinlay (1863), who travelled mainly in Queensland, and Stuart (1861) and Winnecke (1884) in the Northern Territory—contributed little to the geology of the area, but contributed the first knowledge of topography and surface drainage.

Only in the nineteen fifties, with the increased tempo of mapping and palaeontological investigations, did it become possible to bring together the work in Queensland and Northern Territory into a meaningful whole; early work is best considered separately.

Queensland

Gold was discovered in the Cloncurry area in 1867, and its discovery marked the start of geological investigations of the basin. Daintree (1872) was the first geologist to attempt a map of northwestern Queensland: he showed the whole area as Cretaceous, except for an inlier of Silurian metamorphic rock around the Cloncurry Gold Field—an error of dating that was not completely erased for 50 years.

Jack (1885, 1895, 1897, 1898), in the course of traverses to examine the possibility of a railway westward from Cloncurry, and in the search for artesian water, noted that the unfossiliferous limestone of the Barkly Tableland rested unconformably on the metamorphic rocks of the Cloncurry region, and (Jack & Etheridge, 1892), outlined the metamorphic belt. Jack correlated the rocks of the Cairns (Toko) Range, reported by Hodgkinson (1877), with those of the Cloncurry belt, because boring between the two had failed to find artesian water; and having identified *Orthoceratites* among fossils forwarded to him from the Cairns Range, he placed both in the 'Lower Silurian' (Ordovician in present usage). This apparently confirmed Daintree's determination.

Cameron (1900, 1901) accepted Jack's age for the Cloncurry rocks, but stated that they were overlain by sandstone and limestone of possible Devonian age; while Ball (1911) was misled by incorrect identification of fossils into regarding the limestones of the Lawn Hill area as Tertiary (one area is still known as the 'Dentalium Plateau'). Only in 1931 did Shepherd (*in* Ball, 1931) recognize them as Cambrian. Ball's work in the Lawn Hill Mineral Field, besides its economic significance, was of importance in the development of the Proterozoic stratigraphy and geomorphology also.

Long before this Woolnough (1912) had designated the rocks of the Barkly Tableland as Cambrian, and the metamorphic rocks to the east as Precambrian; but his views were not generally accepted. Dunstan (1913, 1920) delineated the 'Cloncurry Series' fairly accurately, but still regarded them as Silurian. He also regarded the limestones of northwest Queensland as Jurassic because they lay below marine Cretaceous. Incidentally, he recorded 6-foot seams of brown coal in water bores on Sandringham station, and coal in bores east of the Hamilton River.

Woolnough's postulates were partly substantiated when Saint-Smith (1924) reported Cambrian trilobites from the headwaters of the Templeton River: by inference, the metamorphic rocks to the east were Precambrian. Shepherd in 1927 subdivided the Precambrian rocks, but did not publish his work; it was used by David (1932) in his geological map of Australia.

Saint-Smith's report foreshadowed the first definitive study of the Cambrian succession in northwestern Queensland, by Whitehouse. In a brilliant series of papers (1930-1945), Whitehouse described the fossils that he and others had collected, and erected a temporal scheme of subdivision of the sequence, which he considered ranged from upper Lower Cambrian to Ordovician. His subdivision was accepted and used in summaries of the geology of Queensland by Andrews (1937), Bryan & Jones (1946), David (1950), and Hill (1951), and in maps of Australia (BMR, 1952) and Queensland (1953); and remains the basis for the meticulous palaeontological and stratigraphic work of Öpik (1956-1970). Öpik of course found it necessary to amend some of Whitehouse's subdivisions, but paid tribute to the inherent soundness of the work. Thanks to Öpik, to Druce & Jones (1970), and to Shergold (1969, 1971), sequences have been established from lowest Middle Cambrian (Ordian) to Middle Ordovician in Queensland—though an immense amount of research in stratigraphic palaeontology remains to be done—and indeed the Cambrian sequence serves as a model for the stratigraphy of the Cambrian throughout Australia.

Systematic field mapping at 1:250,000 or 1 inch to 4 mile scale of the Georgina Basin in Queensland began in 1957 and continued until 1961. It was carried out by joint parties of the Bureau of Mineral Resources and the Geological Survey of Queensland (see Fig. 2). All the maps have been issued, with appropriate explanatory notes; they form the basis of the Queensland portion of the geological map.

Concurrently with the geological mapping, the Bureau of Mineral Resources and petroleum exploration companies undertook geophysical surveys which delineated subsurface features (see below).

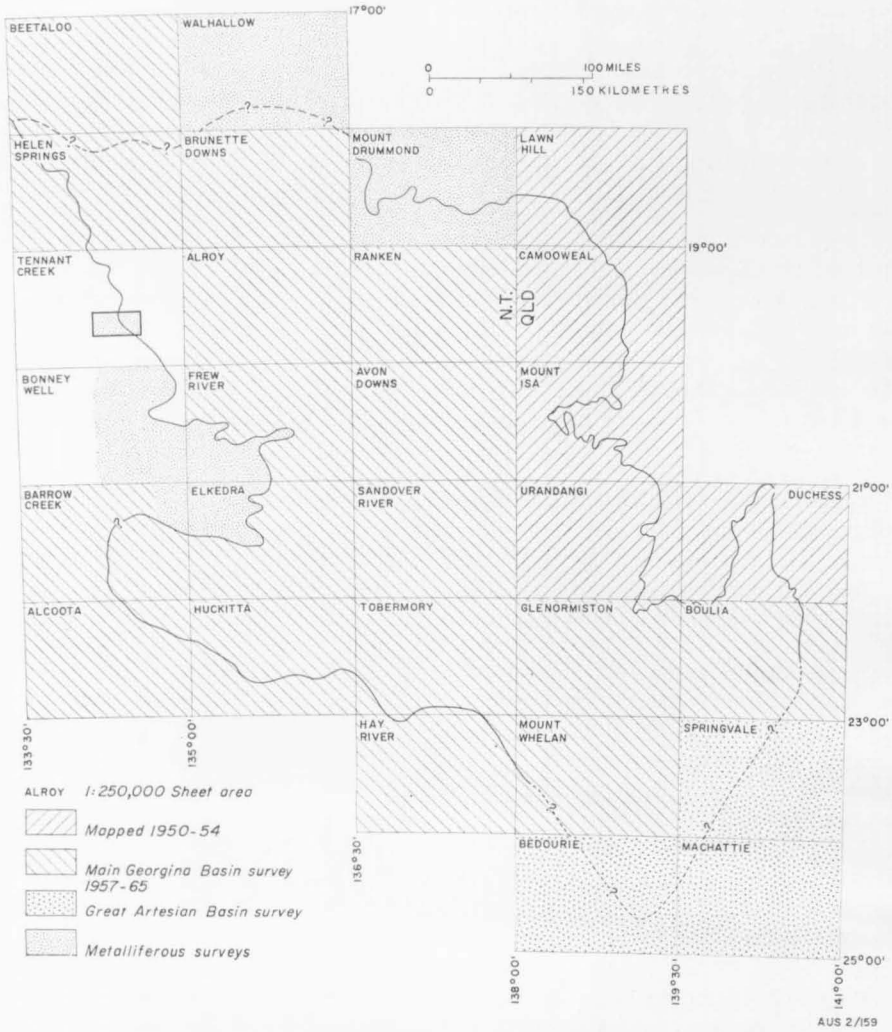


Figure 2. Areas mapped by the Bureau of Mineral Resources

Northern Territory

The Cambrian age of the sediments of the Georgina Basin was recognized earlier than in Queensland because the investigations were not linked, and the early workers in the Territory were therefore not misled by the interpretation of older rocks as Silurian. Also, definitive fossils were found earlier. Brown (1895, 1897, 1903) reconnoitred much of the basin and its western margins; he found Cambrian trilobites near Alexandria homestead which Etheridge (1897) described as *Olenellus brownii* (=*Xystridura browni* (Eth.)). Near Elkedra station in 1898 Davidson (1905) collected other fossils, described by Etheridge (1902) and redescribed by Whitehouse (1936) as *Pagetia significans* (Eth.) and *Peronopsis elkedraensis* (Eth.). The presence of Cambrian sediments in the basin was thus firmly established at an early stage.

On the margins of the basin, Chewings (1928) and Mawson & Madigan (1930) described the geology of the country between Alice Springs and Barrow Creek.

Tindale (1931), an anthropologist, measured and described two sequences in the southwest of the basin: in the Mopunga Range he named the measured sequence the Mopunga Beds, and in the Dulcie Range, at Mount Ultim, he found Ordovician fossils in the sequence he described. In fact it includes both Ordovician and Devonian sediments, but he found no fossils in the Devonian part of the section.

Madigan, whose main area of interest lay in the MacDonnell Ranges and what is now known as the Amadeus Basin, nevertheless showed considerable interest in the southwestern part of the Georgina Basin, and made some progress in relating sediments of the one to the other. He flew across the Simpson Desert at about the latitude of Lake Caroline (Hay River Sheet area), and published (Madigan, 1929) an account of his observations. Later he traversed from Alice Springs to the Elyuah and Mopunga Ranges, relating his observations to those in the western MacDonnell Ranges (Madigan, 1932). In 1937 he gave the first account of the geology of the Huckitta and Tobermory Sheet areas, and in 1939 he led an expedition across the Simpson Desert from west to east (Madigan, 1945).

Since the war, most of the investigations have been made by the Bureau of Mineral Resources. In 1949 Öpik (unpubl.) examined the Upper Proterozoic sequence in the Jervois Range; and in 1955 Joklik published an account of the Harts Range Mica Field which, though it was mainly concerned with the elucidation of the Precambrian stratigraphy and structure of the Harts Range, also includes the Plenty River field, and a reconnaissance through the Huckitta/Oorabbra Rockholes area. He named the Oorabbra Arkose—first discovered by Brown in 1897—which he thought to be the base of the Upper Proterozoic succession.

Elsewhere in the basin, Noakes & Traves (1954), in the course of a land research survey by CSIRO, covered a broad tract of land between Tennant Creek and Mount Isa, and described both Precambrian and Palaeozoic rocks. To the latter they gave the name 'Barkly Group', a name now discarded because later and more detailed mapping did not show the continuity of succession required of a 'Group'.

The Georgina Basin was surveyed by the Bureau of Mineral Resources and the Geological Survey of Queensland between 1957 and 1965. The scope of the survey (Fig. 2), and the officers engaged on it, were:

Queensland

1957—J. N. Casey, M. A. Reynolds, D. B. Dow, P. W. Pritchard, R. R. Vine (all BMR), and R. J. Paten (Geol. Surv. of Queensland)
1958—J. N. Casey, M. A. Reynolds, P. W. Pritchard, K. G. Lucas (all BMR), and R. J. Paten (Geol. Surv. of Queensland)
1959—G. A. Brown
1960—M. A. Reynolds, F. Olgers, and W. Jauncey (all BMR)

Northern Territory

1957—K. G. Smith, J. W. Smith, D. R. G. Woolley, and J. M. Pulley
1958—K. G. Smith, K. Gough, D. R. G. Woolley, and R. R. Vine
1959—K. G. Smith, P. W. Pritchard, D. R. G. Woolley, R. R. Vine, D. J. Forman, and A. R. Jensen
1960—K. G. Smith, R. R. Vine, E. N. Milligan, and P. J. Jones
1961—K. G. Smith and E. N. Milligan; M. A. Randal and G. A. Brown
1962—*Core Drilling*: E. N. Milligan, A. R. Lloyd, G. A. Brown, J. M. Drummond, P. J. Jones, N. E. A. Johnson, and K. G. Smith
Field Mapping: M. A. Randal and R. A. H. Nichols
1963—K. G. Smith, E. N. Milligan, and R. A. H. Nichols
1963—*Stratigraphic Drilling*: R. A. H. Nichols, N. E. A. Johnson, and K. G. Smith
1964—*Stratigraphic Drilling*: A. R. Lloyd, R. D. Shaw, R. A. H. Nichols, and M. A. Randal
1965—M. A. Randal, M. C. Brown, and H. F. Doutch

In the early stages of the survey, air-photographs provided the only accurate record of topography, but the Commonwealth Division of National Mapping subsequently prepared topographic base maps at air-photo scale and at 1:250,000 scale. From about 1960 onwards, levels obtained for, and from, helicopter-borne gravity surveys were of considerable assistance to the geological field parties.

All the 1:250,000 geological sheets included in the Georgina Basin have now been issued, with concomitant explanatory notes.

Petroleum Exploration and Geophysical Surveys

In 1956 a small show of gas was discovered in a water bore near Ammaroo homestead in the Northern Territory (Mackay & Jones, 1956, unpubl.), which stimulated the search for petroleum in the surrounding area. Since then, the whole of the basin and much of its margins have been held under prospecting titles at one time or another, but so far no commercial deposits of either oil or gas have been found. Many areas have been relinquished, and the areas held under permit at the end of 1969 are shown in Figure 3.

Much of the exploratory activities has been carried out under subsidy from the Commonwealth Government, and the results are therefore, under the terms of the Petroleum Search Subsidy Acts, in the public domain, and are listed among the references (p. 138). Sixteen wells have been drilled, thirteen of which were subsidized (Fig. 3).

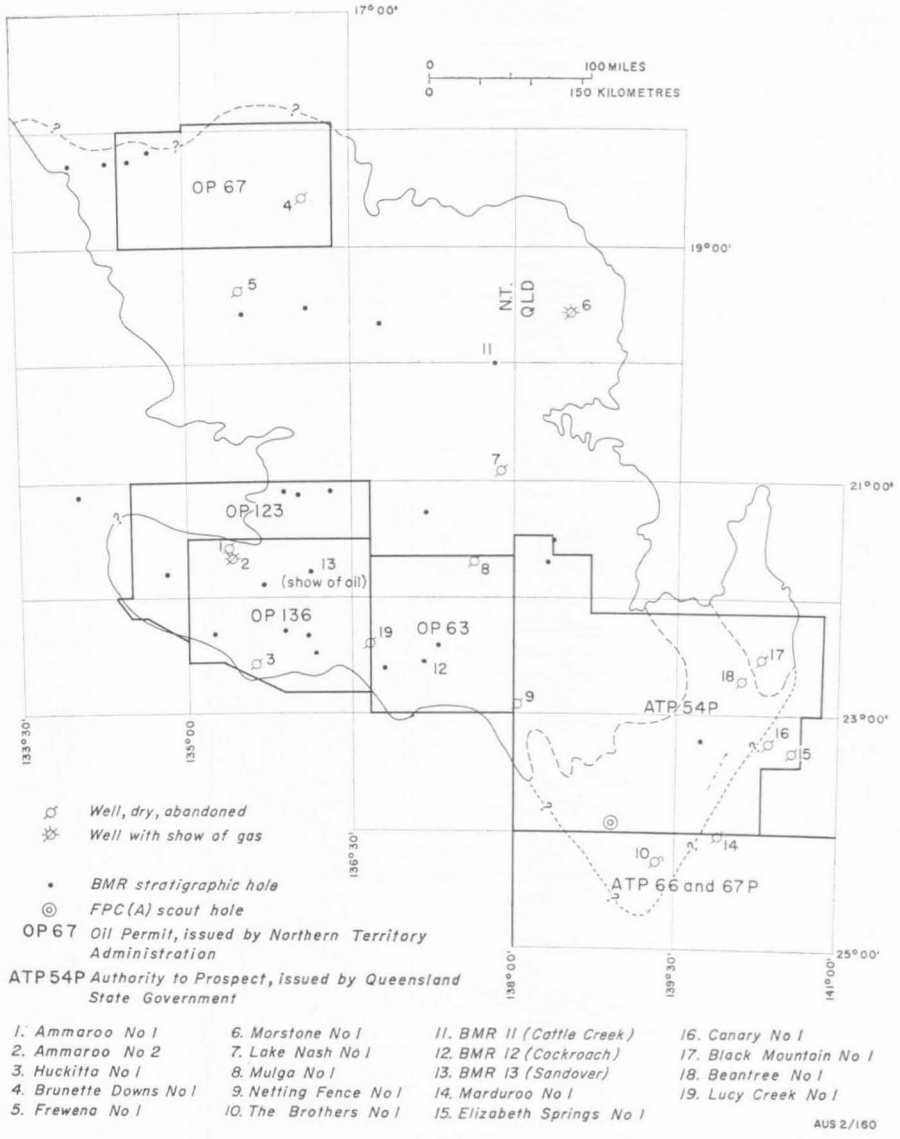


Figure 3. Petroleum tenements, and location of petroleum exploration wells and BMR stratigraphic holes

The only geophysical investigation before 1957 was a gravity traverse by Marshall & Narain (1954); but since that time many surveys have been completed, by both the Bureau of Mineral Resources and exploration companies.

Gravity surveys are shown on Figure 4. Ground traverses by the Bureau (Neumann, 1959a,b, both unpubl.; Barlow, 1965, unpubl.) were followed by reconnaissance surveys using helicopters, which by the end of 1965 had covered the whole basin on a 7-mile grid, with additional stations where necessary. Inter-

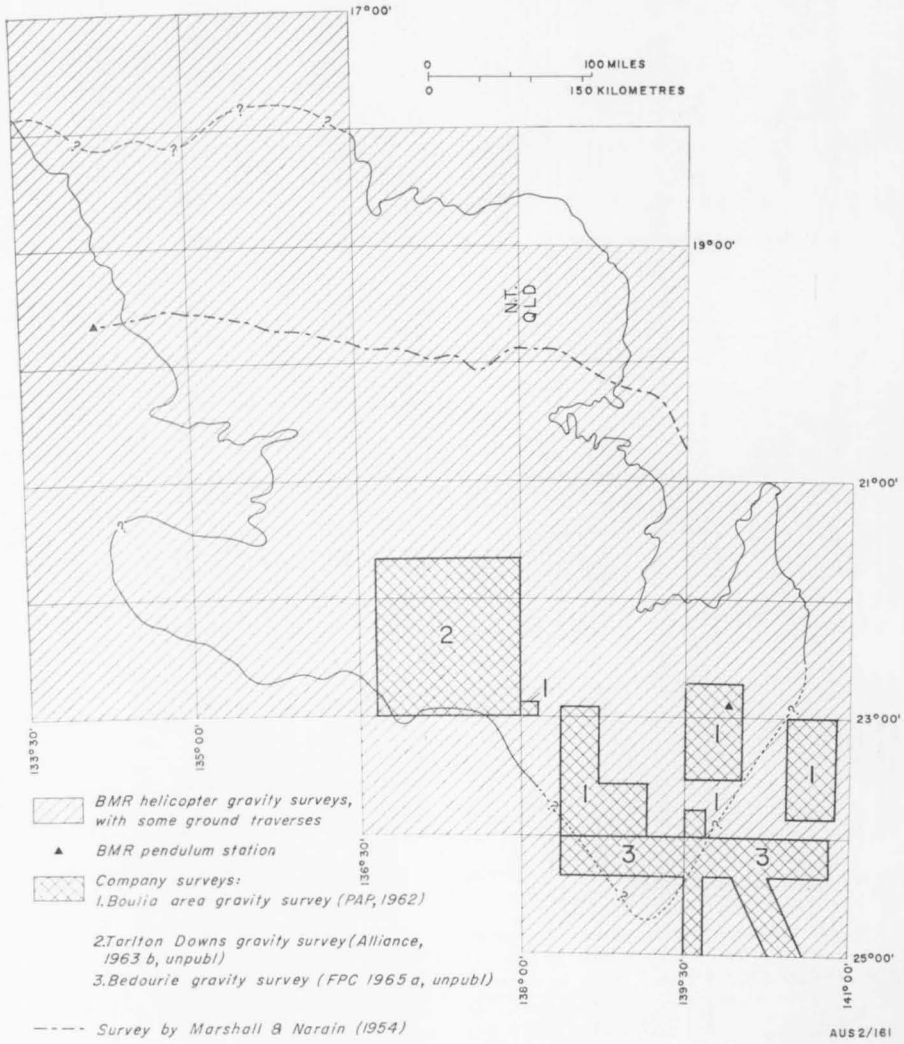


Figure 4. Gravity surveys

pretation of results is still not complete, but Barlow (1965, 1966, both unpubl.), Flavelle (1965, unpubl.), and Gibb (1966, unpubl.) have reported some results.

Pendulum stations have been established at Tennant Creek and Boulia.

Aeromagnetic surveys (Fig. 5) have been flown by the Bureau of Mineral Resources over the whole basin, with traverses at 2-mile intervals (Wells, Milsom, & Tipper, 1966, unpubl.), and depth-to-basement contour (Fig. 6) and total magnetic intensity maps produced. The few wells drilled show that a thick sequence of non-magnetic unprospective Adelaidean and perhaps older rocks overlie magnetic basement.

The company surveys shown on Figure 5 were all subsidized and have contributed considerably to knowledge of depths to magnetic basement (Barkley, 1965b; PAP, 1964; FPC, 1964; all unpubl.).

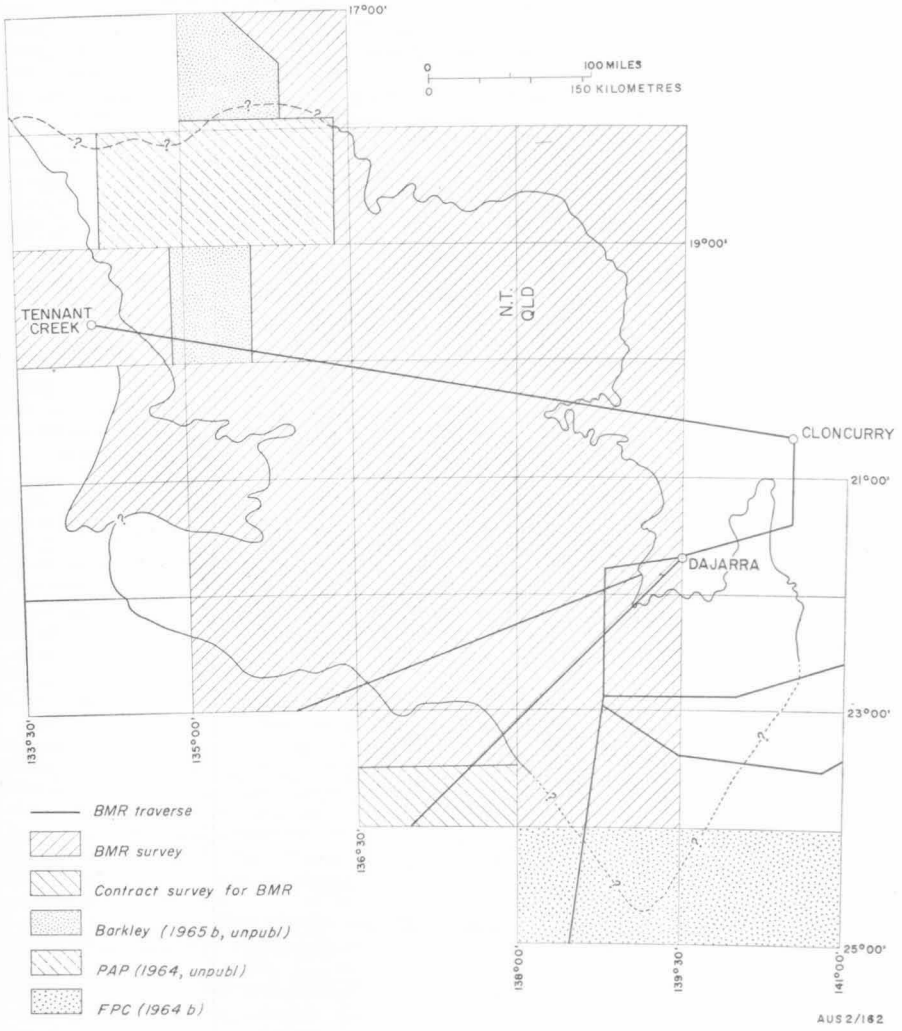


Figure 5. Aeromagnetic surveys

Seismic surveys are shown on Figure 7. In general, poor results have been obtained from reflection traverses in areas underlain by thick sequences of cavernous and fractured Palaeozoic carbonate rocks. The BMR conducted experimental surveys in areas of carbonate rocks near Camooweal (Robertson, 1963, unpubl.) and in the Tobermory/Lake Nash areas (Montecchi & Robertson, 1966, unpubl.), but in both cases the results were poor. All the seismic surveys except those in the Tobermory/Lake Nash area have been done in Queensland in connexion with

Figure 6. Magnetic basement contours. (After Wells et al., 1966, unpubl.)

other surveys probing beneath the Great Artesian Basin in western Queensland and South Australia.

In Queensland, little work has been done in the outcropping part of the Georgina Basin, but the subsidized Springvale-Toko seismic survey (Phillips, 1961, unpubl.) included traverses in the Glenormiston area, where about 75 m of closure was determined over the Netting Fence Anticline (a surface feature) and

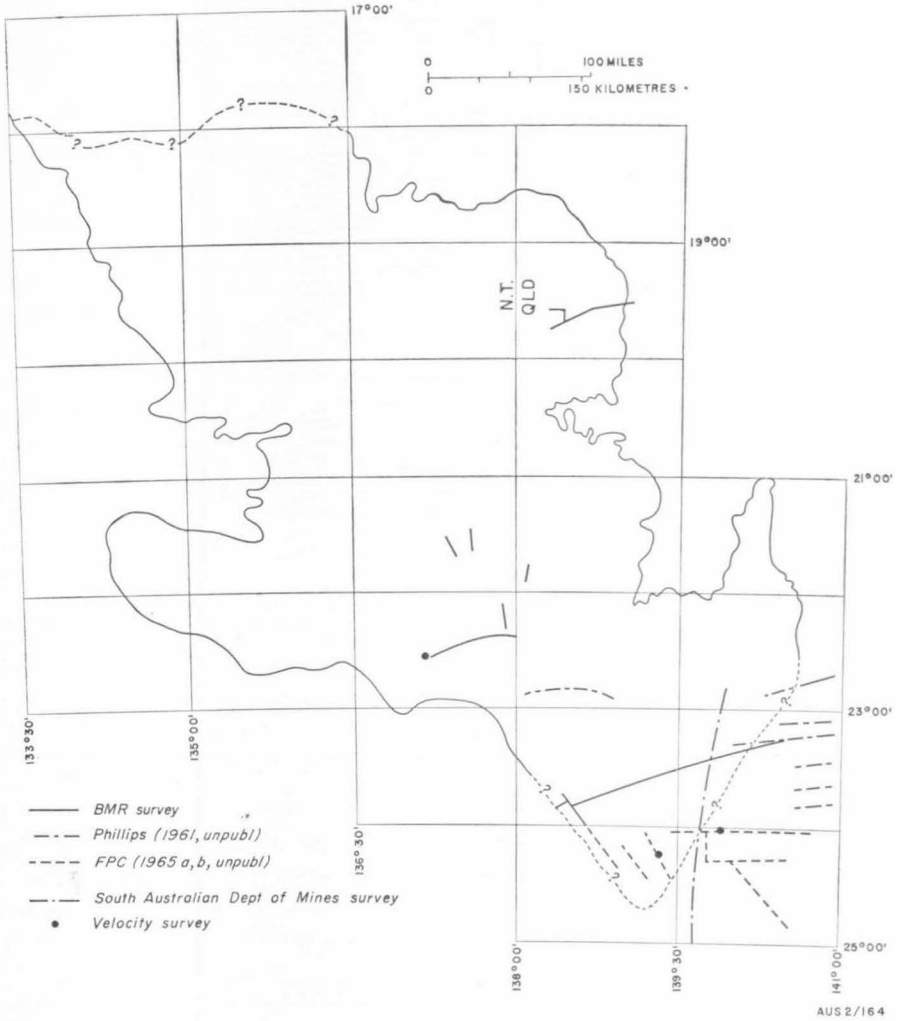


Figure 7. Seismic surveys

a sedimentary thickness of about 2000 m was indicated. Traverses between the Netting Fence Anticline and Glenormiston homestead and from Marion Downs homestead to Watchie Hut yielded no data, but several good reflecting horizons were obtained in the Canary area, where subsequent drilling showed that Palaeozoic carbonate rocks are absent beneath the Mesozoic cover.

Milton & Seedsman (1961, unpubl.) reported the results of a refraction and reflection survey between Marree (South Australia), Birdsville, and Boulia; the deepest persistent reflection obtained is believed to originate at the base of the Mesozoic, but it was too shallow to be recorded north of Breadalbane homestead.

The Bureau of Mineral Resources conducted reconnaissance reflection surveys in the southeastern extension of the Georgina Basin in 1963, 1964, and 1965. The surveys were designed to investigate the probable extension of the Toko Syncline southeastwards from outcrop, and to determine the presence or absence of Palaeozoic sediments between the Adelaidean outcrops at Sylvester Creek and the Canary No. 1 well, which penetrated Adelaidean(?) sediments beneath the Mesozoic cover rocks at 153 m. The latter objective was not attained satisfactorily because of poor-quality data, but the surveys proved that the Toko Syncline extends southeast from outcrop, and that the sedimentary section increases in thickness to the southeast. A strong reflector was mapped at a depth of about 2750 m near the western edge of the Toko Syncline (Pulchera Waterhole area) and was followed eastwards to a point where it was about 100 m below the surface; here a core cut in the reflecting horizon (a limestone) at a depth of 97 m proved it belonged to the Cambro-Ordovician Ninmaroo Formation. On the western edge of the syncline reflectors were recorded to about 4900 m, which is interpreted as the base of the Adelaidean sequence. The depth of 2750 m, when compared with known thicknesses of Mesozoic and Ordovician, indicated a considerable thickness of sediments younger than Ninmaroo Formation and older than Mesozoic in the subsurface extension of the Toko Syncline. The results of the BMR seismic surveys in this area have been reported by Robertson (1965, unpubl.), Jones (1965, unpubl.), Montecchi & Robertson (1966, unpubl.), and Jones & Robertson (1967, unpubl.).

The French Petroleum Co. (Aust.) Pty Ltd has carried out three subsidized seismic surveys which have added to our knowledge of the southeastern extension of the Toko Syncline. The Annandale seismic survey in 1963 was mainly to the west and southwest of the southwestern limb of the syncline, but some traverses were made in the Lake Wickamunna area, where indications of the Toko Syncline were found. The Bedourie survey (FPC, 1965a, unpubl.) covered a large area in the Bedourie area and joined with the 1963 BMR survey near Pulchera Waterhole; the FPC survey delineated the southern part of the Toko Syncline and its eastern edge; it also provided some information on the extension of the Georgina Basin east of the syncline.

The Sandringham survey (FPC, 1965b, unpubl.) was designed to investigate the eastern edge of the Toko Syncline more thoroughly. It covered much of the same area as the Bedourie seismic survey, but with different techniques which resulted in improved record quality.

OUTLINE OF THE GEOLOGY

Nomenclature

Except where indicated in the text, all rock-unit names in this Bulletin are in accordance with the Australian Code of Stratigraphic Nomenclature. The exceptions are mostly the Cambrian units around the margins of the basin, and some units named by well-site geologists.

The Proterozoic Era is subdivided according to current Bureau practice (Dunn, Plumb, & Roberts, 1966) into:

TABLE 3: SUMMARY OF PREVIOUS USAGE OF TERMS FOR THE AREA NOW REFERRED TO AS THE GEORGINA BASIN

Author	*Usage*	*Interpretation*	*Remarks*
Jack (1895)	Used 'Georgina Basin' in title of paper on artesian water supplies.	Geographical	First use of 'Georgina Basin'
Whitehouse (1931)	On p. 118 refers to collection of Cambrian trilobites from 'grey limestones in and around the basin of the Georgina River'.	Drainage basin	
David (1932)	Used 'Camooweal Basin' to denote E. end of important belt of limestone extending from beyond W. Australian border to Boulia, via Wave Hill, Katherine, Daly Waters, Newcastle Waters, Anthony Lagoon, Alexandria Downs, and Camooweal. On David's map, p. 116, Camooweal Basin occupies approximate area of Barkly Tablelands, and on p. 118 he gives age of sediments in basin as Cambrian to Proterozoic.	Sedimentary basin	
Whitehouse (1936)	On p. 64 discusses limestones in basin of Georgina R., and includes map showing 'geology of the Georgina Basin'.	Drainage basin	
Whitehouse (1940)	On p. 23 refers to Tertiary limestones 'in southern portion of the Georgina River Basin'.	Drainage basin	
David (1950)	On p. 115 refers to 'Georgina Region' with area of 60,000 sq. miles, partly in Queensland and partly in Northern Territory, and mainly in basin of Georgina R. Boundaries of region are given in sketch map (*after* Whitehouse, 1936) entitled 'Geology of the Georgina Basin'; basin as shown extends from Elkedra to Brunette Downs, Riversleigh and S. to Boulia. On p. 694 states 'in the Georgina basin the Cambrian beds...' and also that 'the Cambrian strata of the Georgina Region were deposited...'.	Drainage basin and sedimentary basin	
Reeves (1951)	On p. 2485 classified Georgina Basin as one with no oil prospects, and covering 60,000 sq. miles. Accompanying map shows position of basin as approximately that of Barkly Tableland.	Sedimentary basin	

TABLE 3.—*continued*

Author	*Usage*	*Interpretation*	*Remarks*
Noakes (1952)	Used 'Georgina Valley' and 'Barkly Internal Drainage Basin' (subsequently referred to as 'Barkly Basin') as two physiographic units of Barkly Tableland.	Drainage area	
Hossfeld (1954)	Named Barkly Basin and showed it (fig. 6, p. 132) on E. side of Ashburton-Davenport Ra.; considered as area of U. Proterozoic and Cambrian deposition.	Sedimentary basin	
Noakes & Traves (1954)	On p. 39, state 'The Georgina Basin' had already been established as internal drainage basin; topography of Georgina Valley much as now.	Drainage basin	
Stewart (1954)	On p. 43, uses 'Georgina Basin Division' as geomorphological unit of Barkly Region.	Drainage basin	
Traves & Stewart (1954)	On p. 60, use 'Georgina Basin' and 'Barkly Basin' as drainage units.		
Raggatt (1954)	Figured Georgina Basin as area similar to Barkly Tableland.	Sedimentary basin	
Condon (1956)	Figured Georgina Basin as area similar to that of Barkly Tableland.	Sedimentary basin	Basin not defined in text.
BMR (1958)	In referring to Georgina Basin (p. 60) stated 'little is known of the detailed stratigraphy and structure of this basin except where it overlaps the Precambrian of the Mount Isa-Cloncurry area . . . The Ammaroo Bore is at the western margin of this basin'. On p. 60, mentions Barkly Basin; 'apparently shallow, contains Proterozoic and Cambrian sediments, probably marine. Little is known of the details of stratigraphy and structure'.	Sedimentary basin	Basin not defined in text. Barkly Basin figured as including present Daly R. Basin, although latter not named.

TABLE 3.—*continued*

Author	*Usage*	*Interpretation*	*Remarks*
Öpik (1956)	On p. 3, mentions that Georgina Series (Whitehouse, 1931) included Camooweal Dolomite (U. Proterozoic or L. Cambrian) 'as well as rocks of the Undilla Basin which do not belong to the Georgina Basin at all'. Georgina Series described as 'in and around the basin of the Georgina River'. On p. 242 states that Barkly Tableland 'is sometimes referred to as the Barkly Basin but no basin structure is evident for the Cambrian rocks form a blanket and the Camooweal Dolomite is an extended Sheet'.	Drainage basin; sedimentary basin for Undilla Basin	
BMR (1960)	Figured Georgina Basin much as known today, but showed only indications of S.E. extension; included Ordovician rocks of Tarlton and Toko Range areas, and Cambrian of Ammaroo area.	Sedimentary basin	Barkly Basin also shown but much reduced from Condon et al.'s (1958) area. Daly R. Basin shown.
Casey & others (1960, unpubl.)	Defined Georgina Basin in terms broadly acceptable today, but excluded Undilla Basin and Camooweal Dolomite and, by inference, Barkly Tableland area.	Sedimentary basin	Did not show map of Georgina Basin.
GSA (1962)	On Tectonic Map of Australia, showed correct outlines of Georgina Basin with regard to S.W. and S.E. margins; Undilla and Oban Basins shown, but no basin in Barkly Tableland area.	Sedimentary basin	
Smith (1965)	Defined Georgina Basin as now known, but extended N.W. margin slightly N. of present accepted position.	Sedimentary basin	First published definition, but not accompanied by map. This definition followed by Reynolds (1965, unpubl.).

Adelaidean, from the base of the Cambrian to about 1420 m.y.;
Carpentarian, from 1420 to 1800 m.y.; and
Lower Proterozoic, the interval between the top of the Archaean and the base of the Carpentarian (1800 to 2400-2600 m.y.).

The more general terms Proterozoic and Precambrian are used where the age of a sequence is in doubt.

Definition of the Georgina Basin

Table 3 is a synopsis of previous usages of the name Georgina Basin, which has been used in a topographical and geographical as well as sedimentary sense. The Barkly, Oban, Undilla, and Ammaroo Basins are now regarded as part of the Georgina Basin and the names have been discontinued.

The Georgina Basin is defined as a sedimentary basin containing lower and middle Palaeozoic sediments, which extend in a belt trending northwest from western Queensland into the Northern Territory; it is bounded on the east, west, southwest, and north by Precambrian rocks; the northwestern and southwestern margins are covered by Mesozoic sediments. Early Middle Cambrian sediments are regarded as the base of the Georgina Basin succession, but in some marginal areas over a thousand metres of unmetamorphosed Adelaidean or Lower Cambrian sediments underlie the Middle Cambrian sequence.

The outcrop area of the basin is about 285,000 sq km. In the southeast an additional area of about 40,000 sq km is concealed; its margins have been defined approximately by geophysical surveys and test drilling, but the Palaeozoic stratigraphy is little known and the available evidence indicates that Palaeozoic sediments are preserved in grabens separated by horsts of older rocks.

The northwestern margin of the basin has not been delineated geophysically; at present the boundary is placed roughly where the Middle Cambrian sediments are overlain by a continuous sheet of Mesozoic sediments. Cambrian units in the basin are probably connected in the subsurface with those in the Daly River Basin, which are covered by Mesozoic rocks at about latitude 16°S; if the two basins are separated by a basement ridge, it may have a northerly trend in accordance with the strike of the Precambrian rocks in the Katherine-Darwin region.

The western boundary of the basin has not been determined in the Barrow Creek area, where the Cambrian sediments of the basin may be continuous in the subsurface with those of the Wiso Basin (Fig. 1); however, this has not been proved, and there is no real evidence to support the possibility.

Stratigraphy

The Georgina Basin contains Cambrian and Ordovician marine sediments and Devonian and Siluro(?)-Devonian freshwater sequences. The Cambrian and Lower Ordovician sediments consist predominantly of carbonate rocks, the Middle Ordovician sequence mainly of sandstone and siltstone, and the Devonian and Siluro(?)-Devonian formations of sandstone. The only volcanic rocks known are Middle Cambrian basalts near the northern margin in the Mount Drummond Sheet area (Sheet 2).

The sequence has not been metamorphosed or intruded by igneous rocks, and large areas have not been disturbed tectonically. Although there are well documented breaks in sedimentation, many of them were caused by uplift and erosion without deformation. The most severe deformation occurred in the south during the post-Devonian Alice Springs Orogeny (named by Forman, Milligan, & Mc-

Carthy, 1967); faulting predominated and most of the deformation is south of latitude 22°S, but some faults extended northward to about latitude 21°30′S. In the east, an earlier (Lower Ordovician) tectonism affected Cambrian and Lower Ordovician rocks in the Duchess-Boulia area, but in the north the deformation is confined to the northern margin, where the Middle Cambrian sediments have been disturbed along faults trending west. The age of the faulting is unknown.

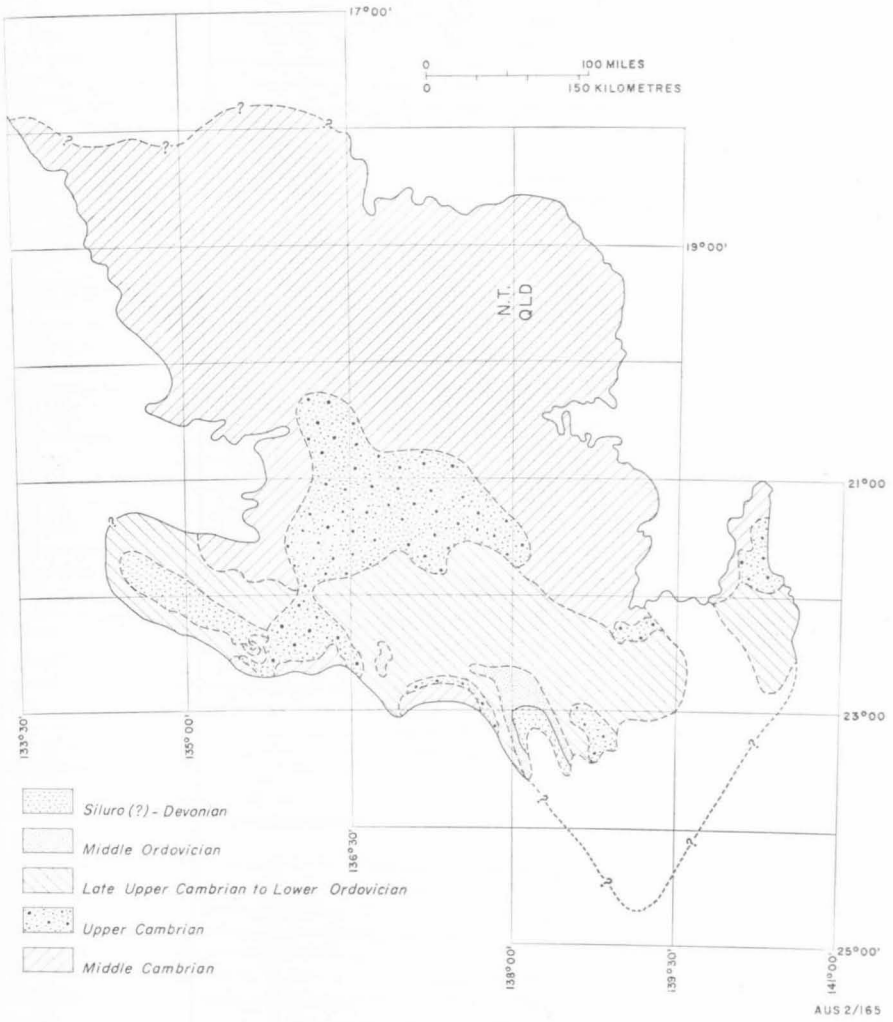
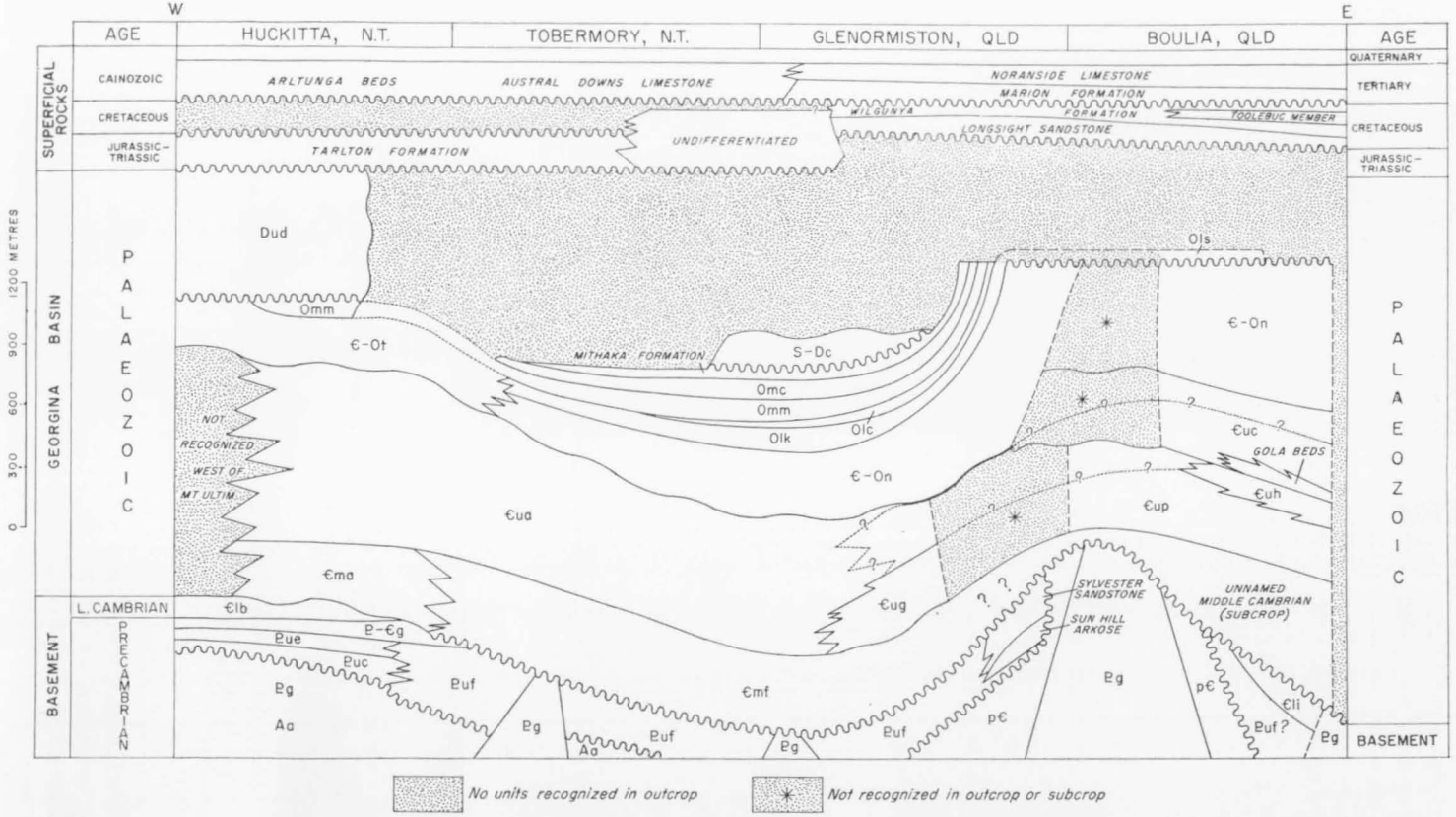


Figure 8. Solid geology

The distribution of sequences is shown on Figure 8. Most of the northern part of the basin consists of a thin undisturbed blanket of Middle Cambrian carbonate rocks, with Upper Cambrian sediments in the Burke River Outlier (Öpik, 1961) and some doubtful Upper Cambrian carbonate rocks in the Avon Downs



Dud *Dulcie Sandstone*; S-Dc *Cravens Peak Beds*; Omm *Nora Formation*; Omc *Carlo Sandstone*; Olc *Coolibah Formation*; Olk *Kelly Creek Formation* Ols *Swift Formation*; €-On *Ninmaroo Formation*; €-Ot *Tomahawk Beds*; €ug *Georgina Limestone*; €uc *Chatsworth Limestone*; €uh *O'Hara Shale*; €up *Pomegranate Limestone*; €ua *Arrinthrunga Formation*; €mf *Marqua Beds*; €ma *Arthur Creek Beds*; €li *Mount Birnie Beds*; €lb *Mount Baldwin Formation*; P-€g *Grant Bluff Formation*; Pue *Elyuah Formation*; Puc *Mount Cornish Formation*; Puf *Field River Beds*; Pg *Proterozoic granite undifferentiated*; p€ *Undifferentiated*; Aa *Arunta Complex*

M(S)118

Figure 9. Distribution of rock units in southern part of basin

and Frew River Sheet areas. The Ordovician and Siluro(?)-Devonian sediments, and most of the Upper Cambrian sediments, are restricted to the southern part of the basin. The thickest sequences exposed at the surface are in the Huckitta, Tobermory-Glenormiston, and Boulia areas.

In the *Huckitta area* 1700 m of one sequence comprises carbonate rocks, with subordinate sandstone, siltstone, and shale. It ranges from Middle Cambrian to Middle Ordovician; parts are richly fossiliferous, and it includes potential source,

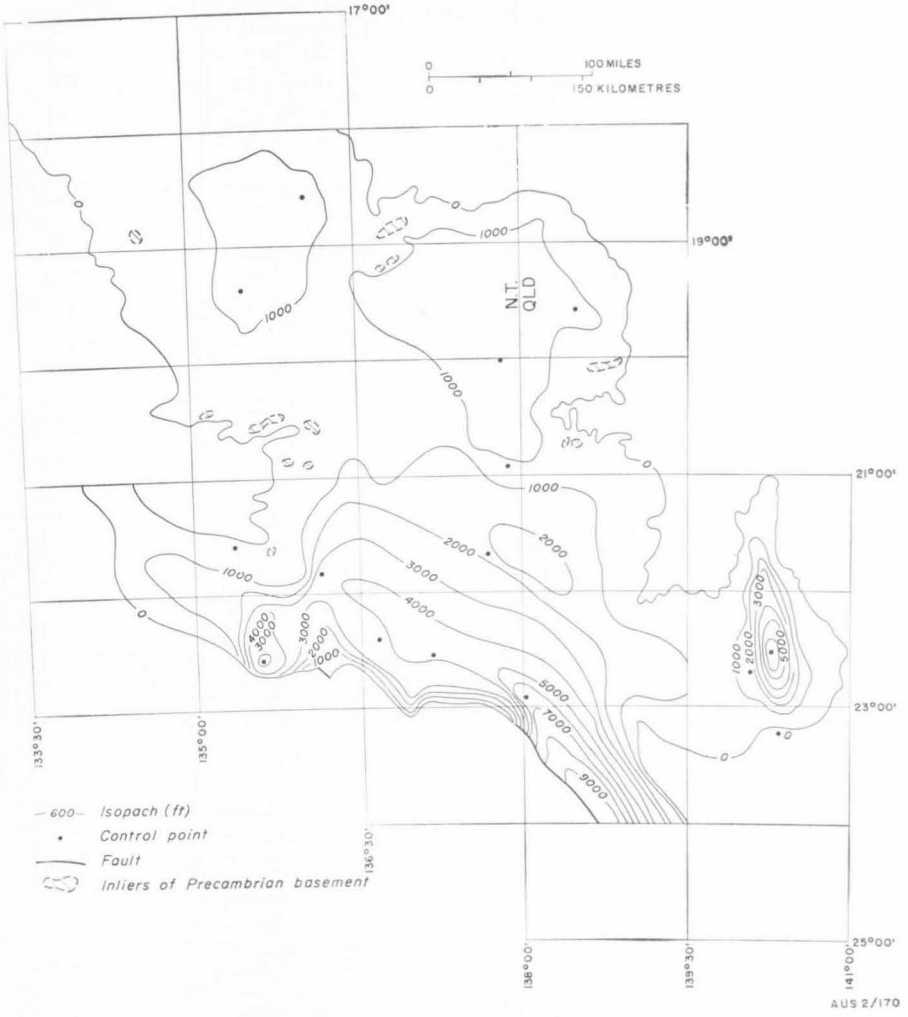


Figure 10. Isopach map of Lower Palaeozoic sequence

reservoir, and cap rocks for petroleum. The sequence is capped by about 640 m of Devonian freshwater sandstone, and is underlain by Lower Cambrian and Adelaidean sediments.

In the *Tobermory-Glenormiston area* the sequence comprises 1800 m of carbonate rocks with subordinate sandstone and shale. The sediments are richly

fossiliferous in parts, and include potential source, reservoir, and cap rocks for petroleum. The basal Middle Cambrian unit rests unconformably on an Adelaidean sequence, and Upper(?) Silurian-Devonian sediments overlie the youngest Middle Ordovician formation.

In the *Boulia area* the sequence comprises 1200 m Upper Cambrian to Ordovician carbonate rocks, with minor sandstone and siltstone. Middle Cambrian sediments are unknown in outcrop, but about 690 m of siltstone and carbonate rocks are known in the subsurface in the Black Mountain No. 1 well.

The stratigraphic units in each area are shown on Table 4, and Figure 9 shows the distribution of rock units, and the basement and cover rocks. The isopachs of the Lower Palaeozoic sequence are shown on Figure 10. For completeness, the only known Palaeozoic sequence in the southeastern extension is also shown on Table 4.

Middle Cambrian

The most widespread sediments are of Middle Cambrian age. They crop out in many isolated localities along the western, southwestern, northern, and eastern margins of the basin, and at several localities north of latitude 21°S. They are known also in The Brothers No. 1 well (FPC, 1965c, unpubl.) at latitude 24°15′40″S; longitude 139°20′30″E, in the southeast, and in the Beantree No. 1 well (Phillips, 1963, unpubl.). The surface distribution of the Middle Cambrian units is shown on Figure 8, and it is assumed that they underlie most of the outcropping part of the basin, although away from the margins and south of latitude 21°S only the following stratigraphic holes and petroleum exploration wells yielded information on the subsurface: BMR 12 (Cockroach), BMR 13 (Sandover), Lucy Creek No. 1, Mulga No. 1, Netting Fence No. 1, and Black Mountain No. 1 (Fig. 3).

Many of the Middle Cambrian sediments are richly fossiliferous, and Öpik (1956a, 1960, 1961) has made extensive studies of the faunas, particularly in northwest Queensland. Öpik's work has resulted in (1) a revision and re-arrangement of the stages formulated by Whitehouse (1936, 1939); (2) the recognition of early, but not the earliest, Middle Cambrian species of *Xystridura;* (3) the recognition that the trilobites in northwestern Queensland belong to the Swedish zones, and the formulation of a zonal arrangement which includes a threefold division of the zone of *Leiopyge laevigata;* (4) the correlation of isolated Middle Cambrian units in the Northern Territory with each other and with units low in the Queensland sequence; (5) the recognition that the Queensland and Northern Territory sequences contain no trilobite species in common; (6) the identification of *Archaeocyathus* cf. *atlanticus* in some definite Middle Cambrian faunas of Northern Territory, thereby indicating the unreliability of *Archaeocyathus* cf. *atlanticus* as a Lower Cambrian index; and (7) the recognition of a similarity between the fauna of the Sandover Beds and that of the Spence Shale and/or *Ptarmigania* faunas of the Rocky Mountains area of the United States of America.

Öpik's correlation chart (1960) for northwestern Queensland is reproduced on Figure 11 with the following modifications: the stratigraphic position of the Camooweal Dolomite has been changed, because it is now known to be of Middle Cambrian age, and the Undilla Basin has been deleted.

In the Northern Territory, palaeontological work on the Middle Cambrian faunas has not been completed, and the fossil assemblages have not been described in detail. Also, in some cases neither boundary of the sequences is exposed, and the

TABLE 4: STRATIGRAPHIC UNITS IN THE SOUTHERN AND SOUTHEASTERN PART OF BASIN

Age	*Huckitta*		*Tobermory-Glenormiston*		*Boulia*		*Southeastern Extension*	
	Formation	*Thickness (m)*	*Formation*	*Thickness (m)*	*Formation*	*Thickness (m)*	*Formation*	*Thickness (m)*
U. Devonian	Dulcie Sst	630						
U. Silurian/ U. Devonian			Cravens Peak Beds	135+				
	Unconformity		*Unconformity*					
	Nora Fm	120+	Toko Group: (Mithaka Fm	90+				
			(Carlo Sst	120				
			(Nora Fm	90				
			(Coolibah Fm	75				
			Disconformity					
L. Ordovician			Kelly Cr. Fm	165	Swift Fm	20+		
L. Ordovician/ U. Cambrian	Tomahawk Beds	240			*Unconformity*			
			Ninmaroo Fm	360	Ninmaroo Fm	750		
	Disconformity		*Disconformity*					
U. Cambrian	Arrinthrunga Fm	960	Arrinthrunga Fm	660	Chatsworth Lst	450	Undifferentiated. Subsurface only	920+ M. and U. Cambrian sediments in The Brothers 1
M. Cambrian	Arthur Cr. Beds	300	Marqua Beds	210+	Subsurface only	689 in Black Mt 1		
	Disconformity		*Unconformity*					
L. Cambrian/ Adelaidean	Mt Baldwin Fm	390	Field R. Beds	1800-2400				

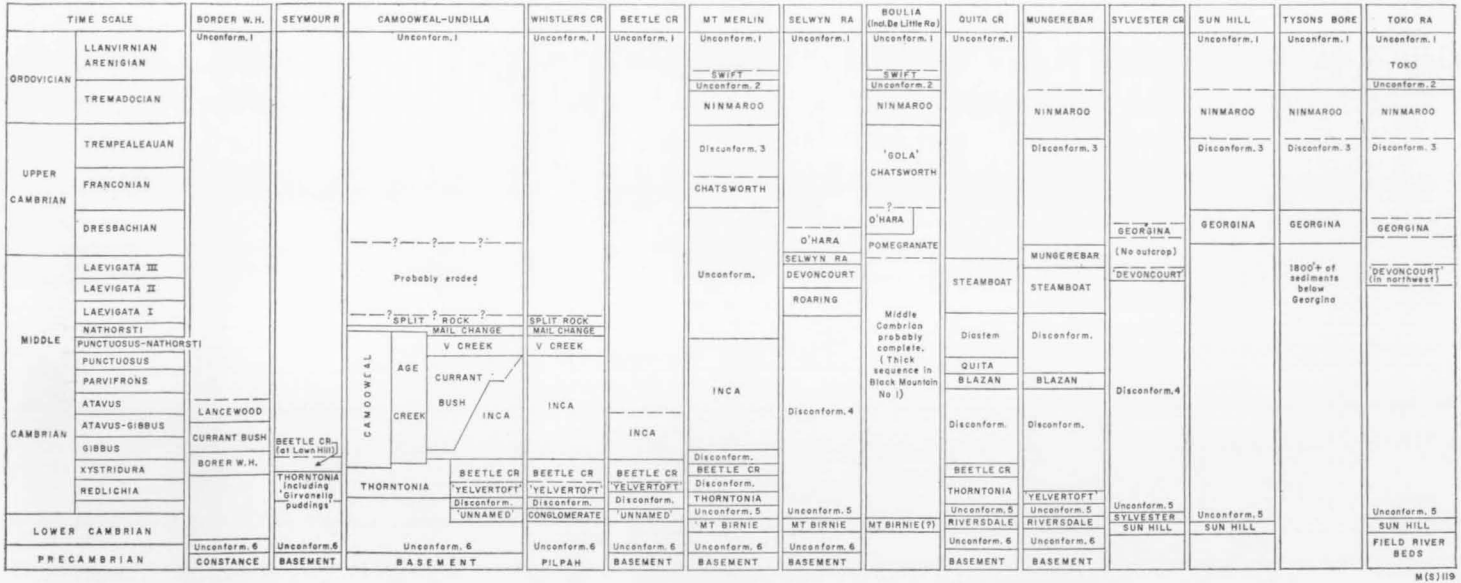
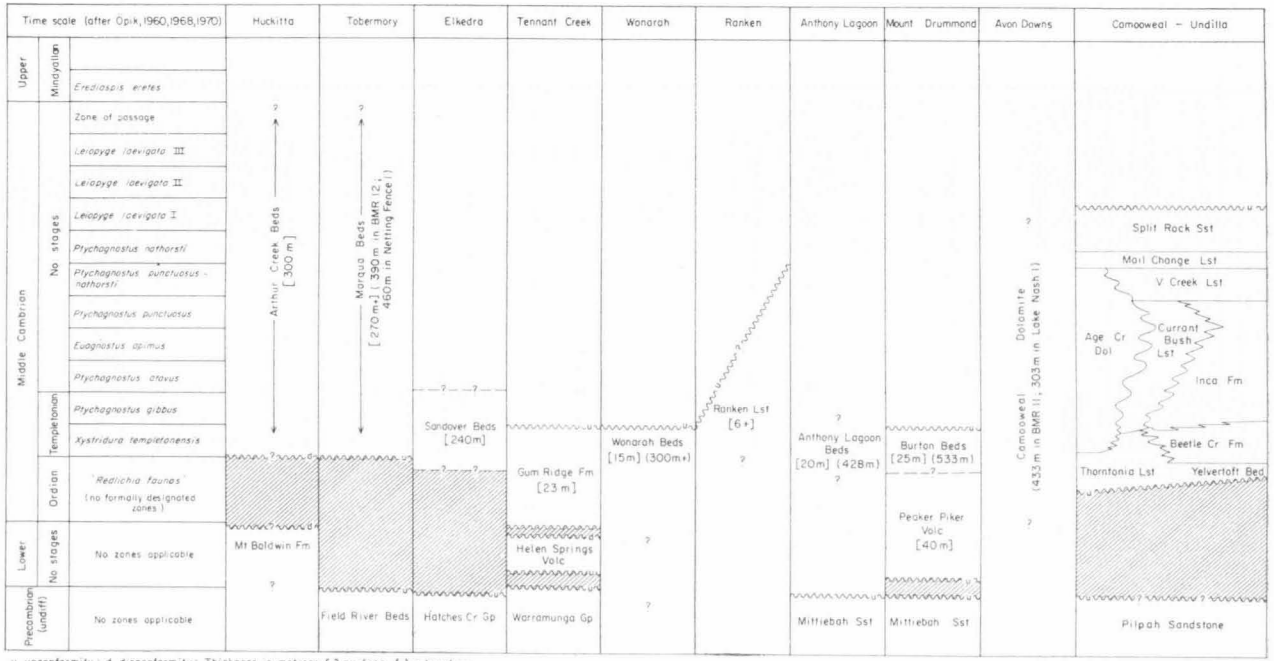


Figure 11. Correlation chart of Cambrian and Ordovician rocks in northwest Queensland. (Opik, 1960).

TABLE 5: CORRELATION CHART, MIDDLE CAMBRIAN SEQUENCE IN NORTHERN TERRITORY



u, unconformity; d, disconformity: Thickness in metres: [ ] surface, ( ) subsurface

units cannot be formally defined. The Middle Cambrian units of the Northern Territory, their thickness, and their probable correlation with each other and with Queensland formations, are shown on Table 5. The details of the Northern Territory units are given in accordance with the common practice of assigning a Middle Cambrian age, and the unit name, to each 'cylinder' of carbonate rock revealed in stratigraphic holes and water bores which began in, or near, outcrops of mapped units of Middle Cambrian age. In most cases, the age of the whole 'cylinder' is not supported by fossils, and the lithology is not specific enough to be diagnostic.

The correlation charts (Fig. 11; Table 5) show several disconformities in the Middle Cambrian of Queensland, and a few localities where upper Middle Cambrian sediments are known in Queensland and in the Northern Territory. Table 5 also shows that the Northern Territory sequences are generally thin around the margins of the basin, but the thicknesses in some wells differ considerably from those indicated by the scanty surface information. Subsurface information is provided by the following stratigraphic holes and petroleum exploration wells:

BMR 11 (Cattle Creek), 433 m (1420 ft) of Camooweal Dolomite

Lucy Creek No. 1, 363 m (1190 ft) of Middle Cambrian sediments

BMR 12 (Cockroach), 390+ m (1279+ ft) of Marqua Beds

Netting Fence No. 1, 460 m (1510 ft) of Marqua Beds(?)

Black Mountain No. 1, 686 m (2259 ft) of unnamed non-outcropping Middle Cambrian sediments, which are probably a thick southward extension from the Burke River Outlier

Beantree No. 1, 41.5 m (136 ft) of lower Middle Cambrian sediments, which indicate a considerable thinning westwards from Black Mountain No. 1, probably over a Precambrian ridge extending southwards from the Cloncurry Complex

Morstone No. 1, 335 m (1100 ft) of Middle Cambrian sediments overlying Precambrian; this gives the thickness of Middle Cambrian in the Camooweal-Undilla area

Alexandria No. 1 water bore, 535 m (1750 ft) of Burton Beds

Brunette Downs No. 1, 318 m (1044 ft) of Anthony Lagoon Beds

Frewena No. 1, 300+ m (1000+ ft) of Wonarah Beds

The Brothers No. 1, 513+ m (1683+ ft) of unnamed non-outcropping Middle Cambrian sediments, in the interval 759-1302 m (2490-4173 ft) (TD); this is not supported by fossils except in the interval 1266-1272 m (4153-4173 ft) and the interval starts from a prominent break in the electric logs at 759 m (2490 ft) (FPC, 1965c, unpubl.)

Mulga No. 1, 79 m (260 ft) of Middle Cambrian (1714-1974 ft); the sequence is not fossiliferous and has been identified from electric logs (Alliance, 1965, unpubl.)

Lake Nash No. 1, 303 m (995 ft) of Camooweal Dolomite unconformably overlying unnamed pyritic red sandstone of Adelaidean or Lower Cambrian age.

Little assistance in computing the thickness of Middle Cambrian sediments in the basin can be obtained from aeromagnetic surveys because the base of the

Middle Cambrian often lies above magnetic basement. Reasonable estimates of thickness away from the margins are possible after study of well results and data from water bores, and the isopachs shown on Figure 12 are based on them.

At the surface, the Middle Cambrian sediments consist predominantly of carbonate rocks, with some sandstone and shale units. Limestone predominates

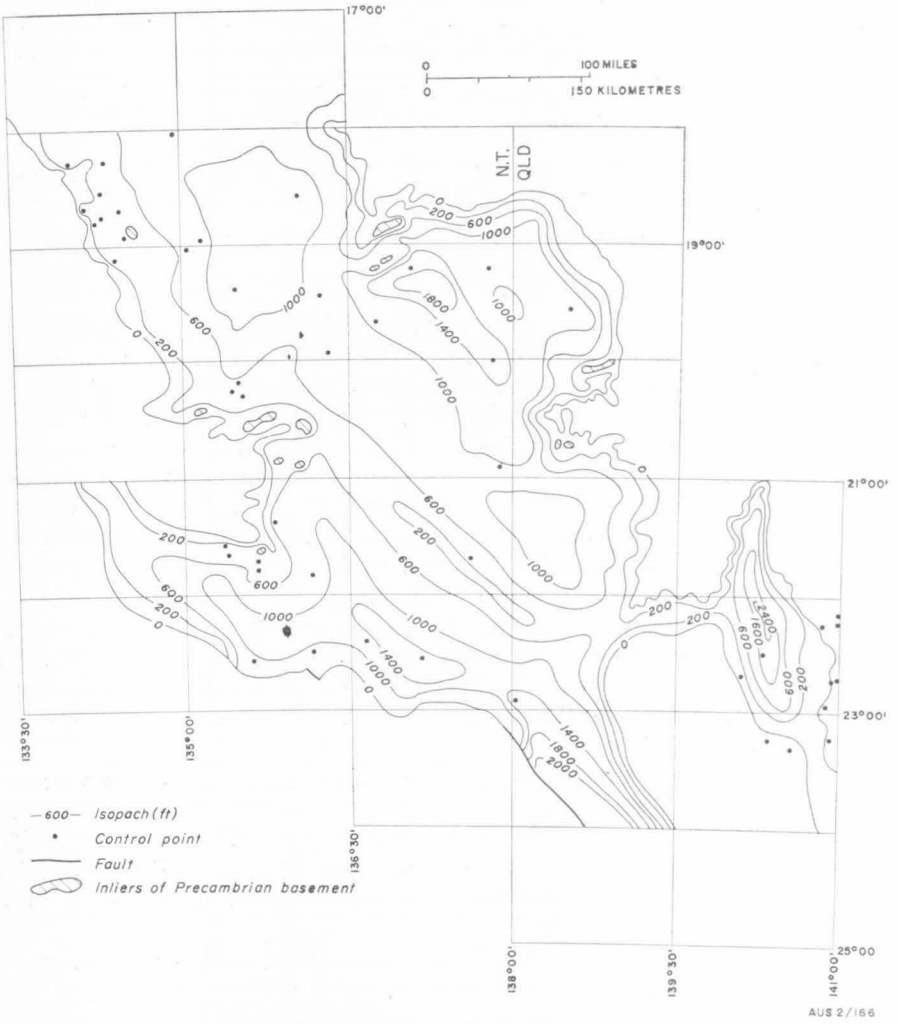


Figure 12. Isopach map of Middle Cambrian sequence

near the margins of the basin, and dolomite is more common away from them. No chemically precipitated dolomite is known in Middle Cambrian sequences; it has all resulted from the dolomitization of limestone. This process, together with weathering of surface outcrops, has obliterated many features of the original rocks. Weathering of dololutite produces a fine-grained siliceous rock which has been mapped as shale and siltstone in many instances (Wonarah Beds, Sandover Beds,

Inca Creek Formation), and weathering of some dolarenites produces a rock of granular texture which superficially resembles sandstone. Much of the Middle Cambrian carbonate rock has been replaced by chert, which shows original structures (breccia, microslump folding, bedding, lamination, oolites). These weathering effects have been confirmed by the fresh rocks obtained by drilling; the subsurface sequences generally contain less shale and siltstone, and more carbonate rock, than is recorded in outcrop. Conglomerate is rare in the Middle Cambrian sequences, and is commonly absent in the basal units, except at the base of the Sandover Beds in the foothills of the Davenport Range. Evaporites are rare, but have been recorded in the Frewena No. 1 well (Barkley, 1965a, unpubl.). Sandstone is not common, but occurs in the higher stratigraphic units in the southwest and east.

All the textures in the carbonate rocks, and the abundance of coquinites, indicate that the Middle Cambrian sediments were deposited in shallow water, and the presence of algae in some parts indicates that the water was very shallow.

Upper Cambrian

In the description of the Upper Cambrian sequence which follows most late Upper Cambrian sequences are excluded as they are best included in the conformable late Upper Cambrian/Lower Ordovician succession. In many localities, Upper Cambrian sediments succeed the Middle Cambrian sequences conformably, but on the Frew River and Avon Downs Sheet areas the Upper Cambrian sediments are assumed to be disconformable on units low in the Middle Cambrian succession. However, the identification of Upper Cambrian units in these areas is not supported by fossils, and if incorrect, the Upper Cambrian sediments may be much more restricted than shown on Figure 8. Correlation between units in the southern part of the basin is shown on Figure 9.

Plate 4 shows the Selwyn Range Limestone as Middle Cambrian, because the information was taken from the published map of Duchess, but in a later publication Öpik (1961) regarded it as Upper Cambrian, although it is apparently unfossiliferous. Accordingly, the Selwyn Range Limestone is discussed here with Upper Cambrian units.

The Upper Cambrian sediments crop out in two main areas—in the west and in the east; the sequences may be continuous between the two areas in the subsurface, but have not been identified in most of the southeastern part. Upper Cambrian sediments have been identified away from outcrop in BMR 12 (Cockroach), Netting Fence No. 1, Beantree No. 1, and Black Mountain No. 1, and in the southeast, in The Brothers No. 1 well.

In the west, the Upper Cambrian sediments comprise the Arrinthrunga Formation (including the Eurowie Sandstone Member) and the Meeta Beds, which are equivalent to, and almost certainly continuous with, the lower part of the Arrinthrunga Formation. The Arrinthrunga Formation consists predominantly of dolomite, with interbeds of blue and blue-black limestone, red and green siltstone, and quartz sandstone which includes the Eurowie Sandstone Member; the thickness ranges from 15 to 30 m, and the beds contain halite casts and ripple marks. Many of the quartz sandstone beds grade laterally and vertically into dolomite. The presence of colonial algae, the cross-lamination of the sandy carbonate rocks, the current-bedding in the quartz sandstone lenses, and the abundance of oolites in the limestone and dolomite attest the shallow-water environment of deposition of the

Arrinthrunga Formation. The Meeta Beds also show evidence of shallow-water deposition, and consist mainly of pelletal dolomite (commonly weathered to chert, with outlines of pellets preserved), cross-bedded quartz sandstone, and some oolitic limestone.

Fossils are rare; only a few early Upper Cambrian trilobites and hyolithids are known in the Arrinthrunga Formation, and a few gastropods in the Meeta Beds. The Arrinthrunga Formation is 975 m thick in the Huckitta homestead area, and thins eastward to about 670 m (2200 ft) in BMR 12 (Cockroach) (Smith & others, 1967) and to about the same thickness in outcrop on the western flank of the Toko Syncline; the thickness drilled in Netting Fence No. 1 well is 820 m (2700 ft) (Fig. 19).

In the east limestone predominates in the Upper Cambrian sequences, and fossils are abundant in many of the formations. Öpik (1960, 1961, 1963, 1967a) has made a thorough examination of the faunas, and has named stages—*Mindyallan,* with two zones, and *Idamean,* with five—in the early Upper Cambrian; the stages correspond in general terms to the Maentwrog and Ffestiniog Stages of Britain, to the *Agnostus pisiformis* and *Olenus* Zones of Scandinavia, to the Dresbachian of North America, and to the Kushanian and Parishanian of northeast Asia. The formations of early Upper Cambrian age—Georgina Limestone, Mungerebar Limestone, Selwyn Range Limestone, O'Hara Shale, Pomegranate Limestone, Chatsworth Limestone, and Gola Beds—are shown on Figure 11, and correlation of some of them with Upper Cambrian units in the western part of the basin is shown in Figure 9.

All these formations are of small areal extent in the east and all surface exposures, except those of the Chatsworth Limestone, are thin; the following maximum thicknesses have been quoted for them:

Chatsworth Limestone—460+ m (Casey & others, 1960, unpubl.)
Pomegranate Limestone—18+ m (Öpik, 1960)
O'Hara Shale—60+ m (Öpik, 1960)
Georgina Limestone—30+ m (Öpik, 1960)
Mungerebar Limestone—30+ m (Reynolds & Pritchard, 1964, unpubl.)
Selwyn Range Limestone—35+ m (Carter & Öpik, 1963).

Most of the thicknesses quoted are for incomplete sections; more recent information, mainly from the Black Mountain No. 1 and Beantree No. 1 wells (Phillips, 1963, unpubl.) shows the following thicknesses:

Chatsworth Limestone—460 m (1500 ft) at Black Mountain (combined surface and subsurface)
Pomegranate Limestone—249 m (817 ft) in Black Mountain No. 1 well, increasing southwestwards to 396 m (1301 ft) in Beantree No. 1 well
O'Hara Shale—49+ m (162 ft) in Black Mountain No. 1 well, but not recognized in Beantree No. 1 well; since it is known to interfinger with the Pomegranate Limestone, its time equivalent could be present there.

The presence of the Pomegranate Limestone and O'Hara Shale in the Black Mountain No. 1 and Beantree No. 1 wells shows that they extend south from their outcrop area, and that the Pomegranate Limestone extends at least as far southwest as Beantree No. 1 well; however, the Chatsworth Limestone is absent in Beantree No. 1 well, and the Pomegranate Limestone is overlain by Mesozoic sedi-

ments. The Chatsworth Limestone has not been identified in the subsurface west of the Burke River Structural Belt, and the surface outcrops of Georgina Limestone and Mungerebar Limestone are overlain disconformably by the Upper Cambrian/ Lower Ordovician Ninmaroo Formation. Öpik (1963) believes that uplift occurred in the Glenormiston area about the end of Idamean time, whereas the Franconian and Trempealeauan fossils in the Chatsworth Limestone of the Boulia Sheet area indicate middle and late Upper Cambrian deposition. In the Netting Fence No. 1 well the Papuan Apinaipi Petroleum Co. Ltd (1965b, unpubl.) reported a sequence of limestone and subordinate calcarenite, dolomite, sandstone, and shale between the base of the Ninmaroo Formation (at 726 m; 2381 ft) and 1548 m (5080 ft); the company divided this into the Georgina Limestone (726-1247 m; 2381-4090 ft), Mungerebar Limestone (1247-1327 m; 4090-4355 ft), and Middle Cambrian Steamboat Sandstone (1327-1548 m; 4355-5080 ft). However, Gatehouse (*in* PAP, 1965b, unpubl.) identified fossils in Core 14 (3 m; 4910-4920 ft) as probably of early Upper Cambrian age, and as belonging to the Zone of

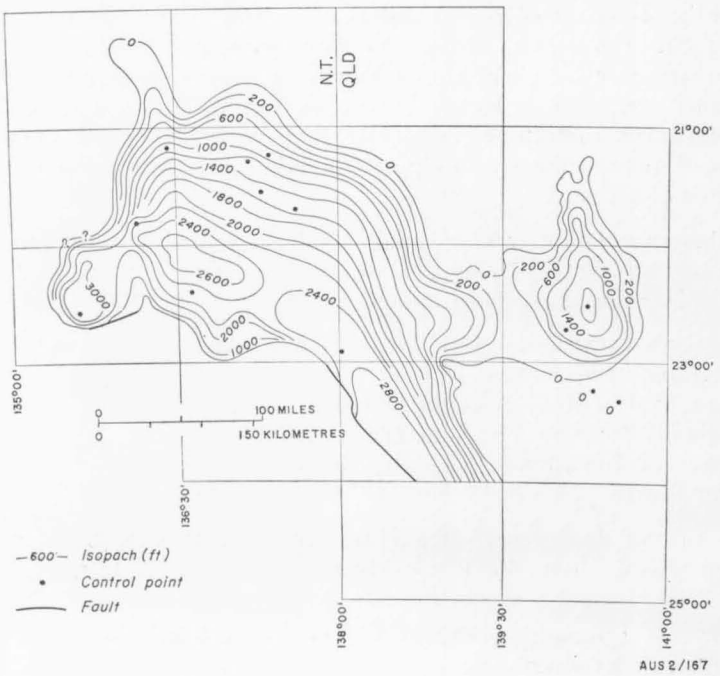


Figure 13. Isopach map of Upper Cambrian sequence

Glyptagnostus reticulatus (Idamean Stage). Therefore it appears that the whole sequence from 726 to 1548 m (2381-5080 ft) belongs to the Upper Cambrian Arrinthrunga Formation. The dip averages 10° and the true thickness is about 790 m (2600 ft), which indicates a thickening of the Upper Cambrian to the west of the Georgina Limestone outcrop near Glenormiston homestead (Fig. 13).

Öpik (1963) considers that the Georgina Limestone, Pomegranate Limestone, and O'Hara Shale were deposited in an epicontinental shallow sheltered sea. The

mild cross-lamination of sand and fossil fragments indicates that the water was mildly agitated at times, but the presence of adult trilobites embedded dorsum up and dorsum down in approximately equal numbers indicates that calm conditions generally prevailed.

The presence of coquinites and intraformational breccia and the cross-lamination in some beds in the Chatsworth Limestone (Casey & others, 1960, unpubl.) indicate shallow-water deposition. Some change in the environment of deposition of the Chatsworth Limestone is indicated by the presence of only a few bituminous beds, whereas the Pomegranate Limestone, Georgina Limestone, and O'Hara Shale contain many bituminous laminae and beds. Öpik (1961) has described the environment of deposition of the unfossiliferous Selwyn Range Limestone as near-evaporitic, but this is the only Queensland Upper Cambrian formation deposited under these conditions.

Upper Cambrian/Lower Ordovician

The Upper Cambrian/Lower Ordovician formations (excluding the Lower Ordovician in the Toko Group) comprise the Tomahawk Beds and the Ninmaroo, Kelly Creek, and Swift Formations. All are restricted to the southern part of the basin; the Swift Formation has a very limited extent along the Burke River Structural Belt, and is unknown in the subsurface, but the other units are widespread in the southwest and southeast (Fig. 8); they are assumed to be present in the buried Toko Syncline in the southeast, although only the Ninmaroo Formation has been identified in the subsurface (Montecchi & Robertson, 1966, unpubl.).

The Tomahawk Beds crop out on both sides of the Dulcie Range (Sheet 3), and also in the Tarlton Range area (Sheets 3, 4). The beds comprise quartz sandstone, calcareous sandstone, dolomite, limestone, and siltstone, much of which is richly glauconitic; measured sections are shown on Figure 29. To the northwest of Huckitta homestead, the sequence consists predominately of quartz sandstone, but in the northeastern part of the Huckitta Sheet area, the southeastern part of the Elkedra Sheet area, and the southwestern part of the Sandover River Sheet area rapid gradation from quartz sandstone to sandy dolomite and dolomite is common.

The Tomahawk Beds are richly fossiliferous, principally in trilobites and ribeirioids, ranging from late Upper Cambrian to Lower Ordovician in age; the time range is equivalent to that of the Ninmaroo and Kelly Creek Formations combined (A. A. Öpik & J. G. Tomlinson, pers. comm.) as shown on Figures 9 and 14. In the Tarlton Range area the three units are in contact; in places it is possible to separate the Kelly Creek Formation from the Tomahawk Beds, but deep weathering and lateritization of the carbonate rocks has produced many lenses of slumped 'siltstone' and 'sandstone' which hamper the mapping of the boundary between the Tomahawk Beds and Ninmaroo Formation; the boundary shown on Sheet 4 is a facies boundary between the carbonate sequence with lenses of sandstone (Ninmaroo Formation) in the east, and the sandy sequence with beds and lenses of carbonate rocks (Tomahawk Beds) in the west.

The Tomahawk Beds appear to rest conformably on and grade into the Arrinthrunga Formation near Huckitta homestead, but to the northwest they transgress on to Precambrian sedimentary and igneous rocks; east of Lucy Creek homestead they appear to be disconformable on the upper (but not top) part of

the Arrinthrunga Formation, and in the Sandover River Sheet area they are almost certainly disconformable on the Meeta Beds, which are equivalent to the lower part of the Arrinthrunga Formation. The cross-bedding and type of sediments in the Tomahawk Beds indicate that they were deposited in shallow water.

The Ninmaroo Formation is of regional extent, and consists mainly of carbonate sediments (Fig. 30) with subordinate sandstone, siltstone, and shale. The formation is rich in trilobites, nautiloids, ribeirioids, and conodonts, and also contains many algal layers. The presence of algae, intraformational breccias, and scour-and-fill structures, and the cross-lamination of sandy laminae, indicate deposition in shallow water.

The Ninmaroo Formation crops out in a narrow belt in the Duchess-Boulia area (Sheet 4) and in a wide belt extending from the Tarlton Range to near Glenormiston homestead. Casey & others (1960, unpubl.) believe that the logs of the water bores indicate continuity of the Ninmaroo Formation in the subsurface between the western outcrop belt and Boulia township (see cross-section on Sheet

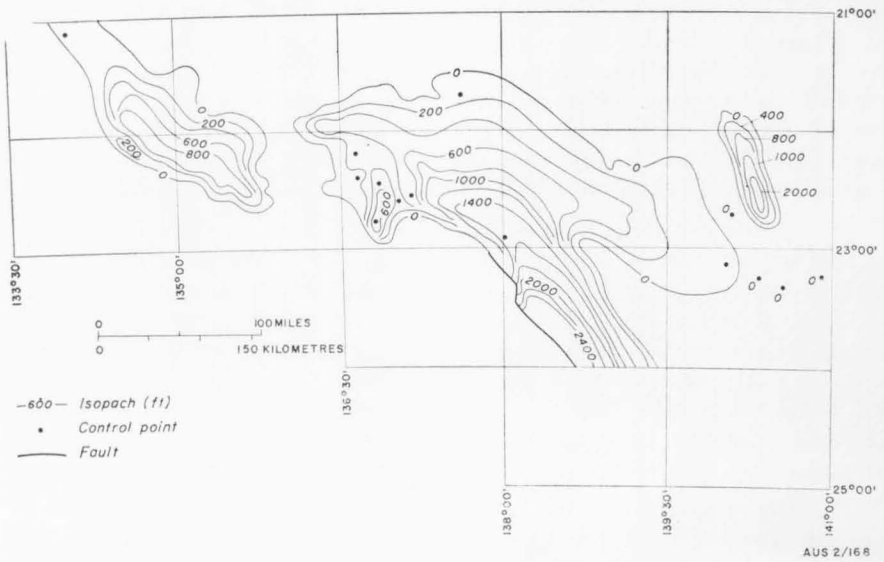


Figure 14. Isopach map of Cambro-Ordovician sequence

4), but continuity between Boulia township and the eastern outcrop belt is uncertain, and the formation is not present in the Beantree No. 1 well (Phillips, 1963, unpubl.).

The thickest sequences of the Ninmaroo Formation are at Black Mountain and Mount Ninmaroo, in the eastern outcrop belt, where the formation appears to be conformable on the Chatsworth Limestone. To the northwest, the formation transgresses the Lower Cambrian Mount Birnie Beds, and Öpik's 1960 correlation chart (Fig. 11) shows a disconformity between the Ninmaroo Formation and Chatsworth Limestone in this (Mount Merlin) area.

In the western outcrop belt, the Ninmaroo Formation has a maximum thickness of about 370 m and is disconformable on the early Upper Cambrian Georgina

Limestone and Mungerebar Limestone. The contact between the Ninmaroo and Arrinthrunga Formations is difficult to define because of the structural complexity and because both formations are essentially composed of carbonate rocks; in one locality, the presence of about 70 m of quartz sandstone at the base of the Ninmaroo Formation may indicate that it is disconformable with the underlying Arrinthrunga Formation. In the north, the Ninmaroo Formation is probably disconformable on the Meeta Beds, although no contact has been observed.

The Kelly Creek Formation rests conformably on the Ninmaroo Formation and interfingers with the upper part of the Tomahawk Beds. Outcrops are restricted to the Tarlton and Toko/Toomba Ranges (Sheet 4); the formation can be recognized in the upper part of the Tomahawk Beds in the Dulcie Range area (Sheet 3), but is thin and cannot be delineated on the map. In the Tarlton Range the formation comprises calcareous, micaceous, and glauconitic sandstone, which is cross-laminated in part, with interbeds of dolarenite and calcarenite; it is about 60 m thick. In the Toko Range the outcrops are mainly sandstone, with some siltstone and dolarenite; the formation is 170 m thick on the western side and about 60 m on the east. It contains a rich fauna of nautiloids, brachiopods, trilobites, ribeirioids, and gastropods.

The Swift Formation crops out only in the Duchess-Boulia area, where a thickness of only about 20 m has been preserved. It consists of chert with interbeds of coquinite, and siltstone containing graptolites. The formation rests unconformably on the Ninmaroo Formation (Casey & others, 1960, unpubl.). Öpik (1960) considers that the Swift Formation was deposited after the main tectonic events in the Burke River Structural Belt, but Casey & others regard the

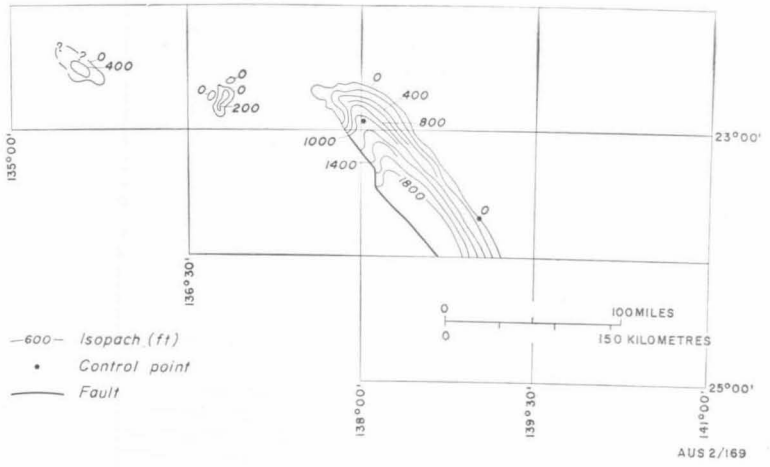


Figure 15. Isopach map of Toko Group

unconformity as a minor event. The Swift Formation is equivalent in age to the Kelly Creek Formation (A. A. Öpik & J. G. Tomlinson, pers. comm.).

The Toko Group, which is mainly of Middle Ordovician age, is restricted to the southern part of the Georgina Basin. It comprises the Lower Ordovician Coolibah Formation and the Middle Ordovician Nora Formation, Carlo Sandstone, and Mithaka Formation. The group is complete in the Toko Range, and presumably

plunges southeastward under the Simpson Desert. In the Tarlton Range, all the formations except the Coolibah Formation have been identified, but in the Dulcie Range only eroded remnants of the Nora Formation are present. Figure 15 is an isopach map of the Toko Group.

Although no break has been detected in the field, J. G. Tomlinson (pers. comm.) believes that the fauna of the Coolibah Formation is considerably younger than that of the Kelly Creek Formation, and a disconformity is usually shown at the top of the latter. The Coolibah Formation, at the base of the group, consists of chert, oolitic limestone, and calcilutite. To the southeast, it thickens from about 15 m near the northwestern end of the Toko Range to 55 m near latitude 23°S and 110 m in the Toomba Range in Queensland. The fauna includes nautiloids, gastropods, ribeirioids, and sponges.

The Nora Formation succeeds the Coolibah Formation, and consists of pelletal dolomite, coquinite, siltstone, and micaceous and glauconitic sandstone. The formation is 115 m or more thick in the Dulcie Range, 60 m in the Tarlton Range, 60 m in the northern part of the Toko Range, and thickens to 120 m to the southeast in the flank of the Toomba Range. The lower part of the formation contains a rich fauna of pelecypods, brachiopods, trilobites, nautiloids, gastropods, and bryozoans, but there are few shelly fossils in the upper part, although tracks and trails are abundant.

The Carlo Sandstone conformably overlies the Nora Formation in the Toko Range, but there is evidence of a short depositional break at the northern end of the Tarlton Range. The formation consists of quartz sandstone with numerous cross-beds, ripple marks, and flute casts; clay pellets are abundant and a few thin beds of siltstone occur in the lower part of the unit. The Carlo Sandstone is about 35 m thick in the Tarlton Range and 60 m in the Toko Range; to the southeast the thickness increases to over 150 m in the Toomba Range. Fossils are uncommon, but nautiloids, brachiopods, and pelecypods are known in the upper half, and trails and worm tracks have been observed throughout. The Carlo Sandstone is the first (and only) sandstone unit in the Cambrian-Ordovician sequence of the Georgina Basin: the currents appear to have been strong during its deposition, and in the Tarlton Range they came from the southeast (Fig. 32).

The Mithaka Formation is the youngest Middle Ordovician sequence preserved in outcrop; only a few thin residuals cap the Tarlton Range, but the formation is more extensive in the Toko Range, and continues southeastwards in the Toomba Range. As the formation crops out poorly, the lithology is imperfectly known, but the following rocks have been observed: gypsiferous siltstone, shale, and sandstone, calcareous sandstone, glauconitic quartz sandstone, and some thin coquinites. The sequence was deposited in shallow water.

The fossils in the Mithaka Formation include trilobites, nautiloids, pelecypods, sponges, brachiopods, and conodonts. The formation is tentatively reported as 18 m thick in the Tarlton Range, and 60 to 120 m in the Toko Range.

Silurian and Devonian

Silurian rocks are unknown in the Northern Territory, but some sediments whose age could range from Upper Silurian to Lower Devonian (Jones, *in* Johnstone et al., 1967; Tomlinson, 1968) are known in the Toko Syncline in Queensland. The rocks are part of the Cravens Peak Beds, which also contain Upper Devonian freshwater placoderms (Tomlinson, 1968; Smith, 1965b). Another freshwater Devonian sequence, the Dulcie Sandstone, crops out in the Dulcie Range.

Tomlinson (1968) has established that both the Cravens Peak Beds and the Dulcie Sandstone include a considerable hiatus, the lower part being Lower Devonian and perhaps uppermost Silurian, and the upper part Upper Devonian.

The Dulcie Sandstone crops out prominently in the Dulcie Range and extends northwest almost to Barrow Creek (Sheet 3). It consists of strongly cross-bedded quartz sandstone, with some beds of silty sandstone, calcareous sandstone, and pebble conglomerate. The formation is 640 m thick in the southeast and thins to the northwest; the thickness in the southeastern part of the Barrow Creek Sheet area is about 450 m and most of the thinning occurs to the northwest of this area.

Freshwater placoderms have been described by Hills (1959) and assigned an Upper Devonian age. The fossils have been found in two horizons southeast of Huckitta homestead, the lower of which is about 490 m above the local base of the formation. Smith & Milligan (1964) reported fragments of fossil fish in the Barrow Creek Sheet area.

In the Toko Syncline, the beds containing the fossils which Jones (*in* Johnstone et al., 1967) regards as possible Lower Devonian or Upper Silurian do not crop out, and the fossils were obtained from seismic shothole samples. The Cravens Peak Beds crop out as cross-bedded quartz sandstone and sandstone with abundant clay pellets; the beds are about 140 m thick in the Toomba Range near the Northern Territory border. Several fragmentary placoderms and one leaf fragment have been found, but none of them was in situ, although it is almost certain that they came from the Cravens Peak Beds.

The thin unfossiliferous conglomerate beds in the Mount Whelan area are regarded as Permian(?) in age (Reynolds, 1968), and are so shown on Sheet 4. Some may be Permian fluvioglacial deposits; it is possible that they represent reworked Adelaidean glacials which were redistributed in early Mesozoic time. It is possible that the conglomerates thicken to the southeast as part of the thick sequence in the buried Toko Syncline.

Structure

Faulting predominates over folding in the Georgina Basin, and most of the visible folds are related to the faulting, although there are a few isolated 'draped' structures such as the Lake Nash Anticline (Fig. 16). In the west and southwest the major tectonic events can be dated as post-Devonian, but elsewhere the events can be dated only as post-Middle Cambrian or post-Lower Ordovician, because of lack of outcrop of younger Palaeozoic rocks. Mild tectonic events in late Mesozoic and Tertiary are known in northwestern Queensland.

Most of the succession north of latitude 21°S consists of thin gently undulating sediments which contain no pronounced fold structures, except for the Lake Nash Anticline, and no faults except in a narrow zone along the northern margin in the Mount Drummond and Lawn Hill Sheet areas. It is likely that broad domes and basins, with very low flank dips, are present in this northern area, but the absence of marker beds, the deep weathering of the rocks, and the paucity of outcrop prevent delineation of any folds which may be present; the structure is also obscured by slumping in the carbonate rocks which predominate in the area. Any folds which may be present are probably draped, such as the Lake Nash Anticline, which is a broad gentle structure about 16 km long, with some steeper dips due to slumping; the anticline trends west-northwest and has no known parallel

structures. The log of the Lake Nash No. 1 well (Amalgamated, 1963a, unpubl.) shows that the rocks in the anticline consist of 303 m of Cambrian carbonate rocks resting unconformably on an Adelaidean or Lower Cambrian sandstone-dolomite sequence.

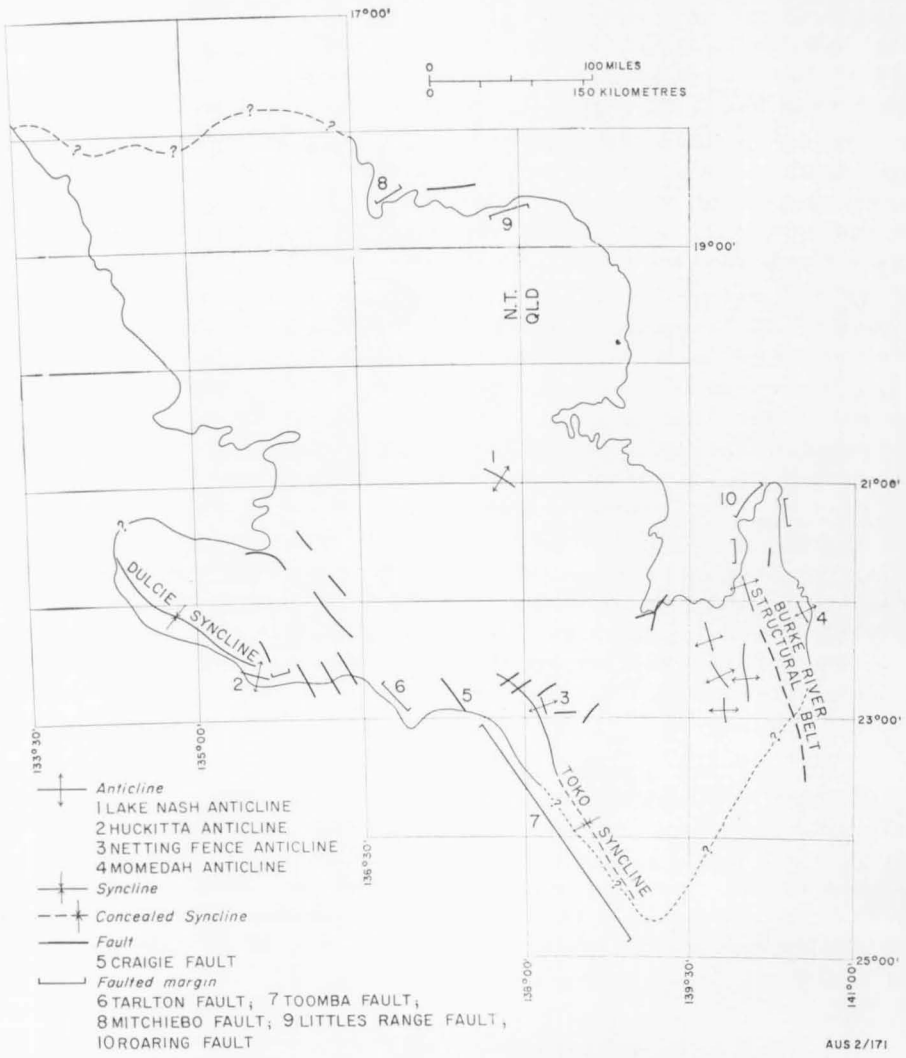


Figure 16. Structure

Two faults have affected the Middle Cambrian sediments along the northern margin: the Mitchiebo Fault (Smith & Roberts, 1963), and the Littles Range Fault (Smith & Roberts, 1963; Carter & Öpik, 1961), which extends from the Northern Territory into Queensland. Both trend west-southwest, parallel to other fault systems in the basement north of the margin. The Mitchiebo Fault is about 55 m long, and has severely disturbed both the Middle Cambrian Burton Beds and

Precambrian sequences. The Littles Range Fault produced vertical dips in some Middle Cambrian strata (the Currant Bush Limestone and Lancewood Shale), but the Camooweal Dolomite was not deformed, although the Constance Sandstone adjacent to the Dolomite was locally severely deformed. Carter & Öpik (1961) regarded these two pieces of evidence as indicative of both Precambrian and post-Middle Cambrian faulting periods, but these authors regarded the Camooweal Dolomite as pre-Middle Cambrian; now that the Camooweal Dolomite is regarded as Middle Cambrian, the evidence for two periods of faulting along the northern margin of the Georgina Basin is not clearly documented. The age of the faulting in the Middle Cambrian rocks is unknown, but Carter & Öpik (1961) state that it was older than Lower Cretaceous. These authors, and Smith & Roberts (1963) record minor faults which have dislocated Mesozoic outcrops in the Lawn Hill/Mount Drummond Precambrian basement area, and Smith & Roberts state that the faulting was always along the line of pre-existing faults; the effect, if any, along pre-existing faults in Cambrian sediments may reasonably be regarded as minor. In the southern part of the basin some mild fault movements have affected the Middle Cambrian sediments in the Elkedra Sheet area, but the major structures in the Barrow Creek, Huckitta, Tobermory, Hay River, Glenormiston, and Mount Whelan Sheet areas are post-Devonian, and others which can be dated only as post-Lower Ordovician occur in the Duchess-Boulia area.

The post-Devonian structures in the west and southwestern parts of the basin generally mask the older Palaeozoic structures, but fault movements probably caused uplift in Upper Cambrian time and after the Middle Ordovician, as well as some suspected breaks in the Middle Cambrian. Faulting predominates in the post-Devonian tectonism, and the major structures are parallel faults, trending northwest. Several of these are shown in the Huckitta Sheet area (Sheet 3), and in the Tobermory, Hay River, and Mount Whelan Sheet areas (Sheet 4), where the more important faults have been named the Tarlton, Craigie, and Toomba Faults. They trend parallel to the major northwesterly trend of Precambrian crystalline rocks and to the major faults in them; this trend has been repeated in several units of younger Precambrian rocks.

All the major faults trending northwest are normal, with downthrown blocks on the northeast side; the throw is more than 1000 m in some localities along the Tarlton, Craigie, and Toomba Faults. The fault zones are narrow, and are marked by steep dips which flatten to the northeast; the intensity of the faults decreases to the north until monoclinal folds are the only evidence of disturbance, in some cases. The faults extend for many kilometres, and the Toomba Fault, which is the largest, probably has a length of about 130 km from latitude 23°S, near the Northern Territory border, to about 24°S near Pulchera Waterhole. Along this fault the beds are overturned (by a maximum of 10°) in a few places, and this has led some writers (Reynolds, 1965a, 1968) to believe that the whole fault is a high-angle reverse fault, caused by thrusting from the southwest. However, the beds have been overturned in a few places only, always in ridges of carbonate rocks where the overturning may be due to hill-creep, collapse, or slumping, or to cross-faulting. It seems that the Toomba Fault is a high-angle normal fault system, with complex cross-faults.

The main effect of the Toomba Fault/Craigie Fault system has been the formation of the Toko Syncline, which is one of the two major folds in the basin; the second is the Dulcie Syncline. Both structures are asymmetrical synclines trend-

ing northwest, with steep dips on the southwestern flanks flattening out rapidly to the northeast to very low angles. Although no fault zone has been found on the surface along the southwestern flank of the Dulcie Syncline, either near the Devonian sediments or away (southwest) from them, I believe that faulting in the basement has caused the steep dips on its southwestern limb. There are no regional anticlinal structures complementary to the synclines, but several prominent drag folds are associated with the Craigie Fault, and one anticline—the Netting Fence Anticline—within the Toko Syncline, and another—the Huckitta Anticline —near the southwestern flank of the Dulcie Syncline. Both anticlines may have originally been compaction structures which have been accentuated later during movement of the downthrown block. Several sharp minor monoclines in the Tomahawk Beds are known in the Lucy Creek/Tarlton Downs area and they may reflect deep-seated structures. Minor folds are known in the Arrinthrunga Formation.

In the Toko Syncline there is a prominent set of faults trending east-northeast, which is complementary to the major faults. They are normal faults, with blocks downthrown to the southeast; the throw does not exceed 60 m, and is usually less than 30 m. Another set of minor faults in the Toko Syncline trends east-west, but they are less prominent and fewer than those trending east-northeast.

Many of the faults in the Dulcie Syncline/Toko Syncline areas, like the synclines themselves, originate between the Upper Devonian and the Mesozoic, because the Upper Devonian sediments are structurally deformed. It is reasonable to correlate the post-Devonian orogeny with the Alice Springs Orogeny (named by Forman et al., 1967), which had its culmination at about the same time, and deformed Devonian and older sediments in the Amadeus Basin to the southwest. The Alice Springs Orogeny is probably of the same age as the Carboniferous Kanimblan Orogeny of eastern Australia.

Between the Dulcie and Toko Synclines, several major faults and some minor faults and folds cannot be dated precisely because they affect either Middle Cambrian or Upper Cambrian sediments only. It is assumed that they were formed, or were last active, during the Alice Springs Orogeny.

The Duchess-Boulia area is a structural entity, insofar as surface structures are concerned, and is known as the Burke River Structural Belt (Öpik, 1960). Öpik has divided the belt into two segments: (1) the northern outliers (Burke River Outlier) and (2) the southern inliers, which protrude through the Mesozoic cover rocks.

The northern outliers occur in a graben, bounded by faults on the north, east, and west, which at about latitude 22°S opens into a trough containing the rocks of the southern segment. The northern outliers contain Cambrian rocks which Öpik (1960, 1961) states are everywhere disturbed, and have been gently folded about axes which trend northwest; the intensity of folding decreases from west to east. Near the faults, dips are almost vertical, and the trend of the bedding is parallel to the faults, but the dips decrease away from the faults and the trend swings so that the beds dip regionally to the southeast. Öpik (1960) states that the vertical displacement along the faults is no more than 300 m on the Roaring Fault, and an estimated 200 to 230 m on other faults.

In the southern segment, two prominent lines of structure have been described by Casey & others (1960, unpubl.). One extends from Mount Birnie to Black Mountain, Mount Ninmaroo, and Dribbling Bore (in Upper Cambrian or Ordovician

rocks), and its surface expression is visible in Cretaceous rocks farther south near Elizabeth Springs and near Mungeroo Knobs, south of Springvale homestead. Along this structural line, Palaeozoic rocks (as far south as Dribbling Bore) have been folded into anticlines and subsequently faulted. The best exposures of the structure are in the Black Mountain/Mount Ninmaroo area, where Casey & others state that the normal fault plane dips steeply east, and the sequence is downthrown about 300 m. The fault line is marked by dolomitization and brecciation, and cuts off the eastern part of a dome in the Chatsworth Limestone. On the western side of the fault, dips are about 35°, but they flatten rapidly to 10° within a distance of 50 m, and then decrease gradually westwards until they are almost horizontal; on the eastern side the dip is vertical, but flattens to horizontal within a distance of 3 km. During post-Cretaceous movement on the fault, a vertical displacement of about 200 m is indicated at Mount Ninmaroo (Casey et al., 1960, unpubl.).

The other structural line is the Momedah Anticline, which extends from near Chatsworth homestead southeast almost to the Hamilton River, at about 22°32′S. This structure is approximately parallel to one through Black Mountain, but the only Palaeozoic rocks exposed are the Upper Cambrian Chatsworth Limestone in the north and the Upper Cambrian Gola Beds in the south; the exposure of Gola Beds in the Momedah Anticline is the easternmost Palaeozoic outcrop in the Georgina Basin. The Cambrian sediments in the Momedah Anticline are folded into an asymmetrical anticline with steep dips on the western limb; the western side of the anticline is faulted and downthrown to the west (Casey et al., 1960, unpubl.). Cretaceous rocks are also disturbed along the line of the Momedah Anticline, and Casey & others have calculated a vertical displacement of about 60 m.

The deformation of the Burke River Structural Belt probably took place between the deposition of the Ninmaroo and Swift Formations. A landmass began to rise between the eastern and western Cambrian areas towards the end of the Middle Cambrian, as can be seen from the differing depositional history of the two geographical regions after Inca Formation time (compare the Selwyn Range area with the Quita Creek area in Fig. 11).

The movement apparently continued into the Lower Ordovician, and the Ninmaroo Formation is caught up in the deformation. The Swift Formation lies unconformably on the Ninmaroo, and it is reasonable to deduce that the climactic period of movement occurred between the two. Since, however, the movements started again much later—Lower Cretaceous rocks are deformed along the same structural lines as the Lower Ordovician, though less intensely (Sheet 4)—and the Swift Formation is also deformed, it is possible that the main period of deformation followed the deposition of the Swift, as suggested by Casey & others (1960, unpubl.). However, I follow Öpik (1960, 1961) in placing it earlier than the Swift, and the palaeogeographic maps (Fig. 17) and the interpretation of geological history of the Duchess-Boulia area are based on this assumption.

Geological History

The history of the Georgina Basin began with the ingress of a shallow sea in early, but not earliest, Middle Cambrian time. The sea was part of a near-meridional sea extending across the continent from Adelaide in the south to the Joseph Bonaparte Gulf in the northwest.

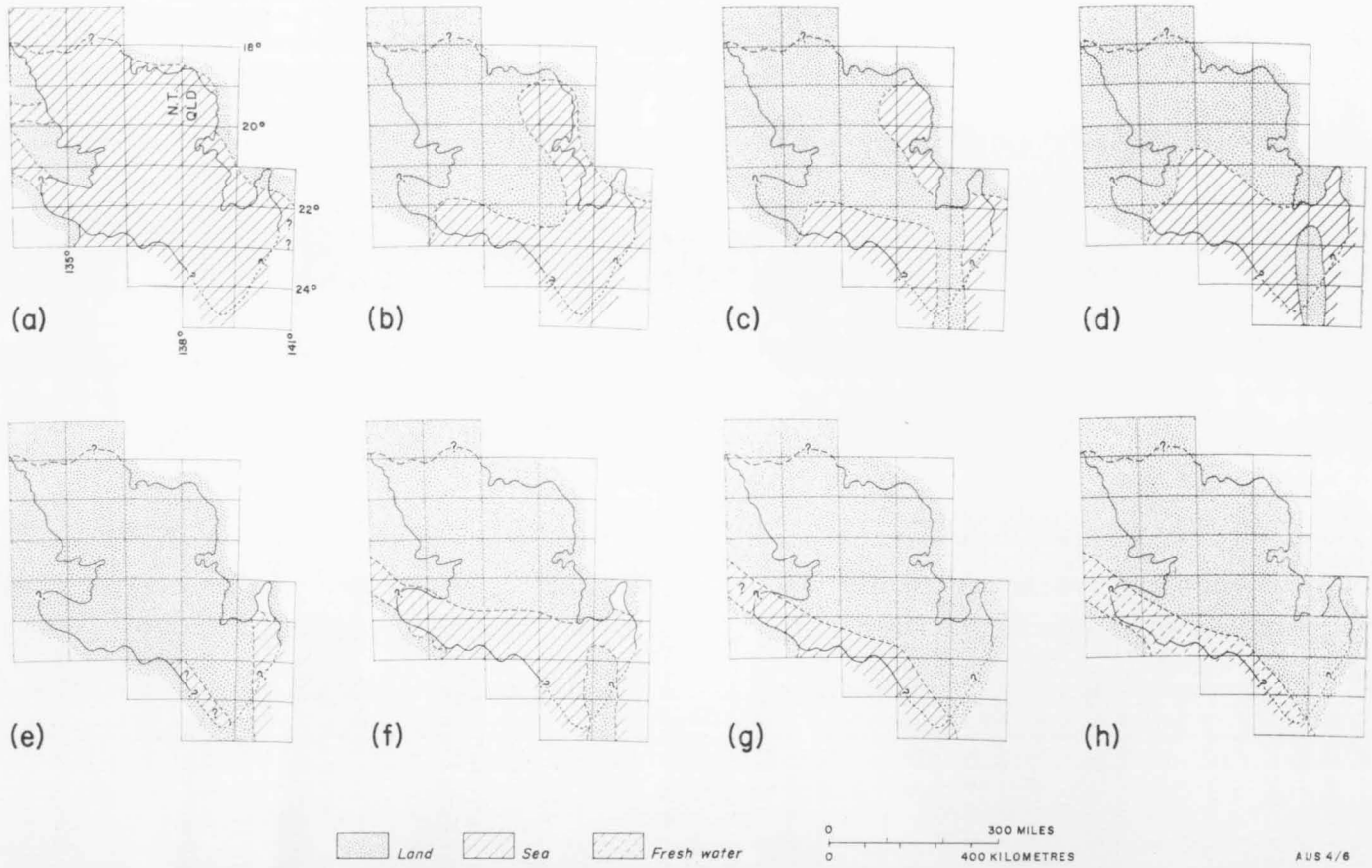


Figure 17. Palaeogeography (a) Early Middle Cambrian; (b) Middle Cambrian, end of *Pt. gibbus* time; (c) Middle Cambrian, end of *P. nathorsti* time; (d) early Upper Cambrian; (e) Upper Cambrian, end of Franconian; (f) late Upper Cambrian/Lower Ordovician; (g) Middle Ordovician; (h) Devonian

PLATE 1

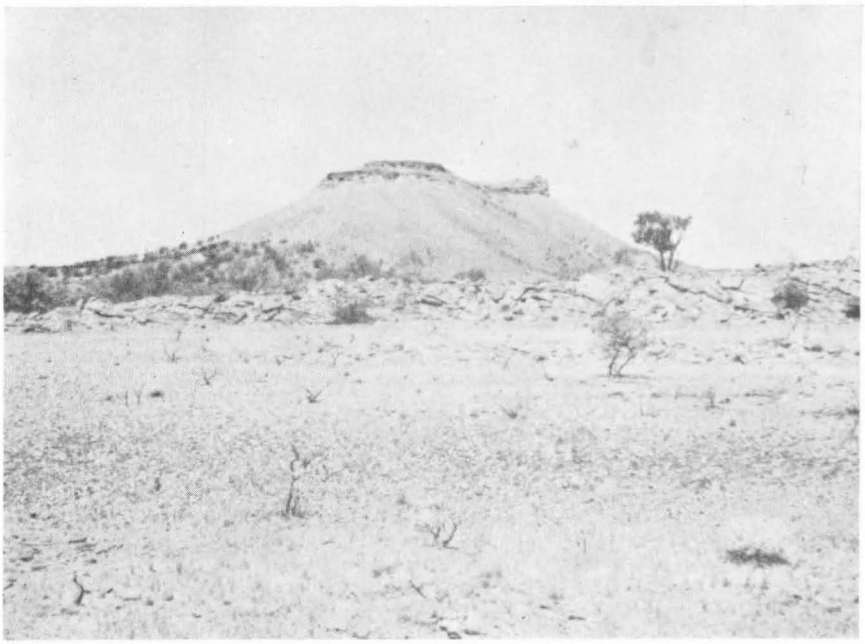


Figure 1. Typical outcrop of the basal glacial unit of the Field River Beds about 30 km southeast of Marqua homestead, Tobermory Sheet area, Northern Territory. The mesa is capped by the Triassic Tarlton Formation

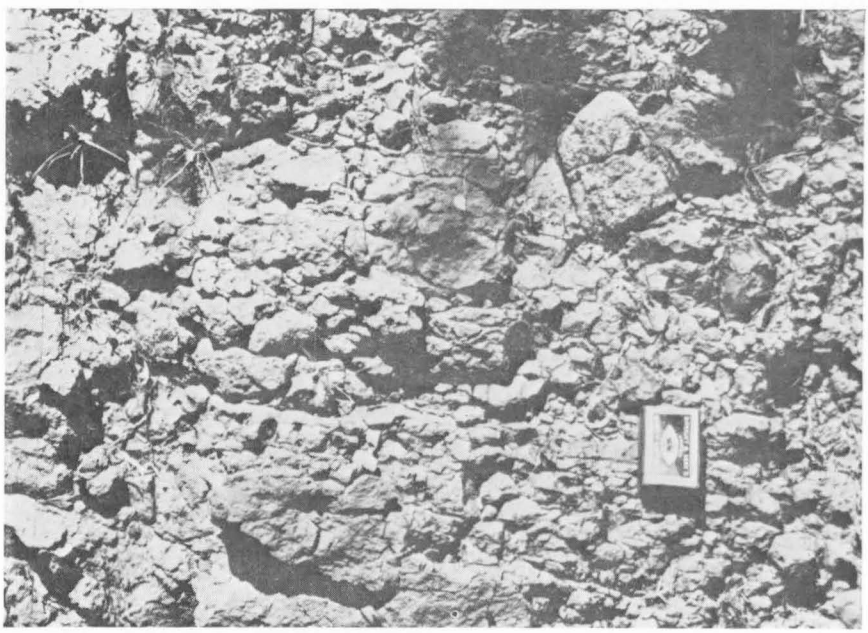


Figure 2. Basal glacial unit of the Field River Beds, Hay River Sheet area, Northern Territory. The beds consist of pebbles and cobbles set in a matrix of green siltstone

PLATE 2

Figure 1. Varves(?) in glacial beds of the Mount Cornish Formation at Mount Cornish, Huckitta Sheet area, Northern Territory

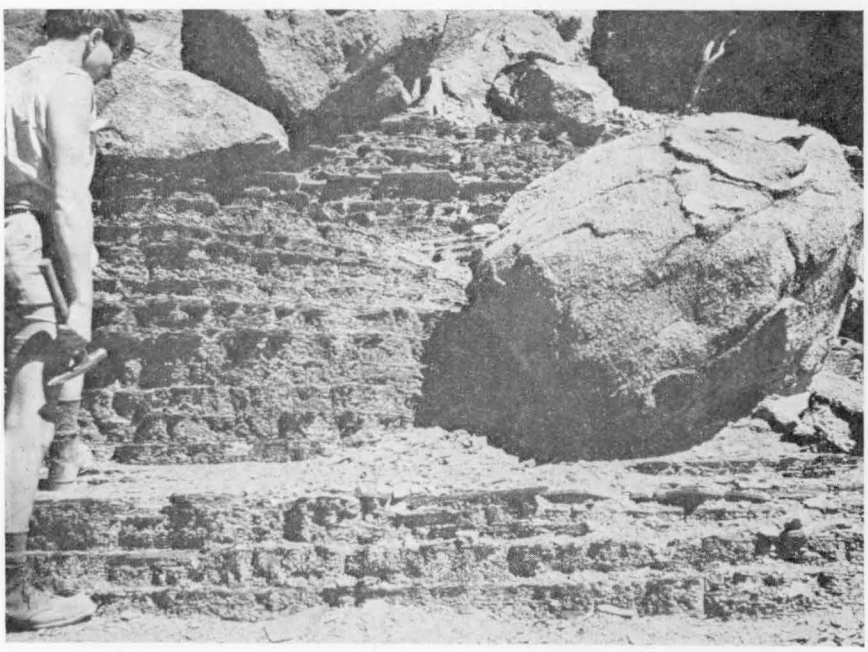


Figure 2. Sandstone and shale of the Mount Cornish Formation, Elyuah Range, Huckitta Sheet area, Northern Territory. The loose blocks are from the overlying Oorabbra Arkose Member of the Elyuah Formation

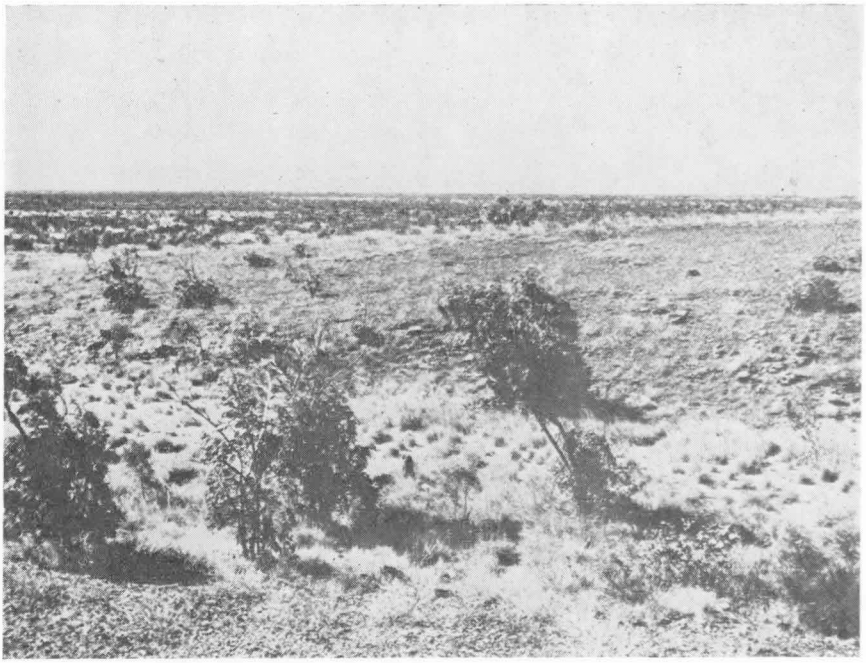


Figure 1. Typical rubbly outcrops of the lower Middle Cambrian Wonarah Beds, about 10 km northwest of Barrys Caves, Ranken Sheet area, Northern Territory

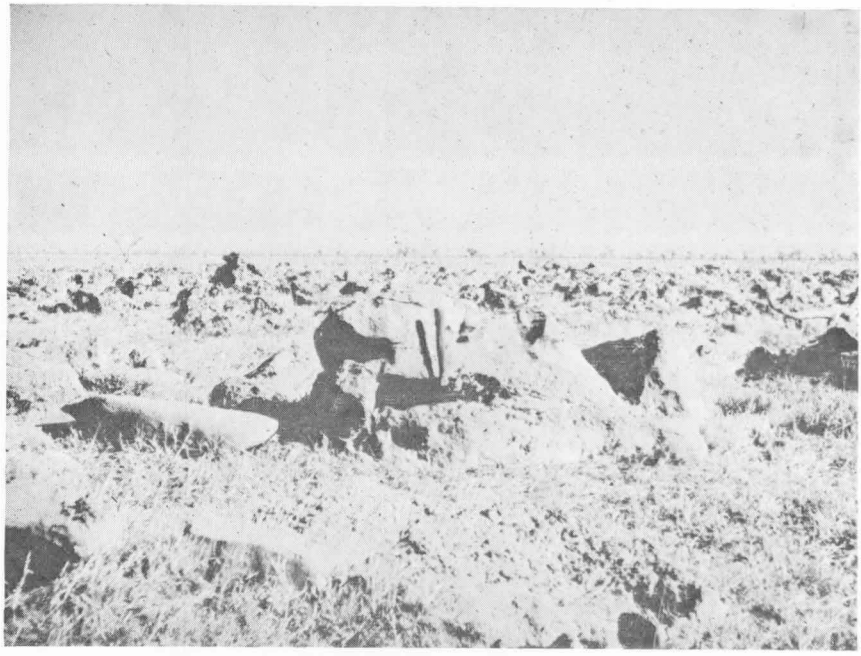


Figure 2. Bouldery outcrop of dolomitic limestone of the Middle Cambrian Anthony Lagoon Beds on Brunette Downs Station, Barkly Tableland, Brunette Downs Sheet area, Northern Territory

Figure 1. Flaggy limestone in the Middle Cambrian Marqua Beds, near top of reference section in the Tobermory Sheet area, Northern Territory

Figure 2. Medium to thick-bedded Camooweal Dolomite, Goonooma Creek, west of New Norfolk homestead, Camooweal Sheet area, Queensland

PLATE 5

Figure 1. Medium crystalline dolomite of Meeta Beds. Note the inclusions of iron oxide in the cores of the crystals and the relatively clear rims which were formed at a later stage. X 45

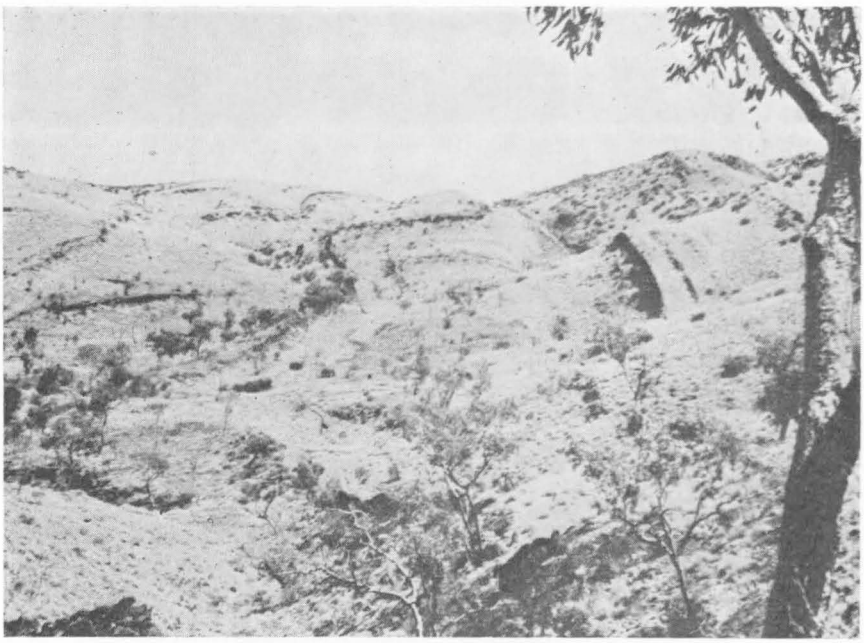


Figure 2. Irregular folds in dark-coloured beds of dolomite in the Tomahawk Beds, about 6 km northwest of the reference section, Huckitta Sheet area, Northern Territory.

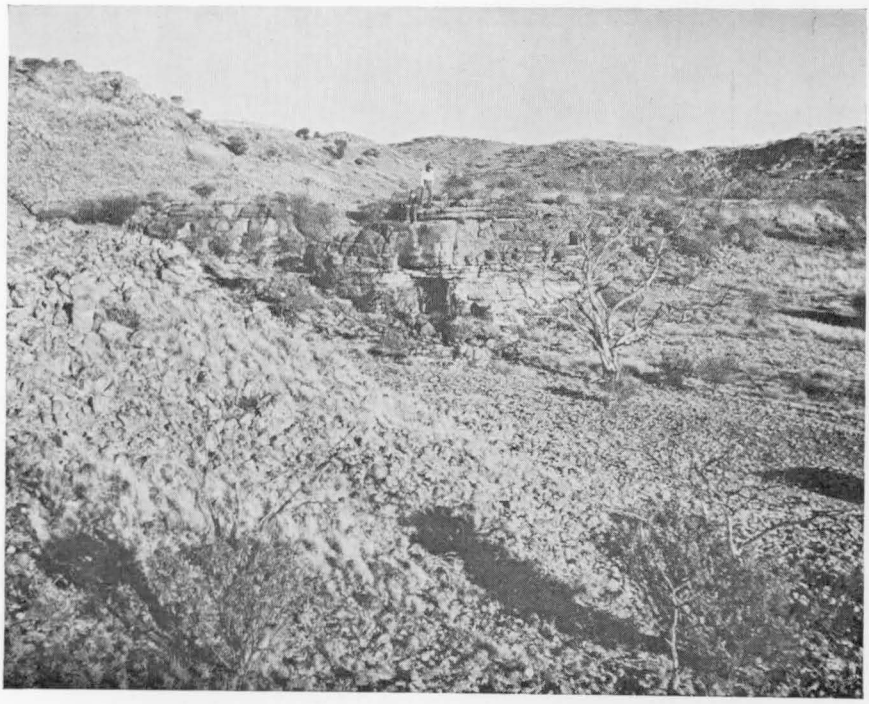


Figure 1. Inlier of the Palaeozoic Ninmaroo Formation in the Cretaceous Longsight Formation, about 20 km west of Alderley homestead, Glenormiston Sheet area, Queensland

Figure 2. Interbedded chert and shale of the Swift Formation, east side of Swift Hills, Boulia Sheet area, Queensland

The early Middle Cambrian sea covered the whole of the basin and extended across at least the southern part and some of the northwestern part of the Cloncurry Complex (Fig. 17a). The original extent of the sea across the Precambrian rocks in the Mount Drummond Sheet area, and southwestwards across the Simpson Desert area, is uncertain, nor is it known whether Middle Cambrian sedimentation extended east of the Boulia Sheet area. In the north, connexions probably existed with the Daly River Basin, and in the west with the Wiso Basin; the Davenport and Ashburton Ranges were probably islands in the Middle Cambrian sea, and their eastern edges formed one of the margins of the Georgina Basin. A connexion with the Amadeus Basin, across part of the submerged Arunta Block, is considered likely (Öpik, 1956b), but this block probably consisted of a series of horsts and grabens and the two basins may have been connected by more than one seaway.

In the north, Middle Cambrian sediments were deposited on a broad epicontinental platform, with a maximum relief of about 360 m, in which there were several parallel depressions trending northwest. Similar conditions prevailed in the west and southwest, but in the east the platform opened southwards into the slightly deeper water of a meridional trough in the Chatsworth-Boulia area.

Few basal conglomerates are known in the lower Middle Cambrian sequence, but they have been recorded around the margins of the Davenport Range, and in northwestern Queensland.

Carbonate rocks predominated in early Middle Cambrian time, but no chemically precipitated dolomite is known and the original sediments consisted of limestone with some shale and siltstone. All the sediments were deposited in shallow water, and most of the seas were rich in marine life. The faunas in the Northern Territory and northwestern Queensland were completely different; Öpik (1956a,b) considered that there were two seas separated by a meridional ridge of Camooweal Dolomite of Lower Cambrian or Upper Proterozoic (Adelaidean) age, but as it is now known that the Camooweal Dolomite contains Middle Cambrian fossils it could not have formed a barrier between the two faunal areas.

During the time of the Zone of *Pt. gibbus* (see Fig. 11) the seas regressed from most of the Northern Territory part of the basin north of latitude 22°S (Fig. 17b), and this part of the basin has been stable ever since, except for the faulting that affected the Sandover Beds in the southeastern foothills of the Davenport Range, and the Middle Cambrian units along the northern margin in the Mount Drummond and Lawn Hill Sheet areas. Before the regression, the early Middle Cambrian sequence was thicker in parts of the Barkly Tableland area than other parts of the basin; for example it is about 300 m in the Frewena/Brunette Downs area, compared with 300 and 335 m for the complete Middle Cambrian sequences in the Huckitta and Camooweal-Undilla areas respectively.

The regression in *Pt. gibbus* time did not affect the continuity of Middle Cambrian sedimentation in the south, the Camooweal-Undilla area in the north, or the Duchess-Boulia area in the east. All the younger Middle Cambrian sediments were predominantly carbonates with local developments of shale, and sandstone lenses high in the sequence. All the sequences were deposited in shallow water, and most of them contain abundant fossils; fossils are less common in the Camooweal Dolomite and Age Creek Formation, both of which were deposited under more turbulent conditions. Öpik (1956a) reported a complete sequence of Middle Cambrian sediments in the Camooweal-Undilla area, and other complete sequences

are indicated in the Huckitta, Tobermory, and Boulia areas, but the palaeontological data are incomplete. In the Dajarra-Duchess area, on the other hand, an upward movement of the Cloncurry Complex in about *P. nathorsti* time (Fig. 11) caused a break, and later Middle Cambrian sedimentation differed on the eastern and western sides of the Precambrian block (Fig. 17c).

The upward movement of the Cloncurry Complex and the overlying Adelaidean/Lower Cambrian sediments initiated an important chain of events in the history of the Georgina Basin: it formed a ridge of basement rocks extending to about latitude 25°S, which separated the Duchess-Boulia area from the remainder of the Georgina Basin in Upper Cambrian and Lower Ordovician time, and recurrent vertical movements of the ridge, or parts of it, affected the distribution of sediments along its flanks.

It is therefore convenient to consider Upper Cambrian and younger history separately for each part of the basin. The ridge of Cloncurry Complex and Adelaidean/Lower Cambrian rocks is referred to as the 'Precambrian ridge' (Fig. 17d).

Duchess-Boulia Area. Sedimentation was continuous from Middle Cambrian into Upper Cambrian time in the Selwyn Range area, and, probably, in the Chatsworth-Boulia area; the structural elements consisted of a platform in the north, opening southwards into a slowly subsiding trough. However, the axis of the early Upper Cambrian trough had been displaced slightly westwards (as indicated by the westward thickening of the Pomegranate Limestone and O'Hara Shale) owing to subsidence of at least the eastern part of the Precambrian ridge. It is likely that at this time an east-west seaway connected the Duchess-Boulia area with the Mungerebar area.

At about the end of Dresbachian time, the eastern part of the Precambrian ridge was uplifted, the sea withdrew from the northern part of the Duchess-Boulia area, and the major faults of the Burke River Outlier were initiated. A trough remained in the Chatsworth-Boulia area and persisted until late in Lower Ordovician time, but its axis shifted eastward to a position almost coincident with the Middle Cambrian axis (Fig. 17f). In this trough about 1050 m of richly fossiliferous carbonate rocks (Chatsworth Limestone and Ninmaroo Formation) was deposited in warm shallow seas where conditions favoured the growth of algal reefs. The eastern, western, and southern extent of these seas is unknown, but the overall distribution of the Ninmaroo Formation suggests a westward connexion with the remainder of the basin in Lower Ordovician time.

The prevalence of beds of breccia in the Ninmaroo Formation suggests regularly recurring tectonic pulses in the Precambrian rocks bounding the Lower Ordovician trough; these pulses reached a climax which resulted in Lower Ordovician folding and faulting of the trough sediments, and accentuation of the faults in Cambrian sediments to the north. At this time, the structures in the Burke River Structural Belt were established, and a subsidiary fault system, trending northeast along the present Hamilton River with the upthrown block to the south, may have been initiated.

After a short period of erosion, the Lower Ordovician sea returned and the Swift Formation was deposited in the northern part of the former Lower Ordovician trough. This transgression was short-lived, and after the sea withdrew there was no later Palaeozoic sedimentation in the Duchess-Boulia area. The Precambrian

ridge, with its capping of Palaeozoic carbonate rocks, remained a positive, stable area until Mesozoic time.

Remainder of the Georgina Basin. To the west of the Precambrian ridge, sedimentation after *P. nathorsti* time (Fig. 11) continued in the Camooweal-Undilla area and was probably continuous in the Huckitta and Tobermory areas; the Huckitta area was a marine platform opening southeastward to slightly deeper water (Fig. 17c). At the end of the Middle Cambrian the sea withdrew from the Camooweal-Undilla area and no younger Palaeozoic sediments were deposited there.

Continuous sedimentation from Middle to Upper Cambrian occurred in the Huckitta-Tobermory area, and also in the Mungerebar area, but in the Sun Hill area the Georgina Limestone transgressed on to Adelaidean sediments. In Dresbachian time the Sun Hill and Mungerebar areas were uplifted but in the Huckitta-Tobermory area sedimentation continued into Franconian time, and considerable thicknesses of shallow-water carbonate rocks, with interbedded siltstone and sandstone, were deposited (Fig. 17d,e). Although the subsequent Upper Cambrian erosional history is unknown, the preserved thickness of the Arrinthrunga Formation indicates that in Dresbachian-Franconian times a trough developed in the Huckitta area, and another in the southeastern part of the present Toko Syncline.

Uplift and erosion in the Huckitta-Tobermory area preceded the ingress of a late Upper Cambrian sea which covered the previously deposited Upper Cambrian sediments and in the northwest transgressed onto Precambrian basement; in the north it lapped early Middle Cambrian sediments. Sedimentation was continuous from late Upper Cambrian until near the end of the Lower Ordovician time (Fig. 17f,g). The Huckitta area had reverted to platform conditions and received only 240 m of sediment, but in the Toko Syncline area about 500 m of sediments accumulated at the northwestern end and a thicker, but unknown amount to the southeast.

The fossils indicate a minor break in sedimentation between the Lower Ordovician Kelly Creek and Coolibah Formations. The Coolibah Formation is the oldest unit of the Toko Group; the group was only deposited in the Huckitta-Tobermory areas, entirely in shallow water. For the first time in the history of the Georgina Basin, deposition of sand exceeded that of carbonate rocks and evidence from the Carlo Sandstone indicates a source in the southeast. The deposition of Ordovician sediments ceased and uplift began, probably in Middle Ordovician time. These events may have been simultaneous in the Huckitta and Tobermory areas, but erosion before the deposition of Devonian or Siluro-Devonian sediments masks the sequence of events.

Marine sedimentation ended in Middle Ordovician time. After uplift and erosion freshwater sediments were laid down in either late Silurian or early Devonian time in the Toko Syncline area, and in either Lower or Upper Devonian time in the Huckitta and Barrow Creek areas (Fig. 17h; see also Fig. 33). The extent of these freshwater sequences is unknown; they are preserved in one belt in the Toko Syncline and in another in the Dulcie Syncline, and are known to extend northwestwards from Barrow Creek area into the Wiso Basin.

The major tectonic event in the history of the Georgina Basin occurred after deposition of the Devonian sediments; its precise date is unknown, but it probably occurred in early Carboniferous time and is tentatively correlated with the Kanimblan Orogeny of eastern Australia. In the Georgina and Amadeus Basins the

event is known as the Alice Springs Orogeny. In the Georgina Basin the effects of the orogeny are seen mainly south of latitude 22°S, but some faults continue northwards to about latitude 21°30′S. Major faults developed with a northwesterly trend, parallel to or coincident with previous faults in the Precambrian basement. The faults are normal, with the downthrow to the northeast, and some have throws of more than a thousand metres. They shaped the southwestern margin of the basin and were responsible for the asymmetry of the Dulcie and Toko Synclines. The intensity of faulting decreased from southeast to northwest, along individual faults. Minor complementary faults trend east-northeast and west. Folding was slight during the orogeny, and igneous intrusions are unknown. The rocks of the Duchess-Boulia area were not affected.

The whole of the Georgina Basin then underwent a long period of erosion until Mesozoic deposition began in late Triassic or early Jurassic time, but Permian sediments may have been deposited in the Toko Syncline area. The extent of the Triassic-Jurassic sedimentation is unknown, but the present outcrop distribution indicates that it was widespread in the southern part of the basin. After another period of erosion, Lower Cretaceous seas covered most, if not all, of the basin, and thin sequences, thickening to the south and southeast, were deposited. A late Cretaceous movement rejuvenated faults and folds in the Boulia area, but there is no evidence of this tectonism in the Northern Territory part of the basin.

By late Miocene time, the thin Mesozoic cover had been stripped from much of the basin, and a lateritic surface was formed. Thin Tertiary sediments were then deposited in a series of freshwater to brackish lakes (Lloyd, 1968). Casey & others (1960, unpubl.), Öpik (1960), and Paten (1964) have reported evidence of a gentle southward tilt which drained the lakes of the Boulia area in late Tertiary time, but there is no evidence of tilting in other parts of the basin.

The final stages in the history of the Georgina Basin area include the stripping of laterite, and the formation of clayey soils over the carbonate rocks and the widespread deposition of sand and soil.

Economic Geology

No metalliferous deposits have been mined in the Palaeozoic rocks of the Georgina Basin, but a few prospects have been tested for lead and manganese. No igneous intrusions or hydrothermal orebodies are known in the Palaeozoic rocks, but it is possible that syngenetic deposits may be present. Galena is not uncommon in the carbonate rocks, and galena and arsenopyrite have been reported in samples from water bores. Samples from petroleum exploration wells and core holes have recently been examined for phosphate, and samples from some core holes have been tested for cobalt, nickel, lead, zinc, vanadium, phosphorus, and strontium without success (Nichols, 1966, unpubl.). Present exploration in the basin is directed mainly towards petroleum and phosphate, and water for the cattle industry is continually being sought, mainly with Government assistance.

Iron

Beds of oolitic ironstone occur in the Nora Formation in the scarp of the Dulcie Range, and several beds of ferruginous sandstone are known in the Tomahawk Beds between Mount Ultim and the southeastern tip of the Dulcie Range (Vine, 1959, unpubl.; Smith, 1964a). The occurrences have not been sampled or mapped in detail, but visual estimation indicates a low grade except in the south-

eastern part of the Dulcie Range, where the iron-rich beds are very thin. Section HX30 of the Nora Formation contains a total of 2 m of oolitic ironstone in the interval from 11.3 to 21 m (37-69 ft) above the base of the formation; a sample from one bed was analysed and was found to contain 39.6 percent Fe_2O_3 and 43.3 percent insoluble residue which consisted mostly of sand grains forming the nucleus of the oolites. A specimen of ferruginous sandstone from the Tomahawk Beds east of Mount Ultim assayed 25.7 percent Fe_2O_3, and 53.4 percent insoluble residue which consisted mainly of sand grains.

Lead

Shows of galena have been tested near Box Hole Bore (22°16′23″S, 135°51′E, about 13 km northeast of Arapunyah homestead, in the Huckitta Sheet area) by Consolidated Zinc Pty Ltd (1961, unpubl.), and Woolley (1961, unpubl.) examined the prospect for the Bureau of Mineral Resources; other prospects have been tested at Little Totts Creek, 40 km north-northeast of Camooweal (Blanchard & Hall, 1942, p. 59), and 16 km north-northeast of Noranside homestead, at 22°01′S, 140°03′E approximately (Shepherd, 1945b; Casey et al., 1960, unpubl.).

The largest of the lead prospects is the Box Hill deposit, where fairly extensive shows of galena were located in a bed of weathered algal dolomite in the top unit of the Arrinthrunga Formation. The mineralization extends over a distance of about 3 km. It was found by a prospector in 1960, and subsequently mapped and drilled by Consolidated Zinc Pty Ltd, but no further work has been done. A few tons of galena were gouged from the surface, but the grade of ore down dip was found to be uneconomic.

The deposit near Noranside homestead is small; Casey & others (1960, unpubl.) have reported irregular blebs and patches of galena, up to 5 cm wide, in brecciated and vuggy dolomite of the Ninmaroo Formation, on the crest of an asymmetrical anticline in the Burke River Structural Belt. The deposit was tested by costeaning in 1956.

The Little Totts Creek deposit consists of small shows of galena in beds of Camooweal Dolomite. A few shallow pits have been sunk on the prospect, but it is of no economic importance.

Manganese

Several low-grade occurrences of manganese have been noted, but none of them have been worked. Concentrations of manganese occur in thin sandstone beds of the Tomahawk Beds about 29 km south of Murray Downs homestead, in the Barrow Creek Sheet area, and the best specimens were found to contain 40 percent MnO_2. Noakes, Carter, & Öpik (1959) reported low-grade manganese in outcrops of the Steamboat Sandstone in the Urandangi Sheet area, and Casey & others (1960, unpubl.) reported nodules and patches of manganese minerals in chert and siltstone of the O'Hara Shale, about 19 km south-southeast of Buckingham Downs homestead; the same authors have reported specimens of rhodocrosite, assaying 13.9 percent MnO_2, in the Ninmaroo Limestone 19 km northeast of Digby Peaks homestead, and pyrolusite and psilomelane at the unconformity between the Ninmaroo and Swift Formations on the western side of the Swift Hills. All the occurrences were probably concentrated by weathering.

Petroleum

No commercial deposits of oil or gas have been discovered in the Georgina Basin, but traces of hydrocarbons were recorded in many of the 16 wells drilled. The logs of the wells are shown in Figure 19.

Potential source beds are present throughout much of the Georgina Basin succession, particularly in the Middle Cambrian formations, but also in early Upper Cambrian and Upper Cambrian/Lower Ordovician formations of north-western Queensland. These formations consist of dark fossiliferous limestone, much of which has a strong petroliferous odour when freshly broken. Some of the dark shale in the early Middle and early Upper Cambrian sediments may also be potential source beds.

Apart from the surface evidence of limestone with a petroliferous odour, indications of hydrocarbons have been reported during water-boring operations; Mott (1952) mentioned a driller's report of petroliferous odours in Tysons No. 1 Bore (13 km southwest of Glenormiston homestead), which penetrated about

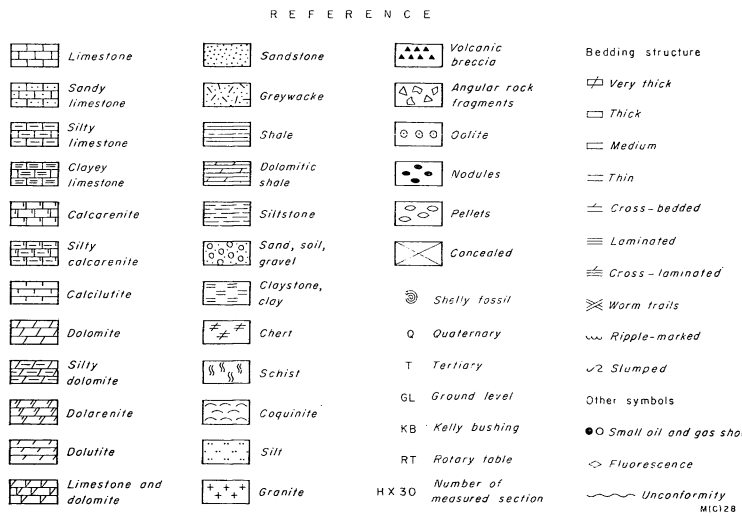


Figure 18. Symbols used in Figures 19-30.
For abbreviations used see facing page

550 m of probable early Upper Cambrian and Middle Cambrian limestone in 1910. Other indications were found in water bores to the east and south of Boulia; the bores probably penetrated Cretaceous sediments, but the gas and oil slicks may have migrated into the Mesozoic rocks from the underlying Palaeozoic sediments after the post-Lower Cretaceous tectonism. In 1956, gas was discovered during water-boring operations in the Ammaroo area in the early Middle Cambrian Sandover Beds (Mackay & Jones, 1956, unpubl.). Shepherd (1945a) recorded oil shale of Middle Cambrian age in a water bore on the main road between Camooweal and Mount Isa, and a sample from the interval 62.5 to 62.8 m (205-206 ft) was estimated to contain about 68 *l* (15 gallons) of petroleum per ton of sediment.

Abundant	abd
Alternating	altng
Aphanitic	aph
Archaeocyathids	Arch
Argillaceous	arg
Asphaltic	asph
Band	Bnd
Bitumen(inous)	Bit, bit
Black	blk
Blue(ish)	bl, (bl)
Boulder	Bld
Brachiopods	Brach
Breccia	Brec
Brown	brn
Calcarenite	Calcaren
Calcite(areous)	Calc, calc
Calcilutite	Calclut
Carbonaceous	carb
Cavernous	cav
Chalky	chk
Chert(y)	Cht, cht
Chocolate	choc
Clay	Cl
Claystone	Clst
Clean	cln
Coarse(ly)	c
Common(ly)	com
Compact	cpct
Conchoidal	conch
Conglomerate	Cgl
Cream(y)	crm
Cryptocrystalline	crpxl
Crystalline	xl
Dark(er)	dk
Dense(er)	dns
Diorite	Dr
Disseminated	dissmd
Dolarenite	Dolaren
Dolomite(ic)	Do, do
Dolutite	Dolut
Echinoids	Ech
Exposed	expd
Ferruginous	fe
Fine(ly)	f
Fissile	fiss
Flaggy	flg
Folded	foldd
Fossil	Foss
Fracture	Frac
Fragment	Frag
Friable	fri
Glauconite(ic)	Gl, gl
Grading	grdg
Gravel	Gvl
Green	gn
Grey	gy
Greywacke	Gwke
Grit	grt
Gypsum	Gp
Hard	hd
Interbed(ed)	Intbd, intbbd
Interval	Intv
Intraformational	intfm
Laminae	Lam
Leached	lchd
Lens	Len
Light(er)	lt
Limestone	Lst
Manganese	Mn
Measured	Meas
Medium	m
Micaceous	mi
Microcrystalline	micxl
Minor	mnr
Mottled	mtl
Near(ly)	nr
Nodular	nod
Occasional(y)	occ
Ochre	Oc
Pellet(al)	Pel, pel
Petroliferous	petrol
Phosphatic	ph
Pink	pk
Pipe rock	Piperk
Poor(ly)	p
Porosity, porous	Por, por
Pyrite(ic)	Py, py
Quartz(ose)	Qz, qzs
Quartzite	Qt
Rock	Rk
Rubble	Rub
Sand(y)	Sd, sd
Sandstone	Sst
Shale	Sh
Silicified	si
Silty	slt
Siltstone	Sltst
Slightly	sli
Small	s
Soft	sft
Sorted	srtd
Stylolite	Styl
Subordinate	subod
Thick(ly)	tk
Thin(ly)	tn
Tight	ti
Trace	Tr
Trilobites	Tril
Unconsolidated	uncons
Unpublished	unpubl
Vug(gy)	Vug, vug
Weathered	wthrd
White	wh
With	c
Yellow	yel

slightly or minor - in ( )
Strong(ly) - underlined

Abbreviations used in Figures 19-30

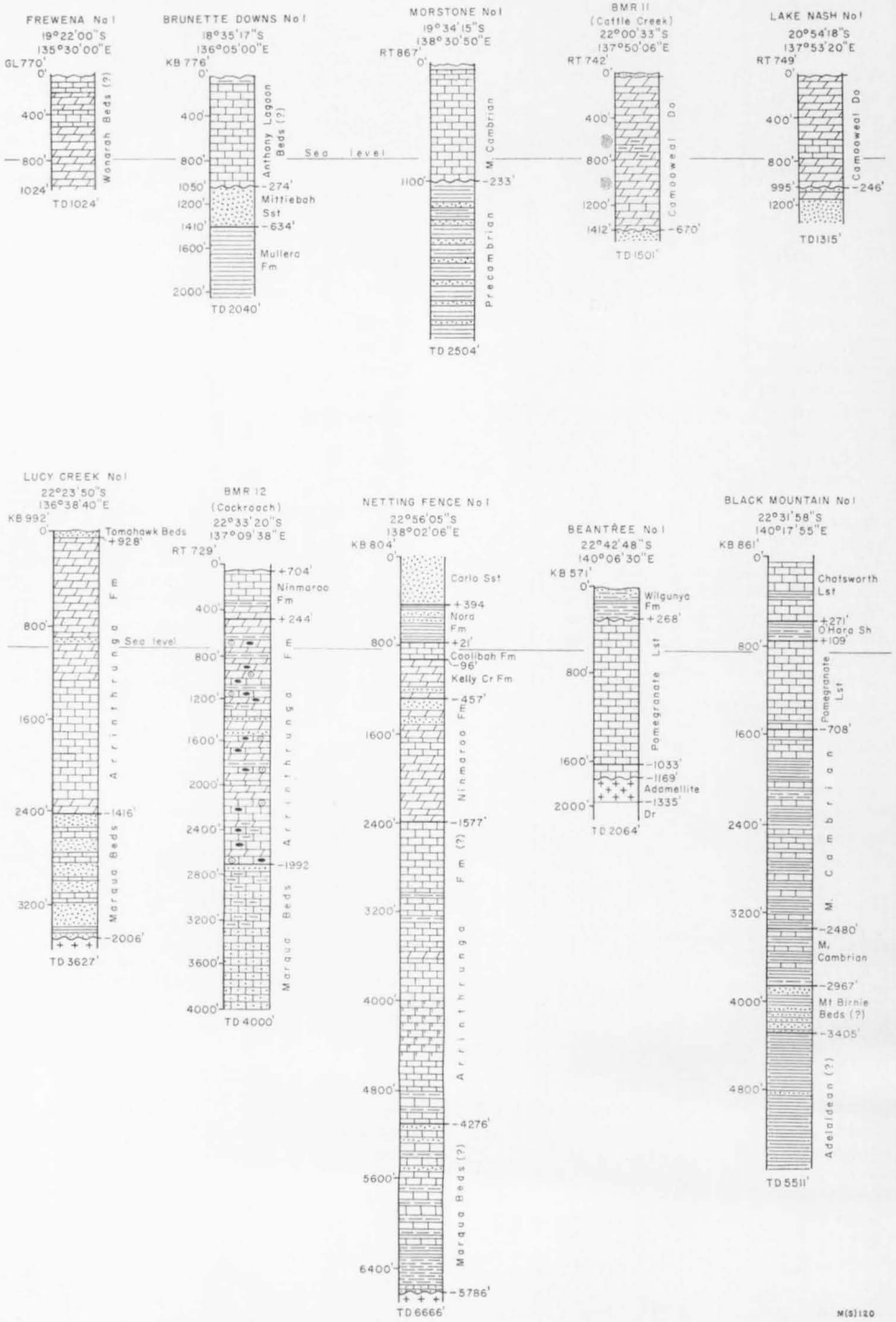


Figure 19. Stratigraphic sequences in petroleum exploration wells and BMR stratigraphic holes

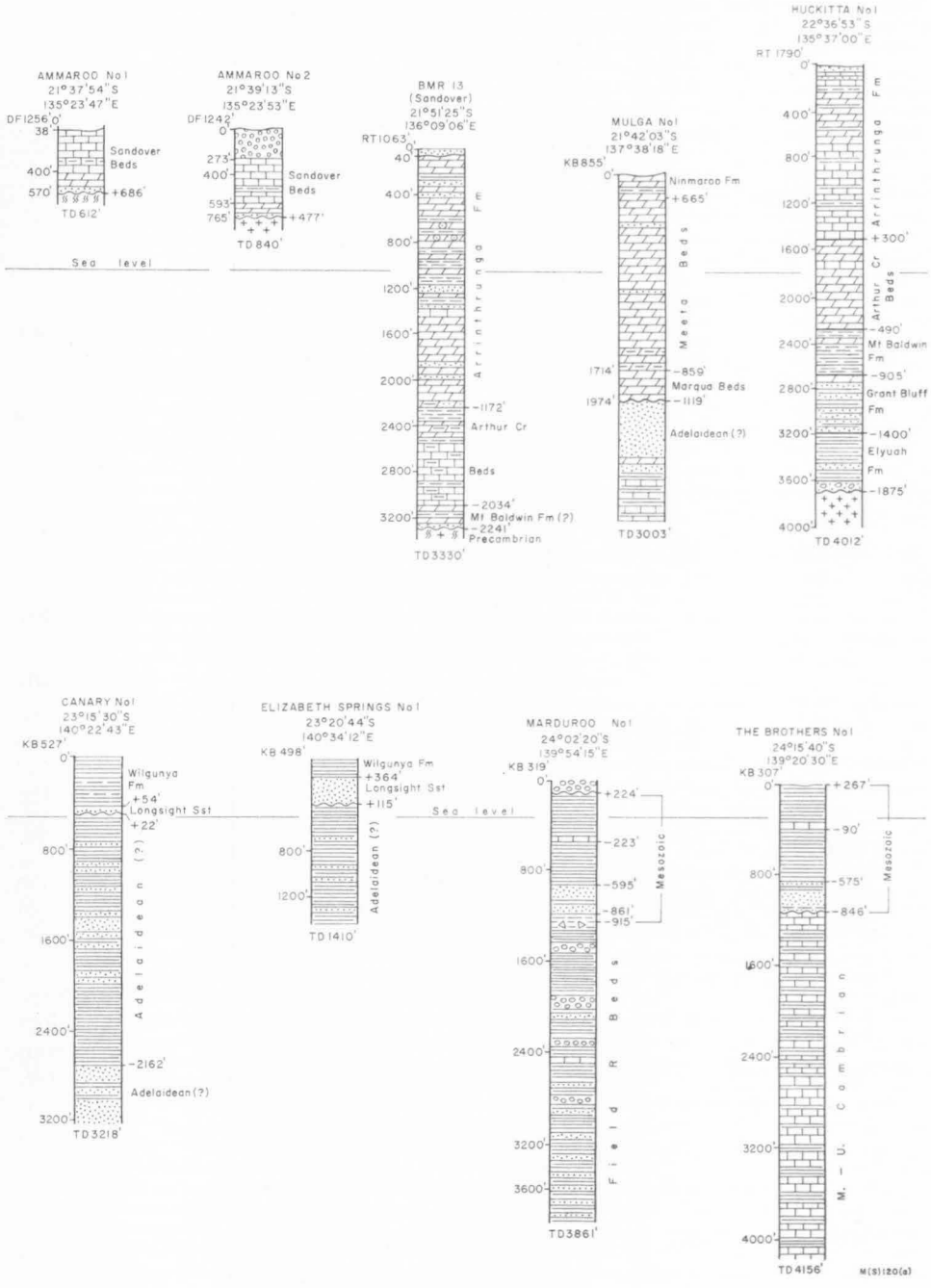


Figure 19. Stratigraphic sequences in petroleum exploration wells and BMR stratigraphic holes (cont.)

Konecki (*in* Casey et al., 1960, unpubl.) has reported the results of analyses of several of the possible source rocks in the Boulia area; some of the results are listed below:

BMR Specimen No.	*Formation*	*Residual Oil Content* (bbl/acre ft)
D126(3)	Pomegranate Limestone	Nil
D124 S(1)	Chatsworth Limestone	7.5
D124 S(2)	Chatsworth Limestone	0.23
B507 A(1)	Chatsworth Limestone	10.1
B510 C	Chatsworth Limestone	4.8
B514	Ninmaroo Limestone	3.1

Konecki also reported low porosity (seldom exceeding 2%), and zero permeability.

The water-bore records, and the results obtained in some of the petroleum exploration wells and scout holes, indicate that porous rocks are common in parts of the Georgina Basin sequence. Most of the porous rocks are carbonates; some of the sandstones are clean and porous, but others are calcareous or silty and not significantly porous. The carbonate rocks might act as good reservoirs, because many of them are vuggy and cavernous, and may have some porosity induced by dolomitization. However, many of them have been recrystallized and the permeabilities are probably low. The dolomitized limestones are generally hard and tight, and the dark limestones generally fail to produce water, as for example in the Chatsworth area of northwestern Queensland, and in several Middle Cambrian limestones in the Northern Territory. However, these formations have always been drilled for water away from known folds.

Cap rocks are present in many formations, but many of them are thin, and drilling results show more siltstone and shaly siltstone than true shale.

There are few suitable anticlinal structures in the Georgina Basin, but some are large; for example, anticlines in the Burke River Structural Belt, and some of the asymmetrical anticlines to the west of it, extend for many kilometres. The dominant structures are normal faults, which have shaped the southwestern margins of the asymmetrical Dulcie and Toko Synclines.

There are many breaks in sedimentation, particularly in Middle Cambrian time, near the margin of the basin, but thicker sections with more continuity of sedimentation are probably present in deeper parts of the basin. The petroleum prospects may be summarized as follows.

Most of the northern part of the basin, north of latitude 21°S, has poor prospects because the sequence is generally undisturbed and thin; the thickness seldom exceeds 300 m, and the sequence consists almost entirely of vuggy and cavernous carbonate rocks which yield prolific quantities of water in the first hundred metres or so, and for the entire section (433 m; 1420 ft) in BMR 11 (Cattle Creek). The following petroleum exploration wells and stratigraphic holes have been drilled in this part of the basin (see Table 6): Lake Nash No. 1, Morstone No. 1, Brunette Downs No. 1, Frewena No. 1, and BMR 11 (Cattle Creek).

In the southern part of the basin, the thickness of section increases, but much of the sequence consists of Upper Cambrian beds, which are exposed at the surface, and in places Lower Ordovician. The main targets for petroleum exploration are the Middle Cambrian sequences at the base of the succession. The thickest sections, including the Middle Ordovician and Devonian formations, crop out only

TABLE 6: SUMMARY OF PETROLEUM EXPLORATION WELLS AND DEEP STRATIGRAPHIC HOLES*

Operator	Name of Well	Total Depth (ft)	Main Stratigraphic Results	Significant Hydrocarbons	Remarks
Barkley Oil Co. Pty Ltd	Frewena 1	1024	M. Cambrian, O - TD	Nil	Test of early M. Cambrian sediments
Papuan Apinaipi Petroleum Co. Ltd	Brunette Downs 1	2040	M. Cambrian to 670 ft; M?-L? Cambrian to 1050 ft; Precambrian below 1050 ft	Nil	Test of early M. and L? Cambrian sediments; carbonate sequence 1044 ft thick
Amalgamated Petroleum Exploration Pty Ltd	Morstone 1	2504	M. Cambrian to 1100 ft; Precambrian below	Nil	Test of M. Cambrian sediments
Bureau of Mineral Resources	BMR 11 (Cattle Creek)	1501	M. Cambrian fossils in Camooweal Dolomite. Camooweal Dolomite to 1412 ft; Adelaidean? below	Nil	Stratigraphic hole testing M. Cambrian
Amalgamated Petroleum Exploration Pty Ltd	Lake Nash 1	1315	M. Cambrian fossils in Camooweal Dolomite; Adelaidean? below 995 ft	Nil	Test of M. Cambrian sediments in Lake Nash Anticline
Farmout Drillers N.L.	Ammaroo 1	612	M. Cambrian, 38-570 ft; Arunta Complex below	Nil	Test of early M. Cambrian sediments
Farmout Drillers N.L.	Ammaroo 2	840	M. Cambrian, 273-765 ft; Precambrian granite below	Small gas flow at 406 ft	Test of early M. Cambrian sediments
Bureau of Mineral Resources	BMR 13 (Sandover)	3330	U. Cambrian to 2235 ft; M. Cambrian, 2235-3097 ft; L? Cambrian, 3097-3304 ft; Precambrian metamorphics below	Traces of oil and gas at 2952-2975 ft	Stratigraphic hole, spudded about 700 ft below top of Arrinthrunga Fm
Alliance Petroleum Australia, N.L.	Mulga 1	3003	Palaeozoic carbonate sequence to 1974 ft; Adelaidean?, 1974 ft-TD. M. Cambrian (1714-1974 ft) very thin	Nil	Spudded in Ninmaroo Fm in area where magnetic basement is 6000-8000 ft below sea level
Exoil Oil Co. Ltd	Huckitta 1	4012	Base of Arrinthrunga Fm, at 1490 ft; base of M. Cambrian, 2280 ft; Mopunga Gp, 2280-3665 ft; granite below	Nil	Tested Huckitta Anticline; spudded 820 ft below top of Arrinthrunga Fm
Exoil Oil Co. Ltd	Lucy Creek 1	3627	Tomahawk Beds to 66 ft; Arrinthrunga Fm, 66-2410 ft; M. Cambrian, 2410-3600 ft; granite 3600ft-TD	Nil	Test of U. and M. Cambrian sediments
Bureau of Mineral Resources	BMR 12 (Cockroach)	4000	Ninmaroo Fm, to 485 ft; Arrinthrunga Fm, 485-2721 ft; Marqua Beds 2721 ft-TD	Nil	Stratigraphic hole, spudded near outcrops of fossiliferous Ninmaroo Fm
Papuan Apinaipi Petroleum Co. Ltd	Netting Fence 1	6666	M. Ordovician; L. Ordovician, U. Cambrian, M. Cambrian to 6590 ft; Precambrian granite below	Nil	Test of Netting Fence Anticline, within Toko Syncline. Only well to drill most of Georgina Basin sequence
Phillips Petroleum Co. Ltd	Beantree 1	2064	Mesozoic to 303 ft; U. Cambrian, 303-1604 ft; M. Cambrian, 1604-1740 ft; Precambrian crystalline basement below	Nil	Drilled near gravity low Ninmaroo Fm and Chatsworth Lst missing
Phillips Petroleum Co. Ltd	Black Mountain 1	5511	U. Cambrian to 1569 ft; M. Cambrian to 3828 ft; L(?) Cambrian to 4266 ft; Adelaidean?, 4266 ft-TD	Nil	Drilled on halfdome truncated by fault; thick sequence of non-outcropping M. Cambrian
Phillips Petroleum Co. Ltd	Canary 1	3218	Mesozoic to 504 ft; Adelaidean?, 504 ft-TD	Nil	Palaeozoic missing
Phillips Petroleum Co. Ltd	Elizabeth Springs 1	1410	Mesozoic to 383 ft; Adelaidean?, 383 ft-TD	Nil	Palaeozoic missing
French Petroleum Co. (Aust.) Pty Ltd	Marduroo 1	3861	Mesozoic to 1234 ft; Adelaidean?, 1234 ft-TD	Nil	Palaeozoic missing
French Petroleum Co. (Aust.) Pty Ltd	The Brothers 1	4156	Mesozoic to 1153 ft; U. and M. Cambrian, 1153 ft-TD	Nil	Stratigraphic test of sediments beneath Mesozoic in concealed (SE) part of basin
	Total	54,694			

* To 31 December, 1966.

near the southwestern margin; they pitch to the southeast in the Toko Syncline and, according to the geophysical evidence, thicken considerably under the Mesozoic cover rocks.

The prospects are considerably improved in the southern part of the basin, but most of the surface anticlines have already been drilled unsuccessfully. Further exploration may prove to be considerably more difficult because (i) the search for fold structures by seismic methods has been generally unsuccessful owing to the difficulty of obtaining reflections through the sheet of carbonate rocks which is present in much of the basin; (ii) economic basement often lies above magnetic basement, and therefore the depth to the base of the Middle Cambrian cannot be calculated from aeromagnetic surveys; (iii) lack of density contrast between the Palaeozoic carbonate rocks and the Precambrian metamorphic and igneous rocks has made gravity interpretation difficult.

The petroleum prospects in the northern part of the basin are poor. In the south, the prospects are slightly better, but still not good, as most of the surface anticlines have already been drilled unsuccessfully, and it will be difficult to select new drilling targets by geophysical methods in use at present.

Phosphate

Large deposits of phosphorite were discovered in 1966 by Broken Hill South Ltd in Middle Cambrian sediments in the Duchess area (Russell, 1967). Sustained and intensive exploration since 1966 has revealed the existence of several other significant deposits at the same stratigraphical horizon around the eastern and northeastern margins of the Georgina Basin. The most important of these occur in the Lady Annie/Lady Jane area, near Yelvertoft, in the Lawn Hill/Border Waterhole area, in the Ardmore Outlier, in the Quita Creek area 35 km south of Ardmore, and in the area east and southeast of Alexandria homestead some 160 km northwest of Camooweal.

The phosphorites are almost entirely restricted to the Beetle Creek Formation and its equivalents, but some secondary phosphatic material is found in associated weathering profiles and there are minor occurrences in other Middle Cambrian units. Lithologically the phosphorites show considerable variation; the commonest type is a medium to fine-grained pelletal rock which cannot be identified with any confidence as phosphorite in the hand specimen. Other varieties include dense fine-grained rocks, in some of which the phosphate is of secondary origin, and phosphatic chert, siltstone, sandstone, and limestone.

The field relationships, textures, and mineralogy of the phosphorites indicate that these sediments were deposited under varying environmental conditions and have suffered varying and complex diagenetic and weathering alterations (de Keyser, 1968, 1969a,b, all unpubl.; de Keyser & Cook, in prep.). Very shallow marine, or even paralic conditions of deposition are indicated in many cases, and it is probable that the finer-grained varieties were laid down in the more paralic (estuarine and lagoonal) environments. Penecontemporaneous phosphatization of biogenic calcareous detritus is believed to have been the most important single process, and early diagenetic phosphatization below the sediment-water interface was probably important in the formation of the argillaceous varieties. Many of the sediments have undergone profound alteration by later diagenetic changes, particularly phosphatization, silicification, and calcitization.

Detailed appraisals of the deposits, by shaft-sinking as well as by drilling, have been carried out by Broken Hill South Ltd, mainly in the Duchess and Lady Annie areas, and a considerable footage of much more widely spaced drilling has been completed, chiefly by International Minerals and Chemicals Development Corp., in the Yelvertoft and Alexandria areas. Enough information has been released to indicate clearly that very large and quite high-grade reserves are present in the province. In the Duchess area Broken Hill South Ltd have announced reserves of beneficiating grade ore of 1300 million tons with an overall grade of 17 percent P_2O_5. In the Lady Annie area the same company have proved ore reserves of 250 million tons with a cut-off grade of 18 percent P_2O_5. I.M.C. Development Corp. stated in 1967 that reserves of low-grade rock (16% P_2O_5) totalling 500 million tons were indicated in the Yelvertoft area. No figures are available for the other deposits, but it is likely that they are all less attractive, whether because of size, grade, or accessibility, than those mentioned.

Feasibility studies on the development of the deposits have been in progress for some time. Apart from the obvious problems associated with the remoteness of the province, lack of an outlet port, and ore treatment difficulties, the current world position of over-supply of phosphate rock and the uncertainty of export markets add to the problems facing the early establishment of a phosphate mining industry.

Groundwater

Because of the general lack of permanent surface water in the Georgina Basin, the pastoral industry depends on supplies of bore water. The required yield from water bores differs from area to area, according to the stock-carrying capacity. For example, a bore yielding 600 gallons per hour might be regarded as satisfactory in the south, but would be of limited use in the Barkly Tableland in the north. Successful bores generally yield at least 600 gallons per hour, and the depth to be pumped should not exceed 180 m.

Two broad groundwater provinces can be distinguished in the Georgina Basin, one to the east of longitude 139°E approximately, and the other to the west. In the eastern area, water is obtained mainly from Mesozoic cover rocks, usually in subartesian bores, but with some artesian bores. A few bores obtain water from Palaeozoic and Cainozoic sediments. In the western area, water is produced almost exclusively from Palaeozoic sediments, but some successful bores produce from Cainozoic aquifers, and a lesser number from the Mesozoic.

The Mesozoic sediments in the eastern belt form part of the Great Artesian Basin, and the hydrology has been studied in some detail. The first hydrological studies in the western belt were made by Randal (1967b), who reported on groundwater in the Barkly Tableland. The Water Resources Branch of the Northern Territory Administration, Darwin, has records of water bores drilled in the Territory, and the records for Queensland are held by the Irrigation and Water Supply Commission in Brisbane.

In the east, most of the water bores produce from aquifers in the Lower Cretaceous Longsight Sandstone; in the north, most of the bores are subartesian, but Casey & others (1960, unpubl.) have recorded 40 artesian bores in the Boulia and northern part of the Springvale Sheet areas. Farther south, where the sediments are thicker, the bores are all artesian. The Longsight Sandstone has usually produced water, but a number of unsuccessful bores have been drilled where the sandstone pinches out against buried ridges of older rocks; in the unsuccessful

bores the water has been too salty or the yield too low. Other aquifers in the cover rocks of the eastern belt have been tapped in the Lower Cretaceous Wilgunya Formation, Tertiary limestone, and Quaternary gravel. There are few successful bores in the Palaeozoic rocks of this belt. The Middle Cambrian units, and early Upper Cambrian formations, consist of dark limestone and shale which have little or no permeability unless fractured. A few successful bores have tapped cavernous Chatsworth Limestone and Ninmaroo Formation, but always in structurally low positions between buried Precambrian ridges.

There are no artesian bores in the western area. The vuggy and cavernous Middle Cambrian dolomite yields large supplies of water in the north, but most of the Middle Cambrian limestone-shale sequences near the margins of the basin, and in the south, seldom yield water except where they are strongly jointed, as in the case of the Sandover Beds on the southeastern margin of the Davenport Range. The groundwater potential of the Middle Cambrian dolomites cannot be assessed accurately, because (1) the yields of the bores have not been adequately tested; (2) the bores have been completed when an adequate supply has been obtained (generally at less than 150 m) and the remainder of the sedimentary sequence has not been tested; (3) the degree of interconnexion of the aquifers is unknown. An example of the yields from the aquifers is given by Randal (1967b), who examined data from about 450 bores on the Barkly Tableland, and reported that more than 75 percent produced more than 1500 gallons per hour, and most produced more than 1000 gallons per hour. The drilling of BMR 11 (Cattle Creek) provided information from depths greater than those normally penetrated in water bores: brief tests by air-lifting gave yields of up to 6000 gallons per hour at 125 m (after yields of 1500-2000 gph higher in the well), and the whole sequence was so cavernous, and presumably interconnected, that circulation was completely lost at 275 m and could not be regained before the base of the Middle Cambrian sequence was reached at 433 m.

In the southern part of the western area, yields of 1000 to 1500 gallons per hour have been obtained from vuggy and cavernous dolomite of the Meeta Beds and the Arrinthrunga, Ninmaroo, and Kelly Creek Formations; sandstone interbeds have also provided good aquifers in the Arrinthrunga and Ninmaroo Formations.

The Upper Cambrian/Lower Ordovician sandstone of the Tomahawk Beds has always proved a good high-yielding aquifer, and some successful bores have been drilled in the Dulcie Sandstone, but this formation, and the Ordovician Toko Group, usually crop out in inconvenient locations, and they have seldom been drilled. In any case, the lithology of the Nora Formation and Mithaka Beds generally does not appear to be suitable for aquifers. The Carlo Sandstone has produced good supplies, but the water was too salty for human consumption, although suitable for stock.

The cover rocks of the western area consist of Tertiary limestone, Quaternary sand, soil, alluvium, and gravel, and Mesozoic sandstone, siltstone, and conglomerate. The Mesozoic sediments are usually erosion residuals above ground level, and are useless as aquifers, but one pocket of Mesozoic near the northwestern end of the Tarlton Range produces 1200 gallons per hour of good water from a depth of 30 m. Tertiary sediments usually occur above the piezometric surface, but some pockets of limestone produce good supplies of water. Quaternary sequences of sufficient thickness and permeability are rare, but gravels have yielded useful supplies in a few locations.

Construction Materials

Adequate supplies of dolomite are available for construction aggregate, but its suitability has not been tested because the need has not yet arisen. For the construction of the Barkly Highway, ferruginous residual soil of lateritic origin was used; it covers considerable areas astride the highway and was obtained from several small quarries alongside the road (Carter, Brooks, & Walker, 1961, p. 248). Similar deposits are used to repair the highway. Slabs of Mail Change Limestone and Camooweal Dolomite have been used in the construction of low bridges on the Barkly Highway, and slabs of dolomite have been used for a variety of purposes, including tank stands, dwelling floors, and even the walls of huts, on pastoral properties.

In the northern part of the basin there is an acute lack of sand suitable for construction purposes, because the desert sands contain a high proportion of silt. In the south, there are generally adequate supplies of good sand in the beds of wide dry rivers; some of the sand contains chert shed from Middle Cambrian sediments and local experience indicates that it may be unsuitable for concrete, presumably because the cement does not bond well to the smooth surfaces of the chert.

ROCK UNITS

Basement Rocks

In many areas the basement is overlapped by the local basal units of the Georgina Basin succession, and in places the Palaeozoic rocks are faulted against the basement. Most of the basement rocks are Precambrian, and range in age from Archaean to Adelaidean, but in places they include Lower Cambrian sediments which form a continuous sequence with Adelaidean sediments. Knowledge of basement rocks under the basin is sparse, but it is known that the Adelaidean and Lower Cambrian sediments have low magnetic intensities, and the depths to magnetic basement computed from aeromagnetic surveys clearly indicate, by comparison with known thickness of the Palaeozoic sequence, that several thousand metres of Adelaidean/Lower Cambrian sediments underlie much of the basin. These sediments may have some petroleum prospects, but they are not highly regarded; therefore in the Georgina Basin economic basement generally lies above magnetic basement.

Figure 20 shows the distribution of Precambrian and Lower Cambrian rocks around the margins of the basin, and the geology of the marginal areas is shown in greater detail on the geological map. For convenience, each margin is discussed separately, and reference is made where appropriate to known occurrences of basement rocks beneath the basin.

Western and Southwestern Margins

The western and southwestern part of the margin is mainly in the Northern Territory (Sheets 1, 2, 4). Crystalline rocks of probable Archaean age and two sequences of Lower Proterozoic sediments form most of the marginal rocks, but several sequences of Adelaidean/Lower Cambrian sediments also crop out, and there are a few outcrops of Lower Cambrian(?) volcanics.

Crystalline Basement Rocks

The crystalline basement rocks crop out along and near the southwest margin, on the Mount Whelan, Hay River, Tobermory, Huckitta, Alcoota, Barrow Creek, and Elkedra Sheet areas. Although the crystalline rocks seldom form the actual outcropping margin they are close to most of it. In the Harts Range and its northern foothills (Huckitta Sheet area) the crystalline rock outcrops are commonly rugged, but elsewhere they crop out in low ridges and hills. They are included in the Arunta Complex of Mawson & Madigan (1930); they have been studied in some detail by Joklik (1955) in the Harts Range, and some units of his Harts Range Group (1955, p. 36) crop out in the southwest part of the Huckitta Sheet area. The Arunta Complex on the margins of the Georgina Basin generally crops out poorly, and Joklik's stratigraphic units cannot be traced beyond the Harts Range area.

The Arunta Complex along the margins includes regionally metamorphosed sedimentary and igneous rocks; gneiss and schist are common, but amphibolite, metaquartzite, and marble are locally prominent. Gneiss predominates in the western part of the Huckitta Sheet area,

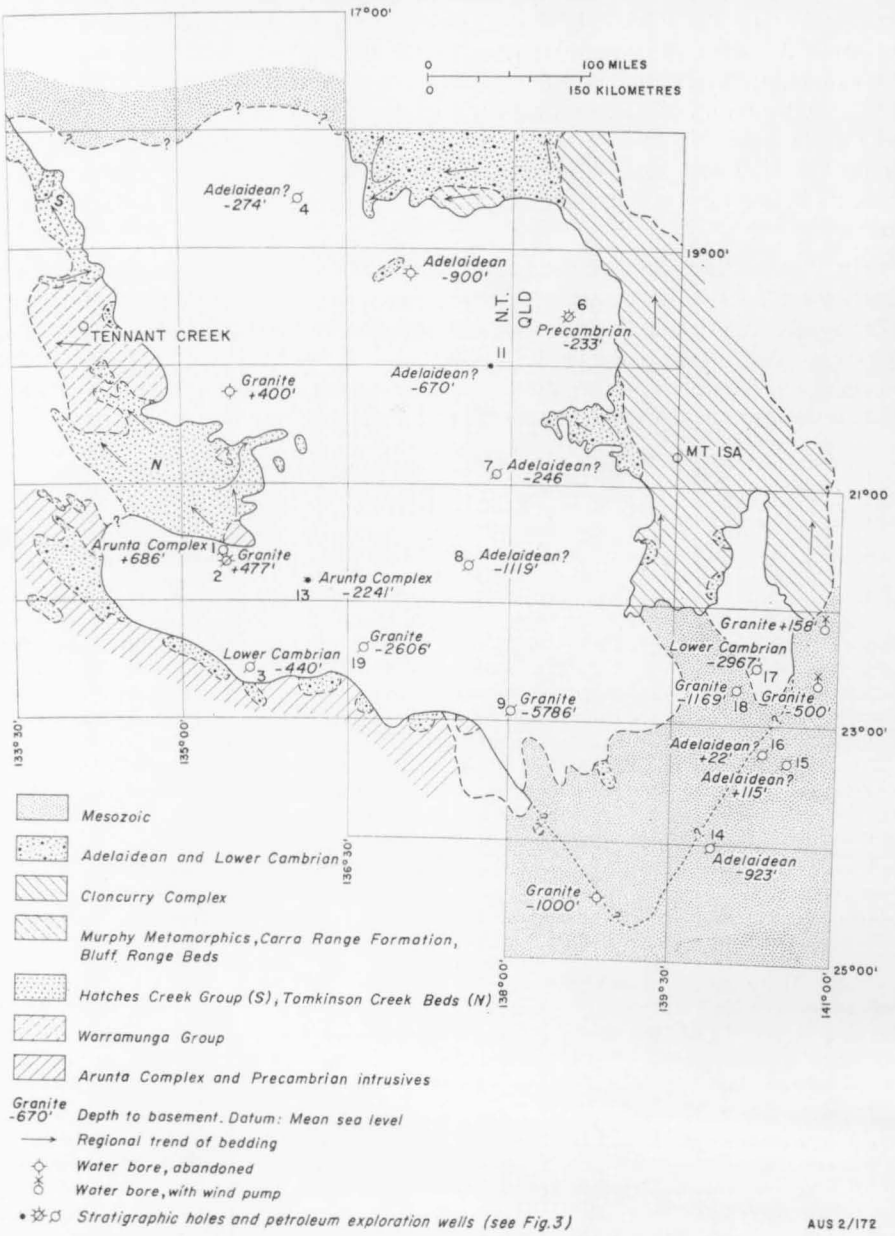


Figure 20. Basement and Mesozoic cover rocks

but elsewhere schist is more common. Morgan (1959, unpubl.) places the grade of metamorphism high in the albite-epidote-amphibolite facies, with slight thermal effects superimposed in places by igneous intrusions. The grade appears to decrease northwards towards the Barrow Creek area, but this impression may be due to paucity of outcrop.

The regional structure of the marginal rocks of the Arunta Complex is uncertain, because of paucity of outcrop and lack of marker horizons. The schistosity is roughly parallel to the bedding in the metasediments, and the dip usually exceeds 60° and is commonly vertical. The trends are generally west or west-northwest in the south and southwest, but swing to the north in the Barrow Creek area.

Because it is older than the Warramunga Group (q.v.), the Arunta Complex is tentatively regarded as Archaean. Some isolated samples have been dated at about 400 m.y. (Hurley, Fisher, Fairbairn, & Pinson, 1961), which is thought to be the age of the metamorphism associated with the Alice Springs Orogeny.

The geological history of Archaean(?) rocks is unknown, but there were two periods of intrusion of unstressed granite in the Lower Proterozoic (Walpole & Smith, 1961). The structural data in the Northern Territory suggests that the latest tectonic event before the Proterozoic era was the break-up of crystalline basement rock into polygonal blocks, along remarkably consistent fracture patterns trending northwest and east, with a minor trend northward (Walpole & Smith, 1961). This break-up, which initiated sedimentation in the Proterozoic era, was caused by tensional stress and resulted in the upthrow of some blocks and the downthrow of others. Proterozoic sedimentation occurred in conformity with the fracture pattern, and the regularity of the pattern in the Proterozoic sediments probably indicates periodicity in the tensional movements which caused the break-up. The same pattern was rejuvenated in Middle Palaeozoic time, when the major effects of the Alice Springs Orogeny in the Georgina Basin were caused by faults trending northwest.

The aeromagnetic survey of the Georgina Basin has revealed buried structural features with a similar northwesterly trend in some areas, for example in the Sandover River Sheet area (Wells & Milsom, 1965, unpubl.).

The subsurface extent of the Arunta Complex beneath the Georgina Basin is unknown, but aeromagnetic patterns attributable to the complex cover large areas of southeastern Northern Territory and extend into Queensland. It is unlikely to be basement to the Georgina Basin sediments at many localities because of the wide distribution of Adelaidean sediments, but in the Ammaroo No. 1 well Middle Cambrian sediments rest directly on a garnetiferous schist which probably belongs to the Arunta Complex, and BMR 13 (Sandover) penetrated gneiss at 1008 m (3304 ft) (Smith et al., 1967), which is also placed in the Arunta Complex. The gneiss is overlain by 63 m (207 ft) of sediments which are tentatively regarded as Lower Cambrian, but may be part of a Middle Cambrian sequence first penetrated at 682 m (2235 ft).

Lower Proterozoic Sedimentary Rocks

The Lower Proterozoic sedimentary rocks comprise the Warramunga and Hatches Creek Groups and the Tomkinson Creek Beds. They provide the basement rocks for about 500 km on the western margin of the Georgina Basin, and are overlapped directly by lower Middle Cambrian sediments.

The *Warramunga Group* is the oldest Lower Proterozoic unit; it crops out in the Tennant Creek, Bonney Well, and Frew River areas (Sheet 1), and probably extends eastwards beneath thin Cambrian sediments for a considerable distance. Ivanac (1954) named the Warramunga Group in the Tennant Creek area, and Noakes (1953) named the Warramunga Geosyncline in which the group was deposited; the limits of the geosyncline are unknown. The group has been studied in most detail in the Tennant Creek area (Ivanac, 1954; Crohn & Oldershaw, 1965; Dunnet & Harding, 1969), and Smith, Stewart, & Smith (1961) have mapped it in the Bonney Well and Frew River Sheet areas.

The Warramunga Group consists essentially of siltstone, shale, greywacke, and sandstone, with subordinate grit and pebble beds. Graded bedding is common and slump structures are abundant, but there is little cross-bedding and ripple marks are rare (Crohn & Oldershaw, 1965). The beds have a strong cleavage trending west, and are deeply weathered and tightly folded. These features, together with the general absence of marker beds and the lateral gradation from one rock type to another, have made subdivision of the Warramunga Group difficult.

The full thickness of the group has not been determined; Crohn & Oldershaw have recorded a thickness of at least 760 m northeast of Tennant Creek township, and 920 m to the southeast, and Dunnet & Harding measured 3000 m north of the township; none of the sequences is complete.

The fold axes in the Warramunga Group generally trend west, and the folding is commonly isoclinal. Prominent faults trending northwest cut the group; the faults are probably vertical, with a heave of not less than 1500 m, and the northeast block is downthrown. Numerous quartz-filled shears trend northeast and northwest, and the prominent shears associated with gold mineralization trend west.

In the Tennant Creek area, ironstone and magnetite bodies in the Warramunga Group are often associated with the gold mineralization, and a considerable amount of magnetic prospecting has been done both on the ground (Daly, 1957) and from the air (Spence, 1962, unpubl.); accordingly, the magnetic behaviour of the Warramunga Group has been studied in more detail than the other Precambrian rocks on the margin of the Georgina Basin. In the Tennant Creek area magnetite-rich bands in non-cropping rocks of the Arunta Complex also give rise to magnetic anomalies, and the aeromagnetic surveys adjacent to the Tennant Creek area (Barkley, 1965b, unpubl.) do not show conclusively that the Warramunga Group constitutes the shallow magnetic basement revealed by these surveys. However, the magnetic intensity contours in the Warramunga Group in the eastern part of Tennant Creek area (BMR maps G236-12 and G237-14, 1962) match well with magnetic intensity contours of Barkley Oil's Alroy-Walhallow survey in the Alroy Sheet area, and this, together with the strike of the Warramunga Group, and absence of major faulting, indicates that the Warramunga Group extends for some distance to the east of Tennant Creek. There is no subsurface geological information to support this, and in the Frew River Sheet area an unsuccessful water bore passed through a thin section of Cambrian sediments, into granite at 154 m (Smith, 1964b).

The Warramunga Group is regarded as Lower Proterozoic on isotopic age grounds (see p. 63).

The *Hatches Creek Group* crops out in the Davenport and Murchison Ranges, where it lies unconformably on the Warramunga Group (Smith et al., 1961). The group also crops out in the Crawford and Osborne Ranges (Barrow Creek Sheet area), where it rests unconformably on the Arunta Complex (Smith & Milligan, 1964).

Hossfeld (1954) named the Hatches Creek Group near Hatches Creek Wolfram Field (Frew Sheet area), but did not define its constituent formations. Smith et al. (1961) traced it throughout the Davenport and Murchison Ranges, and modified Hossfeld's definition slightly to include sediments at the base of the sequence. Although the name Hatches Creek Group does not conform to the Australian Code of Stratigraphical Nomenclature, it has been in common usage for many years and its retention has been allowed.

The Hatches Creek group occurs in the Davenport Geosyncline (Walpole & Smith, 1961), which contains at least 6100 m of mixed geosynclinal sediments, with both basic and acid lava flows. The sediments of the Crawford and Osborne Ranges are not marginal to the Georgina Basin, and are not considered here. The Davenport and Murchison Ranges are prominent topographic features, consisting of long strike ridges of steeply dipping silicified psammites, separated by wide flat valleys underlain by softer psammites and pelites. Here the Hatches Creek Group consists of thin to medium-bedded, medium and coarse-grained, ripple-marked, cross-bedded, pink, grey, and brown silicified sandstone, shale, and basic and acid lavas. The group has not been metamorphosed except for some thermal metamorphism near intrusive bodies, and some dynamic metamorphism in fault zones where the pelites have been converted to mica schist, and the psammites to quartz schist.

The Hatches Creek Group has been strongly folded and faulted, and intruded by basic rocks, porphyry, and granite during a Precambrian orogeny. The fold axes trend northwest through most of the Davenport/Murchison Range area, but east of Hatches Creek settlement the axis trend northeast. The folds comprise anticlines and synclines, and domes and basins, and some of the synclines are about 100 m long. Two major fault trends have been developed, one northwest and the other northeast.

The extent of the Hatches Creek Group beneath the Georgina Basin is unknown. In the Ammaroo No. 1 well (Farmout, 1963, unpubl.) and BMR 13 (Sandover) the basement rocks belong to the Arunta Complex, and no sediments of the Hatches Creek Group were encountered.

These results, coupled with the small outcrops of the Arunta Complex about 55 km northeast of Ammaroo homestead (Sheet 3), might indicate that the Hatches Creek Group does not extend far to the southeast from the margins of the Davenport Range. However, Wells et al. (1966, unpubl.) attribute the magnetic patterns in the southeastern part of the Elkedra Sheet area to the Hatches Creek Group, and they also consider that the group probably constitutes magnetic basement at shallow depths over the whole of the Frew River Sheet area and the western part of the Avon Downs Sheet area.

The *Tomkinson Creek Beds* form most of the western margin north of Tennant Creek, and crop out prominantly in the Ashburton Range. The beds were formerly known as the Ashburton Sandstone (Noakes & Traves, 1954; Ivanac, 1954; Crohn & Oldershaw, 1965), but as the unit had not been formally named, and as there was some confusion with the Ashburton Beds in Western Australia, Randal & Brown (1970) have renamed the unit the Tomkinson Creek Beds, pending its division into formations. The mapping of the Tomkinson Creek Beds is incomplete; Ivanac (1954), and Dunnet & Harding (1969) mapped part of the beds in the Tennant Creek Sheet area, and Randal & Brown in the Helen Springs (Randal & Brown, 1970) and Beetaloo (Brown & Randal, 1969) Sheet areas.

The relationship between the Tomkinson Creek Beds and the underlying Warramunga Group is uncertain; Ivanac considered that the Warramunga Group graded upwards into the (now) Tomkinson Creek Beds; Crohn & Oldershaw supported this view, but stated that the regional structure indicated an unconformity between the two units. Randal & Brown mapped part of the Tomkinson Creek Beds which are stratigraphically well above the base, and had no opportunity to study the basal contact. The regional geology and lithological similarities between the Hatches Creek Group and the Tomkinson Creek Beds suggest that the Tomkinson Creek Beds are regionally unconformable on the Warramunga Group.

The Tomkinson Creek Beds crop out in strike ridges. In the south, about 40 km north of Tennant Creek, they strike west, but the strike swings to north just east of the Stuart Highway and the beds crop out almost continuously to Newcastle Waters. They consist of fine, medium and coarse-grained, ripple-marked, cross-bedded quartz sandstone, siltstone, and dolomite with minor pebble conglomerate; Ivanac (1954) reported interbedded basic lavas in the Tennant Creek area and estimated the total thickness in this area to be 3350 m. Randal & Brown (1970) estimate the total thickness as 15,000 to 17,000 m.

The Tomkinson Creek Beds have been strongly folded and faulted. They are intruded by porphyry about 44 km north of Tennant Creek.

The eastern extent of the Tomkinson Creek Beds beneath the Georgina Basin is unknown; complete aeromagnetic coverage is lacking on the Helen Springs Sheet area, and no subsurface geological information is available except from a few water bores near the eastern margin of the beds.

Precambrian Intrusive Rocks

Numerous Precambrian igneous rocks intrude the Arunta Complex and Lower Proterozoic sedimentary rocks near the southwestern and western margins of the Georgina Basin, and in a few instances, both surface and subsurface, form basement to the Georgina Basin succession. The igneous rocks do not intrude the Adelaidean and Lower Cambrian sediments.

Granite intrusions are common along the southwestern and western margins, and there are numerous porphyry and basic intrusions in the Tennant Creek/Davenport Range area. Many of the granites have been named on the published 1:250,000 Sheets and in the accompanying Explanatory Notes, but the names have been deleted on the 1:500,000 Sheets. All the granites along the western and southwestern margins on Sheets 1, 3, and 4 are believed to be pre-Adelaidean. Hurley et al. (1961) used the K/Ar method to date eleven of them: the ages fall into two well defined groups, one averaging 1630 m.y. and the other 1440 m.y. One granite, 19 km southeast of Tennant Creek township, is included in the older group, and the others are in the second group. However, Wilson, Compston, Jeffery, & Riley (1960) using the Rb/Sr method, obtained an age of 1840 m.y. for a granite in the Huckitta Sheet area which Hurley had dated as 1440 m.y. old. The Rb/Sr age is regarded as more reliable, and all the granites may be considerably older than Hurley's results indicate.

Porphyry intrusions are common in the Davenport Range/Tennant Creek area, and one intrusion into the Ashburton Sandstone has been noted. Basic intrusive rocks are also common in the Arunta Complex, and in the Hatches Creek and Warramunga Groups.

Smith et al. (1961) have established the order of intrusion in the Davenport Range: (i) basic rocks, (ii) porphyry, and (iii) granite. Elsewhere the rocks are not in juxtaposition. The extent of these igneous bodies under the Georgina Basin is unknown, and on aeromagnetic profiles the disturbed patterns of these rocks cannot be distinguished from the patterns of the Arunta Complex. However, Wells & Milsom (1965, unpubl.) have interpreted some sharp peaks on the northeastern Sandover River Sheet as basic dykes at shallow depth. Granite has been recorded in Ammaroo No. 2, BMR 13 (Sandover), and Netting Fence No. 1 and in a water bore on Epenarra station (Frew River Sheet area), all near the margin of the basin, and also in the Kamaran Downs No. 3 Bore, which probably marks the western margin of the southeastern extension of the basin.

TABLE 7: ADELAIDEAN AND LOWER CAMBRIAN SEQUENCES ALONG THE MARGINS OF THE BASIN

Age	Rock Unit	Lithology	Thickness (m)	Fossils	Stratigraphic Relationship	Distribution				Principal References
						Southwest	West	North	East	
L. Cambrian	Helen Springs Volcanics (Clh)	Amygdaloidal basalt, tuff, agglomerate, rhyolite. Strongly weathered	15+	—	Unconformable on Ashburton Sst and Warramunga Gp	—	Helen Springs, Tennant Cr	—	—	Noakes & Traves (1954)
L. Cambrian	Makbat Sst	Sandstone with yellow flaggy siltstone near top; minor brown shale with conglomerate	300		Unconformable on Cloncurry Complex				Duchess, Boulia	Carter et al. (1961)
L. Cambrian	Mt Birnie Beds (Cli)	Conglomerate, sandstone, green shale, arkose	75	Diplocraterion, Crossochorda	Unconformable on basement; overlain by M. Cambrian sediments	—	—	—	Duchess	Öpik (1960)
Adelaidean	Sylvester Sst (Puy)	Quartz sandstone	600?		Conformable on Sun Hill Arkose	—	—	—	Mt Whelan	Casey (1959)
Adelaidean	Sun Hill Arkose (Puh)	Arkose, green shale, pebble conglomerate, arkosic dolomite	300+	Protichnites					Mt Whelan	Casey (1959)
L. Cambrian	Riversdale Fm (Clr)	Red sandstone, red conglomerate, red and purple dolomite	3-30	—	Unconformable on L. Proterozoic of Cloncurry Complex; overlain disconformably by M. Cambrian sequence	—	—	—	Urandangi (Ardmore Outlier), Glenormiston	Noakes et al (1959)
L. Cambrian	Mt Baldwin Fm (Clb)	Red quartz sandstone, red siltstone, red greywacke, red and yellow dolomite	420	Archaeocyathids, brachiopods	Conformable on Grant Bluff Fm; disconformable?	Huckitta	—	—	—	Smith (1964a)
L. Cambrian to Adelaidean	Grant Bluff Fm (P-Cg)	Glauconitic grey quartz sandstone, red, green, and blue shale, brown dolomite	60-570	Algae; Helcionella near Barrow Cr	Conformable on Elyuah Fm and Field R. Beds	Barrow Cr, Alcoota, Huckitta, Tobermory	—	—	—	Smith (1964a)
Adelaidean	Elyuah Fm (Pue)	Red and green shale, arkose	30-1050	—	Unconformable on Archaean	Hay R.				
					Disconformable on Mt Cornish Fm	Huckitta	—	—	—	Smith (1964a)
Adelaidean	Mt Cornish Fm (Puc)	Boulder beds, cyclic siltstone and fine sandstone, arkose, dolomite. One ground moraine	10-360		Unconformable on Arunta Complex and on granite	Huckitta	—	—	—	Smith (1964a)

TABLE 7.—*continued*

Age	Rock Unit	Lithology	Thickness (m)	Fossils	Stratigraphic Relationship	Distribution: Southwest	West	North	East	Principal References
Adelaidean	Field R. Beds (Puf)	Boulder beds, cyclic siltstone and fine sandstone, green siltstone, arkose, dolomite, red siltstone	1800	—	Base not exposed, overlain by Grant Bluff Fm, and unconformably by M. Cambrian sediments	Tobermory, Hay R., Mt Whelan				Smith (1963a)
Adelaidean	Central Mt Stuart Beds (Pus)	Red arkose, greywacke, sandstone, siltstone, dolomite; grey quartz sandstone	30-450				Alcoota, Barrow Cr			Smith & Milligan (1964)
Adelaidean?	Colless Volc. (Puo)	Vesicular basalt; some intermediate lavas	60?		Unconformable on Mullera Fm; overlain unconformably by M. Cambrian sediments		Lawn Hill			Carter et al. (1961)
Adelaidean	South Nicholson Group (Mittiebah Sst (Psi)	Quartz sandstone, glauconite sandstone, some pebble and cobble conglomerate	2700+	—	Conformable on Mullera Fm			Mt Drummond, Ranken, Brunette Downs		Smith & Roberts (1963)
	(Mullera Fm (Psl)	Siltstone, shale, sandstone	375-2400		Conformable on Constance Sst			Lawn Hill, Mt Drummond		Carter et al. (1961), Smith & Roberts (1963)
	(Constance Sst (Psa)	Quartz sandstone, pebbly sandstone, siltstone	300-1650		Disconformable on Carpentarian sediments			Lawn Hill, Mt Drummond		Carter et al. (1961), Smith & Roberts (1963)
Adelaidean?	Pilpah Sst (Pui)	Sandstone; some pebble conglomerate	300		Unconformable on Cloncurry Complex; overlain unconformably by M. Cambrian sediments				Mt Isa, Comooweal	Carter et al. (1961)

TABLE 8: DISTRIBUTION AND THICKNESS OF ADELAIDEAN AND LOWER CAMBRIAN SEDIMENTS ON THE SOUTHWESTERN AND WESTERN MARGINS OF THE BASIN
(thickness in m)

Unit	Barrow Creek	Alcoota	Huckitta			Tobermory			Hay River	
			Mopunga Range	Elyuah Range	Jervois Range	Keepera Ridges	Southeast	Mt Winnecke	Mt Barrington	Mt Woods/ Queensland border
Mt Baldwin Fm	Not present	Not present	180	420	360	Not present	Not present	Not present	Not present	Not present
Grant Bluff Fm	90	300	125	160	160-205	450	Not present	570	160	450
Elyuah Fm	Not recognized; probably equivalent to part of Central Mt Stuart Beds	Not recognized; probably equivalent to part of Central Beds	90-1080	30-190	135	Not present; may be equivalent to top part of Field R. Beds	Not present	Not present	Not present	Not present
Mt Cornish Fm	Not present	Not present	45	10-35	25	—	—	—	—	—
Field R. Beds	Not present	Not present	—	—	—	290	660	Not present	Not present	1800?
Central Mt Stuart Beds	70-240	300?	—	—	—	—	—	—	—	—

Note: The Central Mt Stuart Beds are not shown in strict order of superposition; they are probably time-equivalents of the Mt Cornish Fm and Elyuah Fm. and also of the upper part of the Field R. Beds.

Adelaidean(?)

The *Rising Sun Conglomerate,* which was named by Ivanac (1954), crops out in small patches about 25 km southeast of Tennant Creek township. It rests unconformably on the Warramunga Group and on Precambrian porphyry (Crohn & Oldershaw, 1965). The sequence is about 60 m thick and consists of boulder conglomerate, grit, and quartzite succeeded by sandstone, siltstone, and mudstone. The decrease in thickness and in the diameter of the pebbles, cobbles, and boulders from east to west indicates a source in the east. The sequence has been faulted and folded.

The age of the Rising Sun Conglomerate is uncertain; the lithology and structural deformation are akin to those of the Hatches Creek Group and the Tomkinson Creek Beds, but it cannot be a remnant of either of these units unless the underlying porphyry is much older than the porphyries which intrude them (at present all porphyries are assumed to be of the same general age). The Rising Sun Conglomerate is considered to be Adelaidean(?).

The extent of the Rising Sun Conglomerate beneath the Georgina Basin is unknown.

Adelaidean and Lower Cambrian

Adelaidean and Lower Cambrian rocks crop out in many places along the southwestern and western margins of the Georgina Basin; they are mostly unmetamorphosed sediments, but include some volcanics in the west. The BMR aeromagnetic surveys and core drilling indicate that the Adelaidean/Lower Cambrian sediments probably form thick sequences beneath the Middle Cambrian rocks in much of the basin.

The stratigraphy of the Adelaidean/Lower Cambrian around the margin of the basin is shown in Table 7, and Table 8 gives the stratigraphy on the western and southwestern margins, where the oldest sediments are glacial sequences—the Field River Beds and Mount Cornish Formation.

The *Field River Beds* are the oldest and thickest of the outcropping Adelaidean sequences. Smith (1963a) named the beds in the Field River area of the Northern Territory, where they crop out in the northeastern quadrant of the Hay River Sheet area. They extend northwest to the Tarlton Range, and eastwards under the Toko Syncline and beyond in the southeastern extension of the basin. The basal part of the Field River Beds forms low rounded hills, but the beds higher in the sequence form prominent strike ridges, which are separated by valleys underlain by poorly outcropping pelites and carbonate rocks. The thickness of the Field River Beds is at least 2000 m, but only about 60 percent of this can be measured.

In the northeastern part of the Hay River Sheet area Smith (1963a) recorded the sequence given in Table 10 (Appendix). In this sequence, some 760 m is concealed. The nature of the contacts between successive major intervals is uncertain because of poor exposure in most localities.

The basal sequence of the Field River Beds contains numerous bands and lenses of boulder beds. The boulders are up to 1.3 m across and include gneiss, schist, quartzite, granite porphyry, and algal dolomite; many are faceted and some are striated and polished. They lie in a roughly stratified matrix of green siltstone. It is conjectured that they are of glacial origin. Higher in the sequence boulders are present in arkose beds which may denote a second period of glaciation.

In the southeastern part of the Tobermory Sheet area and in the Hay River Sheet area, lower Middle Cambrian sediments rest unconformably on the lower portion of the Field River Beds. The late Adelaidean tectonism so indicated is largely masked by later events, but it probably included northwesterly and westerly fault activity, and in the grabens so formed the main part of the Field River sequence is preserved.

The sandstone sequences at Mount Knuckey and Mount Gardiner, in the Hay River Sheet area, are tentatively included in the Field River Beds. About 1050 m are exposed at Mount Knuckey, and about 245 m at Mount Gardiner.

The Field River Beds are correlated with the Areyonga Formation (Prichard & Quinlan, 1962) in the Amadeus Basin, which is a glacial sequence resting disconformably on the Bitter Springs Formation.

The *Mount Cornish Formation* has been named from Mount Cornish (lat. 22°46′S, long. 136°29′E, approx.) in the Huckitta Sheet area (Smith, 1964a). It crops out in a few localities at Mount Cornish, and in the Jervois, Elyuah, and Mopunga Ranges. It is also regarded as a probable glacial sequence, and is correlated with the Olympic Member of the Pertatataka Formation (Wells, Ranford, Stewart, Cook, & Shaw, 1967), a glacial sequence in the Amadeus Basin.

The Mount Cornish Formation consists of blue-green siltstone, containing boulders, cobbles, and pebbles, laminated cyclic siltstone and sandstone, and minor dolomitic arkose and quartz greywacke. The formation rests unconformably on the Arunta Complex and on associated granites, and is overlain disconformably by the Elyuah Formation.

The boulders in the Mount Cornish Formation consist of gneiss, schist, granite, metaquartzite, porphyry, and dolomite. They are well rounded, wedge-shaped, pyramidal, and kidney-shaped, polished, and some are striated. No glaciated pavements have been seen, but Condon (1958, unpubl.) has recorded a ground moraine in the northeastern end of the Elyuah Range, where 3 m of unstratified boulder clay contains boulders and cobbles of granite, and cobbles and pebbles of quartz and metaquartzite.

The thickness of the Mount Cornish Formation is 365 m in the type section at Mount Cornish, but elsewhere it ranges from 12 to 34 m.

The subsurface extent of the Field River Beds and the Mount Cornish Formation beneath the Georgina Basin is unknown, but Adelaidean glaciation was widespread in the southern part of the Northern Territory and remnants of the Field River Beds or Mount Cornish Formation are probably preserved in many places. Neither of them has been identified in any of the wells drilled in the Northern Territory, but the Field River Beds are probably widespread in Queensland (p. 24).

The *Mopunga Group,* named by Noakes (1956) and modified by Smith (1964a), comprises the Elyuah, Grant Bluff, and Mount Baldwin Formations. The group is complete only in the Huckitta Sheet area, but the resistant Grant Bluff Formation is widespread and extends intermittently from near Barrow Creek settlement southeastwards almost to the Queensland border at about latitude 23°S. Table 8 shows the distribution and thickness of the group on the western and southwestern margins of the Georgina Basin; the table also includes other units or parts of units which may be equivalent to the Elyuah Formation.

The *Elyuah Formation* consists of a basal arkose (locally called the Oorabbra Arkose Member in the Elyuah Range) and a younger sequence. The arkose rests disconformably on the Mount Cornish Formation, and unconformably on the Arunta Complex and Precambrian granite. The considerable variation in thickness of the Elyuah Formation is due to changes in thickness of the arkose member. The shale sequence is usually about 105 m thick.

The *Grant Bluff Formation* succeeds the Elyuah Formation conformably and gradationally in the Huckitta Sheet area; in the Hay River and Tobermory Sheet areas it conformably overlies the Field River Beds, and near Barrow Creek settlement the Central Mount Stuart Beds. The type section is at latitude 22°44′S, longitude 135°4′E, in the Elyuah Range (Smith, 1964a), where it is 162 m thick. The formation consists predominantly of grey, fine to medium-grained, thin-bedded, glauconitic quartz sandstone and siltstone, shale, and thin beds of algal dolomite. Worm trails are abundant, and a lower Cambrian *Helcionella* (Smith & Milligan, 1964) was found near Barrow Creek settlement. In the Huckitta Sheet area the Grant Bluff Formation underlies the fossiliferous Lower Cambrian Mount Baldwin Formation, and is generally regarded as late Adelaidean in age, but the diachronous nature of the unit is well illustrated in the Barrow Creek Sheet area, and some of the additional section in the Tobermory and Hay River Sheet areas is probably also of Lower Cambrian age.

The *Mount Baldwin Formation* conformably overlies the Grant Bluff Formation, and is overlain, probably disconformably, by the lower Middle Cambrian Arthur Creek Beds at the base of the Georgina Basin succession. The type section is in the Elyuah Range and is a continuation of the type section of the Grant Bluff Formation (Smith, 1964a).

The Mount Baldwin Formation consists predominantly of dark red glauconitic sandstone, siltstone, shale, and greywacke, with minor pink and grey sandstone, and brown and yellow dolomite. Near the top of the formation, beds of dolomite contain archaeocyathids and brachiopods of Lower Cambrian age (A. A. Öpik & J. G. Tomlinson, pers. comm.), but the position of these fossils in the Lower Cambrian time scale has not been determined.

In the Huckitta and western part of the Tobermory Sheet areas there is no evidence that the Mopunga Group was deformed at the same time as the Field River Beds and Grant Bluff Formation in the Hay River Sheet area and southeastern part of the Tobermory Sheet area.

The extent of the Mopunga Group beneath the Georgina Basin is unknown. In the Northern Territory, BMR 13 (Sandover), Mulga No. 1, Lake Nash No. 1, and BMR 11 (Cattle Creek), terminated in red sediments beneath the lower Middle Cambrian; fossils were found only in BMR 13 (Sandover), but they have not been determined.

The *Central Mount Stuart Beds* were named by Smith & Milligan (1964). They crop out in a belt extending northwestwards from the Sandover River (Alcoota Sheet area) almost to Barrow Creek settlement; and also in the southwestern part of the Barrow Creek Sheet area. The sediments are predominantly red, and comprise arkose, greywacke, siltstone, and dolomitic siltstone; they are mostly strongly cross-bedded, and some are ripple-marked. The presence of boulder beds near the local base in the northwestern part of the Alcoota Sheet area, and of probable varves near the base of Central Mount Stuart (outside the mapped area, a few kilometres southwest of lat. 22°S, long. 133°30'E), indicates a glacial origin for the lower part of the Central Mount Stuart Beds.

The Central Mount Stuart Beds unconformably overlie the Arunta Complex and Precambrian intrusive rocks, and are overlain conformably by the Grant Bluff Formation near Barrow Creek settlement. The thickness of the beds depends in part on the configuration of the basement, and ranges from 73 to 137 m south of Barrow Creek settlement, but increases southeastwards, on the Alcoota Sheet area, to about 300 m.

The Central Mount Stuart Beds generally dip at low angles to the southwest away from the Georgina Basin. The exposures may be on the upthrown side of a major fault trending northwest, and the beds could form basement to the Georgina Basin northeast of the postulated fault, but their subsurface distribution is unknown.

The *Helen Springs Volcanics,* named by Noakes & Traves (1954), crop out in small areas in the Tennant Creek Sheet area (Ivanac, 1954; Crohn & Oldershaw, 1965) and extensively in the Helen Springs Sheet area (Randal & Brown, 1970). They comprise deeply weathered amygdaloidal basalt, tuff, agglomerate, and rhyolite, and thin interbeds of sandstone and siltstone in the Helen Springs Sheet area. The maximum thickness in the Tennant Creek area is 15 m, and in the Helen Springs area 37 m.

The Helen Springs Volcanics unconformably overlie both the Warramunga Group and Tomkinson Creek Beds, and are overlain unconformably by the Middle Cambrian Gum Ridge Formation. They are considered to be Lower Cambrian in age, but have not been dated isotopically.

Northwestern Margin

No Precambrian or Lower Cambrian rocks crop out along the northwestern margin, which is tentatively drawn along the boundary between Mesozoic and Cambrian sediments.

Northern Margin

The northern margin of the Georgina Basin extends from about latitude 18°S and longitude 136°30'E in the Northern Territory, to about latitude 18°30'S and longitude 138°30'E in Queensland. The margin is defined thus for convenience, and coincides mostly with the southern margin of the South Nicholson Basin (GSA, 1962; Smith & Roberts, 1963), which contains a thick sequence of Adelaidean rocks named the South Nicholson Group. Older rocks, which unconformably underlie the South Nicholson Group, also form part of the margin of the Georgina Basin. In places, these Precambrian rocks are seen to be overlapped by the Georgina Basin sediments, but elsewhere the Precambrian and Cambrian outcrops are separated by a zone, about 12 km wide, covered by superficial sand.

The oldest Precambrian rocks, which form the basement to the South Nicholson Group, are Lower Proterozoic; they are succeeded by Carpentarian rocks. They have not been differentiated on Sheet 2, but Smith & Roberts (1963) have described and named several units in the Mount Drummond Sheet area, of which the *Murphy Metamorphics, Carrara Range Formation,* and *Bluff Range Beds* are either in contact or nearly in contact, with the Georgina Basin sediments. A summary description of these units is given in Table 9, which is based on Smith & Roberts (1963, table 1), with amendments to Carpentarian age on the advice of H. G. Roberts (pers. comm.).

The *Nicholson Granite,* which intrudes the Murphy Metamorphics, has been dated by the K/Ar method at 1815 m.y. (McDougall, Dunn, Compston, Webb, Richards, & Bofinger, 1965); so the metamorphics are Lower Proterozoic.

The extent of the Lower Proterozoic and Carpentarian rocks under the Georgina Basin is unknown. The Carpentaria rocks generally dip away from the margin of the basin, but Wells, Tipper, & Milsom (1964, unpubl.) ascribe some magnetic anomalies in the western part of the Mount Drummond Sheet area to the Murphy Metamorphics. Several anomalies in the Carrara Range area are associated with fault zones, but the sources of the anomalies could not be related to any geological horizon. The Murphy Metamorphics may extend east-

TABLE 9: LOWER PROTEROZOIC AND CARPENTARIAN SEDIMENTS ON THE NORTHERN MARGIN OF THE BASIN
(after Smith & Roberts, 1963, table 1)

Period	*Rock Unit*	*Known Maximum Thickness (m)*	*Lithology*	*Structure*
			Unconformity	
Carpentarian	(Bluff Range (Beds (((	2700	Quartz sandstone, dolomitic sandstone, limestone, dolomite, siltstone, shale, dolomitic siltstone.	Dips generally N, 0-80°. Strongly strike-faulted.
	(Carrara Range (Fm	2295	Porphyritic rhyolite, trachyte, vesicular basalt, trachyte tuff, agglomerate, conglomerate, quartz sandstone, minor shale.	Dips generally N, 0-80°. Very strongly faulted (mainly strike faults).
			Unconformity	
L. Proterozoic	Murphy Metamorphics	?	Quartz-sericite schist, sheared siltstone, greywacke, ashstone, intermediate feldspar porphyry, minor sheared calcareous siltstone, metamorphosed ashstone; monzonite?	Near-vertical dips.

wards into Queensland, but if so the aeromagnetic results on the Lawn Hill and Camooweal Sheet areas indicate that this would be at a considerable depth, and far too deep to be basement to the Georgina Basin.

The *South Nicholson Group,* named by Smith & Roberts (1963), comprises four formations of Adelaidean age—the Maloney Formation, Constance Sandstone, Mullera Formation, and Mittiebah Sandstone. The Maloney Formation is a local facies variant of the Constance Sandstone and has been included with the Constance Sandstone on Sheet 2.

Carter et al. (1961, pp. 117, 119) named the *Constance Sandstone* from the Constance Range area (Lawn Hill Sheet). The type section is at latitude 18°27′35″S, longitude 138°17′00″E. The formation borders the Georgina Basin for 150 km and extends westward into the Northern Territory, where Smith & Roberts mapped it on the Mount Drummond Sheet area. It consists mainly of medium-grained cross-bedded ripple-marked quartz sandstone, with extensive pebble beds and some siltstone lenses. Carter et al. (1961) recorded thicknesses ranging from 300 to 1100 m, and Smith & Roberts (1963) recorded a maximum thickness of 1700 m in the southwestern part of the South Nicholson Basin. The Constance Sandstone has been gently folded into basins and domes, where dips exceeding 40° are rare except near faults. The formation has been extensively faulted, and some of the faults, notably the Mitchiebo Fault and Little Range Fault, have been reactivated and have affected the Cambrian sediments in the Georgina Basin.

The *Mullera Formation* in the Lawn Hill Sheet area of Queensland was named by Carter et al. (1961). It extends into the Northern Territory across the central part of the Mount Drummond Sheet area. The Mullera Formation conformably overlies the Constance Sandstone, and is conformably overlain by the Mittiebah Sandstone in the west, and unconformably by Cambrian sediments of the Georgina Basin succession in Queensland and the Northern Territory.

The Mullera Formation consists predominantly of thin-bedded micaceous pink and white siltstone, shale, and fine-grained sandstone. Elsewhere, north of the margin, the formation contains extensive sedimentary oolitic ironstone (mainly hematite, siderite, and chamosite) and glauconitic sandstone. Carter et al. (1961) give the thickness of the Mullera Formation in northwest Queensland as 1100 to 2100 m, and Smith & Roberts (1963) state that the thickness in the Northern Territory ranges from 380 to 2450 m, and that the formation thins to the north. The folding and faulting in the Mullera Formation is similar to that of the Constance Sandstone. McDougall et al. (1965) report a K/Ar age of 1040 m.y. and a Rb/Sr age of 1160 m.y. from glauconite of the Mullera Formation. The older date is considered to be more reliable, and on this basis the whole of the South Nicholson Group is considered to be of Adelaidean age.

The *Mittiebah Sandstone* crops out only in Northern Territory, along the exposed western margin of the South Nicholson Basin in the Mount Drummond, Ranken, and Brunette Downs Sheet areas; its westernmost outcrop is about 16 km west of longitude 136°30′E, roughly at latitude 18°S. Smith & Roberts (1963) named the formation in the Mittiebah Range, where an incomplete section is about 2750 m thick; they believe that the formation thins to the north. The Mittiebah Sandstone generally consists of fine to medium-grained cross-bedded quartz sandstone, with some glauconitic sandstone near the base, and lenses of pebble and boulder conglomerate. The formation crops out poorly in the Ranken Sheet area (Randal, 1966a).

The extent of the South Nicholson Group beneath the Georgina Basin is unknown. The Alexandria No. 1 Bore (lat. 19°03′S, long. 136°47′E) terminated at 536 m (1760 ft) in sandstone which Randal (1966a) interprets as Mittiebah Sandstone, after passing through a Cambrian carbonate sequence from the surface to the top of the sandstone at 533 m (1750 ft). The Brunette Downs No. 1 well (PAP, 1965a, unpubl.), 16 km northeast of Brunette Downs homestead (Sheet 1), penetrated Cambrian sediments to 320 m (1050 ft), followed by sandstone to 430 m (1410 ft), and a siltstone sequence from 430 to total depth at 628 m (2060 ft). From the siltstone sequence P. R. Evans (pers. comm.) has obtained hystrichospherids which are identical with those from the outcrop of the Mullera Formation, and the sequence below the Cambrian in Brunette Downs No. 1 is therefore interpreted as 110 m (360 ft) of Mittiebah Sandstone, underlain by 198+ m (650+ ft) of the Mullera Formation.

Aeromagnetic surveys (Wells et al., 1964, unpubl.; PAP, 1964, unpubl.) indicate that the South Nicholson Group is non-magnetic or weakly magnetic; basement is shallow over most of the Brunette Downs Sheet area, but many of the magnetic anomalies are ascribed to intrabasement features, and the South Nicholson Group is probably relatively thin. On the other hand, deep magnetic basement is indicated over much of the Ranken, Mount Drummond,

Lawn Hill, and Camooweal Sheet areas, and since the Morstone No. 1 well and BMR 11 (Cattle Creek) indicate that the Cambrian sequence is thin, some or all of the sequence between magnetic basement and the base of the Cambrian could be the South Nicholson Group. However, the Precambrian basement sediments in BMR 11 (Cattle Creek) and Morstone No. 1 have not been identified with outcropping formations.

The *Colless Volcanics* (Carter et al., 1961) crop out in small areas in the Lawn Hill Sheet area (Sheet 2). The formation unconformably overlies the Mullera Formation and is overlain by Middle Cambrian sediments. The contact with the Camooweal Dolomite is obscured, but Carter et al. report an unconformity between the Colless Volcanics and the Thorntonia Limestone.

The Colless Volcanics consist of basalt, commonly vesicular, and are thought to be about 60 m thick. Their age is probably Adelaidean, but may be Cambrian.

Eastern Margin

The eastern margin consists mainly of the Cloncurry Complex, whose outcrop extends in a near-meridional belt from about latitude 18°30′S to about latitude 22°S, where the width of the belt is about 190 km. Gravity surveys (Gibb, 1966, unpubl.) indicate that the belt extends subsurface to about latitude 25°S, and Gibb has named the positive gravity feature over the belt the *Cloncurry Regional Gravity High*. Part of the eastern margin consists of the Adelaidean(?) Pilpah Sandstone and of three Lower Cambrian(?) units—the Riversdale Formation, Makbat Sandstone, and Mount Birnie Beds.

The brief description of the *Cloncurry Complex* which follows is based on Carter et al. (1961). The complex comprises 31 formations and 9 granite masses. For convenience, most of the formations and granite masses have been grouped as 'Undifferentiated Proterozoic' on Sheets 2 and 4, but a few units have been delineated to show regional structure.

The complex was deposited in two geosynclinal basins separated by a narrow basement belt of metamorphic rocks; Carter et al. (1961, p. 40) show the basement belt as a narrow near-meridional zone, with the western boundary to the east of Mount Isa and Dajarra and the eastern boundary generally west of longitude 140°E. The meridional belt is now occupied by the Leichhardt Metamorphics and Kalkadoon Granite. All the rocks of the Cloncurry Complex on Sheet 2 were deposited in the western basin, and those shown on Sheet 4 include some deposited in both basins; the Marraba Volcanics belong to the eastern basin.

Sedimentation in both basins was essentially arenaceous and dolomitic, with up to 6000 m of basic lavas in places. Five separate periods of granite intrusion have been recorded, and at least five of dolerite intrusion. The eastern basin suffered two major diastrophisms, but the western basin was affected by only the second.

The Precambrian strata have a wide range of metamorphic grade. The rocks deposited in the eastern basin display fracture cleavage, slaty cleavage, schistosity, gneissose foliation, and migmatization. Most of the rocks belong to the greenschist facies, but the amphibolite facies is evident over large areas. Regional metasomatism has affected a large part of the eastern geosynclinal belt. In the western basin, the Proterozoic rocks are much lower in metamorphic grade; they show, at most, slaty cleavage, and contact metamorphic effects are confined to narrow aureoles around the granites.

In the eastern basin, the faults are of the strike-slip type, and trend 030° to 045° and 130° to 150°; the faults trending 030° to 045° are the best developed. Strike faults are common, and easterly dipping high-angle reverse faults occur south of Cloncurry. Folded beds on near-meridional axes generally dip steeply.

In the western basin, strike-slip faults trend 045° and 130°, and east-west normal faults are common. Strike faults are also important, and the Mount Isa Fault is a high-angle west-dipping reverse fault. Folding is linear but open, with dips up to 80°, and occasionally overturned in the eastern part, but in the west folding is commonly of the basin and dome type, with axes in many directions.

The formations shown separately on Sheets 2 and 4 are briefly described below.

The *Eastern Creek Volcanics* were named by Carter et al. (1961, p. 73) from Eastern Creek, a tributary of Gunpowder Creek. The sequence comprises interbedded metabasalt and metasediments, with some intermediate and acid lavas near the top; the basic lavas are remarkably uniform throughout, and give a most intense pattern of magnetic disturbance (Wells et al., 1964, unpubl.). The formation crops out over a wide area, and has been subjected in different places to regional, thermal, and dislocation metamorphism, or combina-

tions of these. Intense fracturing west and northwest of Mount Isa has produced schist, and some thermal effects from the intrusion of Sybella Granite have produced high-grade metamorphic rocks west of Mount Isa and throughout the outcrop of the Eastern Creek Volcanics on the Urandangi Sheet area. The schists and gneisses south of Ardmore homestead are included in the Eastern Creek Volcanics, but they may belong to an older sequence.

The thickness ranges from 4500 to 6000 m, but in many places they are poorly exposed. The Eastern Creek Volcanics are younger than the Ewen Granite (Carter et al., 1961, pp. 145-6), which has been dated by the Rb/Sr method at 1780 m.y. (McDougall et al., 1965), and this, together with the regional stratigraphy, indicates a Carpentarian age.

The *Marraba Volcanics* (Sheet 4) consist of metabasalt, quartzite, and tuff; arenaceous rocks are most abundant at the base of the succession, and tuff predominates towards the top. Metabasalt is abundant throughout but predominates in the middle of the succession. The Marraba Volcanics have not been intensely metamorphosed; mica schist, slate, and sericite schist are known, and much of the metabasalt is schistose. The maximum thickness is probably not less than 3000 m, but intricate folding prevents reliable determination. The outcrops on Sheet 4 are part of a large northerly pitching anticline.

Carter et al. (1961, pp. 72-3) correlate the Marraba Volcanics with part of the Eastern Creek Volcanics, which are assigned a Carpentarian age.

The *Sybella Granite* is exposed in a belt trending north for about 180 km along the eastern margin of the Cloncurry Complex, and in places is overlapped by Cambrian sediments. The Sybella Granite includes four distinct types—a weathered core, foliated porphyritic granite, massive porphyritic granite, and microgranite. It has been dated (Richards et al., 1963) by the K/Ar method as about 1400 m.y.—uppermost Carpentarian.

The *Kalkadoon Granite* crops out in a meridional belt about 260 km long, and attains a maximum width of about 40 km near Dajarra. The main mass, of granodiorite, is older than the Cloncurry Complex, but minor granite and adamellite are younger. Carter et al. (1961, p. 157) believe that the Kalkadoon Granite may be as old as, or even older than, the Ewen Granite, which is the earliest granite established by field evidence. The 1400 m.y. K/Ar age (Richards, 1963) for the Kalkadoon granite is considerably younger than the field evidence suggests. Because of the uncertainty, it is shown on Sheet 4 as Proterozoic.

The extent of the Cloncurry Complex beneath the Georgina Basin is outlined by the aeromagnetic and gravity surveys. Across the strike, on the western margin of the complex, magnetic basement drops steeply and regularly, and Wells et al. (1964, unpubl.) state that in the Camooweal Sheet area the contours fall at about 200 m per km (1000 ft per mile). The trend of the edge of the complex is meridional, and has been followed across the Mount Isa and Urandangi Sheets to the Glenormiston Sheet area, where a basement ridge, probably caused by Eastern Creek Volcanics, persists at least as far south as 22°30′ (Wells & Milsom, 1965, unpubl.). The low-amplitude anomalies are similar to those over outcrops of the Sybella Granite.

The eastern boundary of the Cloncurry Complex probably coincides with the eastern margin of the Cloncurry Regional Gravity High, but the eastern margin of the preserved Georgina Basin lies west of longitude 141°E, and is formed by a subsurface which may or may not belong to the Cloncurry Complex. Casey & others (1960, unpubl.) have recorded this granite in several water bores in the eastern part of the Boulia Sheet area, and Reynolds (1965b) has recorded it in a water bore in the northeastern part of the Springvale Sheet area.

Adelaidean(?)

The *Pilpah Sandstone* crops out over an area of about 1700 sq km along part of the eastern margin of the Georgina Basin. Noakes & Traves (1954, p. 36) named the unit and Carter et al. (1961, p. 121) defined it. The Pilpah Sandstone unconformably overlies several stratigraphic units of the Cloncurry Complex and is overlain by several Middle Cambrian formations of the Georgina Basin succession.

The Pilpah Sandstone comprises fine to medium-grained well sorted light brown to white sandstone, with some coarse-grained sandstone and pebble and cobble conglomerate. Ripple marks and cross-bedding are common throughout the formation, and the maximum thickness is about 300 m. The sandstone has been folded into domes and basins with axes generally trending northwest. Dips rarely exceed 30°. The formation is faulted in a few places.

The Pilpah Sandstone has many features in common with the Constance Sandstone, with which it can be tentatively correlated.

The subsurface extension of Pilpah Sandstone as basement to Georgina Basin sediments is unknown, and is not indicated by the gravity and aeromagnetic surveys; for example Wells & Milsom (1965, unpubl.) report basement at 2450 m (sub-sea) beneath outcrops of Pilpah Sandstone.

Adelaidean/Lower Cambrian

The *Makbat Sandstone,* named by Carter et al. (1961, p. 122), crops out over less than 50 sq km in each of the Duchess and Boulia Sheet areas. The formation consists predominantly of sandstone, which is poorly sorted and commonly feldspathic, and grades upwards into yellow sandy siltstone. Brown shale, and 15 m of conglomerate, also occur in the sequence; the minimum thickness is 300 m.

The Makbat Sandstone is moderately folded, well compacted, and indurated, but not metamorphosed, although cut by quartz veins. The sandstone is underlain by the Kalkadoon Granite and by other sequences of the Cloncurry Complex; no contact has been observed in the field, but a metamorphic discordance indicates that they are separated by an angular unconformity. Carter et al. (1961, p. 122) considered the Makbat Sandstone to be Upper Proterozoic (Adelaidean).

Lower Cambrian

The *Mount Birnie Beds,* named by Öpik (1960), consist of a sequence of conglomerate, sandstone, green shale, and arkose, which rests unconformably on the Cloncurry Complex, and is overlain unconformably by lower Middle Cambrian formations. The presence of *Diplocraterion* and *Crossochorda* indicates a Lower Cambrian age (Öpik, 1960). The Mount Birnie Beds have small areal distribution along the margin of the Cloncurry Complex in the Boulia and Duchess Sheet areas, and the maximum exposed thickness is 75 m.

The *Riversdale Formation,* named by Noakes et al. (1959), crops out only in an outlier near Ardmore homestead in the Urandangi Sheet area. The formation consists of red sandstone with several bands of conglomerate, succeeded by red sandy dolomite; it rests on Precambrian basement and forms erosional residuals beneath the lower Middle Cambrian sediments. The preserved thickness ranges from 3 to 30 m, and the dip does not exceed 5°. No fossils have been found in the formation and its age may be Adelaidean or Lower Cambrian, but on the basis of correlation with the Mount Birnie Beds a Lower Cambrian age is preferred.

Southeastern Margin

The southeastern margin is not exposed and has drawn partly from geophysical information on the extent of the Toko Syncline and partly from geological information from wells and water bores. This margin coincides only in part with the Diamantina Gravity Gradient figured by Gibb (1966, unpubl.), because this gravity feature defines the southern limit of the Cloncurry Complex, whereas Adelaidean/Lower Cambrian basement rocks are known well to the north.

The most important geological information on the southeastern margin comes from the following wells:

The Canary No. 1 well (23°15′30″S, 140°22′43″E) penetrated the base of the Mesozoic sequence at 154 m (504 ft), then continued in shale to 850 m (2688 ft), and arkose from there to total depth of 981 m (3218 ft) (Phillips, 1963, unpubl.). The shale and arkose are apparently unfossiliferous, and at present are considered to be of Adelaidean age. Harding (1969) has quoted an age of 710 ± 250 m.y. for shale below the Mesozoic sequence.

The Elizabeth Springs No. 1 well (23°20′44″S, 140°34′12″E) drilled the base of the Mesozoic sequence at 117 m (383 ft), and thence shale of probable Adelaidean age to total depth of 430 m (1410 ft) (Phillips, 1963, unpubl.). Harding (1969) has reported an age of 710 ± 250 m.y. for samples of the shale.

The Marduroo No. 1 well (24°02′20″S, 139°54′15″E) drilled the base of the Mesozoic at 379 m (1242 ft), and from there to total depth of 1177 m (3861 ft) the well penetrated a sequence of sandstone and shale, with some boulder beds indicative of glacial sediments (FPC, 1964a, unpubl.). The sequence is referred to the Adelaidean Field River Beds, and Harding (1969) has reported an age of 720 ± 130 m.y. for shale from the well.

The Brothers No. 1 well (24°15′40″S, 139°20′30″E) was drilled about 65 km west-southwest of Marduroo No. 1 and penetrated Ordovician(?) and Cambrian sediments at 351 m (1153 ft), beneath Mesozoic cover (FPC, 1965c).

The Adelaidean(?) sediments in three of these wells probably belong to the Field River Beds, which are expected to be widespread beneath the southeastern Georgina Basin; one indication of this is the occurrence of Sun Hill Arkose and Sylvester Sandstone in the Mount Whelan Sheet area (Sheet 4). Although these outcrops are well within the margin of the basin as known at present, they are described here for convenience.

The *Sun Hill Arkose,* named by Casey (1959), crops out only in the Mount Whelan Sheet area (Sheet 4). The name is taken from Sun Hill, 19 km southeast of Glenormiston homestead, and the type area is partly at that locality and partly in low hills 1½ km to the north.

The formation consists of arkose, arkosic sandstone, micaceous greywacke, siltstone, dolomitic siltstone, conglomerate, and some lenses of dolomite. The only fossils known are worm trails and trilobite(?) tracks. The base of the formation is not exposed, but in places it overlies probable varves of the Field River Beds, in exposures too small to show on the 1:500,000 scale map. The maximum exposed thickness is 45 m.

Casey (1959) remarked on the lithological similarity between the Sun Hill Arkose and the arkosic beds in the Hay River Sheet area of the Northern Territory which are now mapped as Field River Beds.

The *Sylvester Sandstone* was named by Casey (1959) from outcrops along Sylvester Creek on Marion Downs station (Sheet 4), about 55 km west of the homestead. The type area is 13 km north-northeast of Watchee Bore, and 6 km southeast of Rocky Yard, on Marion Downs station.

The formation consists of silicified sandstone, with many slump rolls and balls, and green siltstone. The base of the sequence is not exposed, and the top is either eroded or overlain unconformably by Mesozoic sediments. The maximum thickness is 360 m in the type area.

The Sylvester Sandstone probably overlies the Sun Hill Arkose conformably, but the contact has not been seen (Casey, 1959). It is a correlate of the upper part of the Field River Beds. No fossils have been found and the age of the formation is based on a clear identification of the tracks in the underlying Sun Hill Arkose as trilobite tracks, which would place it in the Lower Cambrian.

The extent of the Sun Hill Arkose, Sylvester Sandstone, and/or Field River Beds below the southeastern part of the Georgina Basin is unknown, but it is probable that they underlie much of the Toko Syncline and of the basin to the east of the syncline.

Middle Cambrian

NORTHERN TERRITORY

Gum Ridge Formation

Derivation of Name: From Gum Ridge, a Trigonometrical Station about 25 km east-northeast of Tennant Creek. Named by Öpik (*in* Ivanac, 1954; see also Öpik, 1956b).

Distribution: Tennant Creek, Frew River, and Bonney Well Sheet areas (Sheet 1). Discontinuous belt from about 48 km northeast of Tennant Creek southeastwards for about 190 km to northeast margin of Davenport Range. The outcrops are all on or near the margins of Lower Proterozoic rocks; there is some evidence in water bores on the Frew River Sheet area (Smith, 1964b) that the formation extends to the north and east in the subsurface.

Lithology: Shale, limestone, sandy limestone, chert, and fine-grained sandstone at Gum Ridge; shale, chert, sandstone, and conglomerate on margin of Davenport Range.

Thickness: 13.5 m at Gum Ridge Trigonometrical Station; 3 to 23 m on and around margin of Davenport Range; 150 m in subsurface (Frew River Sheet area).

Contacts: Unconformably overlies Lower Proterozoic Warramunga and Hatches Creek Groups, and Precambrian igneous rocks intruding them; unconformably overlies Lower Cambrian Helen Springs Volcanics; top eroded.

Fossils (Öpik *in* Ivanac, 1954; Öpik, 1956b): Trilobites, brachiopods, hyolithids, sponges.

Age: Lower Middle Cambrian, Ordian Stage (Öpik, 1967b); *Redlichia* Zone.

Description and Comment

The Gum Ridge Formation is part of an extensive sheet of Middle Cambrian sediments in the northern part of the basin, and is one of the basal formations of the Georgina Basin sequence. Before 1956 most, if not all, of the *Redlichia*-bearing sediments in Australia were regarded as late Lower Cambrian, but Öpik (1956b) has shown that *Redlichia* is associated with other Middle Cambrian fossils in northern Australia.

The Gum Ridge Formation is usually poorly exposed in rubble-covered rises; the rubble generally consists of angular fragments of chert and silicified shale, some of which are rich in fossils. In many localities, the rubble has been recemented to form pavements and large blocks, but in places it has been redistributed over the surface of depressions and plains which may or may not be underlain by the Gum Ridge Formation.

The subsurface extent and thickness of the Gum Ridge Formation are unknown, but it probably extends at shallow depth under much of the Frew River, Tennant Creek, and Alroy Sheet areas. Reliable logs of three water bores on Epenarra station (Frew River Sheet area) show sequences of dolomite, limestone, chert, and sandstone which are believed to belong to the Gum Ridge Formation (Smith, 1964b). However, no fossils have been found, and the beds could belong to a younger Middle Cambrian sequence. Two of the bores reached total depths of 88 m and 110 m in the Gum Ridge Formation, but the third (section A-B, Sh. 1) passed into granite at 154 m below surface. In this bore the Quaternary was 15 m thick, and the Cambrian sequence had a thickness of 139 m.

The Gum Ridge Formation has not been metamorphosed or intruded by igneous rocks and no folding or faulting movements have affected it.

Wonarah Beds

Derivation of Name: From Wonarah Telegraph Repeater Station, on Barkly Highway (lat. 19°55'S, long. 136°21'E), and about 275 km by road from Tennant Creek. Named Wonarah Beds by Öpik (1956b) from outcrops along Barkly Highway.

The name is synonymous with the Alroy Downs Beds (David, 1932), and formed part of the Barkly Group of Noakes & Traves (1954).

Distribution: Alroy and Frew River (Sheet 1), and Avon Downs and Ranken (Sheet 2) Sheet areas. Discontinuous belt from Frewena (Sheet 1) to Barrys Caves (Sheet 2) approximately, and on both sides of Barkly Highway.

Lithology: Shale, oolitic limestone, coquinite, dololutite (all deeply weathered on surface); dolomite, limestone, siltstone, and sandstone known in subsurface.

Thickness: In outcrop, seldom exceeds 15 m; in subsurface, at least 140 m in water bores, and 368+ m (1204+ ft) in Frewena No. 1. No well or water bore has penetrated the whole sequence; maximum thickness probaby less than 450 m, and in most places it is probably less than 30 m.

Contacts: Base not exposed, top eroded; no subsurface data available on basal contacts; probably unconformable on Precambrian basement.

Fossils: (Öpik, 1956b, p. 41): Trilobites, brachiopods, and a mollusc (*Helcionella*).

Age: Lower Middle Cambrian. The fossils of the Wonarah Beds are slightly younger than those of the Gum Ridge Formation, but since all the fossils are from surface samples and there is adequate subsurface evidence that each locality is underlain by about a hundred metres of near-horizontal Cambrian sediments, it is likely that lower parts of the Wonarah Beds are equivalent to, and perhaps contiguous with, the Gum Ridge Formation, as suggested by Öpik (1956b, fig. 2, p. 6).

Correlates: Burton Beds (Alexandria Beds of Öpik, 1956b), and Sandover Beds; may intertongue with Ranken Limestone (Öpik, 1956b, fig. 2, p. 6), but no contacts observed.

Description and Comment

The low surface exposures are commonly deeply weathered and covered with chert rubble. Randal & Nichols (1963, unpubl.) record laterite cappings, up to 10 m thick, on the Wonarah Beds. Outcrops are rare, but some are known near Barrys Caves (Sheet 2), where Randal & Brown (1962b, unpubl.) recorded the sequence given in Table 11 (Appendix).

Fossils are abundant in chert scree from the Wonarah Beds.

In the subsurface, the Wonarah Beds usually consist of carbonate rocks, with minor siltstone and sandstone. The logs of the Frewena No. 1 well, three BMR core holes, and one water bore are summarized in Figure 21. The Barkley Oil Co. Pty Ltd (1965a, unpubl.) recorded limestone and dolomite, with some red and purple shale, to 149 m (490 ft), and dolomite from 149 to 312 m (490-1024 ft) (TD) in Frewena No. 1. Gypsum is abundant in the interval from 110-149 m (360-490 ft) and also in the upper half of the dolomite interval. All the carbonate beds are vuggy.

In core hole Grg 17, Milligan (1963, unpubl.) recorded red, chocolate, and green siltstone and sandstone interbedded with dolomitic limestone; he considered that the lithology resembled

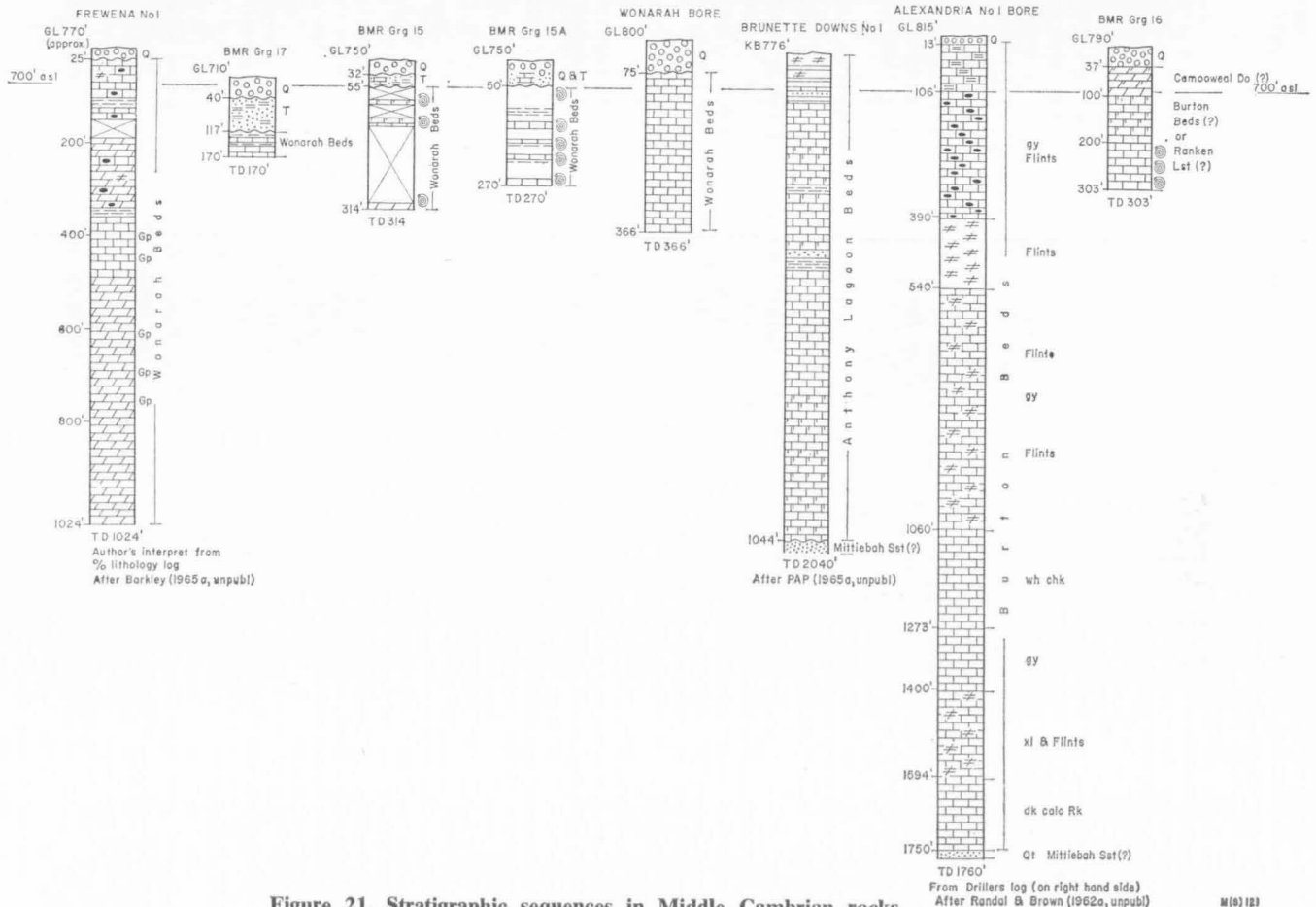


Figure 21. Stratigraphic sequences in Middle Cambrian rocks

M(8) 123

that of the Anthony Lagoon Beds rather than the Wonarah Beds. Pending further evidence the sequences in Grg 17 and Frewena No. 1 are here placed in the Wonarah Beds.

As core recovery in Grg 15 was poor, Grg 15A was drilled a kilometre to the south (not shown on Sheet 1). In addition to the logs of the cores (Fig. 21), Milligan (1963, unpubl.) summarized the sequence in both core holes (Appendix, Table 12).

The log of the water bore at Wonarah Telegraph Repeater Station shows the typical lithology reported by drillers from many water bores in the area. The subsurface carbonates are commonly vuggy and cavernous and yield good supplies of subartesian water, which is usually suitable for stock and domestic use.

Anthony Lagoon Beds

Derivation of Name: From Anthony Lagoon homestead (lat. 17°59'S, long. 135°32'E) in Walhallow Sheet area (Sheet 1). Name given by Plumb & Rhodes (1965) to rubbly outcrops of dolomite, limestone, calcareous sandstone, and chert on black-soil plains around Anthony Lagoon and Creswell Downs homesteads. Randal (1966b) included outcrops in Brunette Downs Sheet area.

Distribution: Brunette Downs and Walhallow Sheet areas (Sheet 1). Crop out in low well defined ridges in northwest part of Brunette Downs Sheet area, and in low lateritized rises in central part. The wide distribution of shale on the grassy black-soil downs, and information from water bores, suggests that much of the downs in the Brunette Downs and Walhallow Sheet areas may be underlain by the Anthony Lagoon Beds.

Lithology: Outcrop: lateritized dolomite, limestone, ripple-marked quartz sandstone, and siltstone. Rubble on black-soil downs includes blocks of yellow-brown to buff coarse-grained dolomite interbedded with fine-grained limestone, grey fine-grained calcareous sandstone, chert, silicified limestone, silicified coquinites, silicified oolitic limestone, and oolitic chert.

Subsurface: limestone, dolomitic limestone, chert, calcarenite, calcilutite, sandstone, and shale in Brunette Downs No. 1 (Fig. 21); dolomite, limestone, sandstone, and shale in drillers' logs of water bores. Geologists' examinations of chips from water bores show silty micaceous limestone and dolomite, and grey, tan, and red-brown quartz sandstone.

Thickness: 395 m (1044 ft) in Brunette Downs No. 1; up to 210 m in water bores; less than 15 m in outcrop.

Contacts: Top eroded; base known only in Brunette Downs No. 1, in which Beds rest on weathered surface of Adelaidean Mittiebah Sandstone. Overlain by Mesozoic and Cainozoic sediments.

Fossils: Algae, and fragments of trilobites and echinoderms(?), in surface rubble; indeterminate brachiopods below 204 m (670 ft) in Brunette Downs No. 1.

Age: Lower Middle Cambrian(?).

Correlates: May be extension of Wonarah Beds to south, and Burton Beds to east.

Description and Comment

Owing to poor outcrop, deep weathering, and the lack of diagnostic fossils, very little is known of the Anthony Lagoon Beds. In the northern part of the Georgina Basin, the carbonate sequence beneath the rubbly outcrops and surrounding black-soil plains is referred to the Anthony Lagoon Beds. It is assumed that the Beds are a local facies variant in the carbonate sequence which extends continuously over much of the northern part of the basin. The Anthony Lagoon Beds are probably equivalent to many of the named lower Middle Cambrian formations, and the age of the oldest beds in the sequence probably varies in accordance with local basement topography.

Part of the northwestern margin of the Georgina Basin cannot be delineated because of the uncertainty as to the northern limits of the Anthony Lagoon Beds. The black-soil plains are commonly underlain by Cambrian carbonate rocks, but similar soils can be developed on the Tertiary carbonate rocks.

The Anthony Lagoon Beds have not been metamorphosed and no structural trends are evident. In the subsurface, the carbonate rocks are usually vuggy and cavernous in part, and yield good supplies of water (Randal, 1967b).

Peaker Piker Volcanics

Derivation of Name: From Peaker Piker Creek in southwest part of Mount Drummond Sheet area. Creek flows near outcrops of Peaker Piker Volcanics and drains areas probably

underlain by them. Named and described by Smith & Roberts (1963, pp. 10-11); no type section designated.

Distribution: Mount Drummond Sheet area only (Sheet 2). In mesas and low hills in west, mainly north of Fish Hole Creek, and near Peaker Piker Creek in southwest. Subsurface distribution unknown; Smith & Roberts (1963) report areas of black soil, formed by weathering of the Volcanics, contiguous with outcrops.

Lithology: Strongly weathered vesicular and non-vesicular basalt, with some trachyte(?) and minor dolerite flows; lenses of sandstone near base, south of Peaker Piker Creek.

Thickness: 37 m.

Contacts: Unconformably overlies Mullera Formation and Mittiebah Sandstone; conformably overlain by Burton Beds. At one locality, Smith & Roberts (1963) report a lens of lava in a siltstone-shale sequence of the Burton Beds.

Fossils: No fossils found in sandstone near base.

Age: Lower Middle Cambrian.

Description and Comment

The Peaker Piker Volcanics are particularly susceptible to lateritization and weathering. In outcrop, their distribution is similar to that of the overlying Burton Beds. They have not been recorded in water bores, possibly because adequate supplies were obtained in the overlying carbonate rocks.

Wells et al. (1964, unpubl.) recorded a few scattered low-amplitude short-wavelength anomalies in the smooth magnetic profiles in the northwestern part of the Mount Drummond Sheet area which they consider are due to shallow sources in the Peaker Piker Volcanics.

The Peaker Piker Volcanics have not been folded, but in places they have been faulted; the age of the faulting is unknown.

Middle Cambrian fossils have been found in siltstone-shale 6 m above a lens of lava in the Burton Beds (Smith & Roberts, 1963). Smith & Roberts regard the lava as a late phase of the activity represented by the Peaker Piker Volcanics, and therefore place the Volcanics in the lower Middle Cambrian. This is the only record of probable Middle Cambrian vulcanicity around the margins of the Georgina Basin, but many volcanics in the Northern Territory, including the Helen Springs Volcanics on the northwestern margin of the basin, underlie fossiliferous Middle Cambrian sequences and are regarded as Lower Cambrian in age. However, there is no palaeontological evidence to support the Lower Cambrian age and all, or some, of the volcanics could be early Middle Cambrian.

Burton Beds

Derivation of Name: From Burton Creek, which drains part of outcrop area in western part of Mount Drummond Sheet area. Named by Smith & Roberts (1963, p. 11); Randal (1966a) traced them southwards to Alexandria homestead and other areas in Ranken Sheet area. The name Burton Beds supersedes the Alexandria Beds of Öpik (1956b, p. 40). Smith & Roberts do not give a reference section for the Burton Beds, but Öpik (1956b, p. 40) states that the best exposure is at the 'old well' on Alexandria station, 11 km northwest of the homestead, where 36 m of Cambrian sediments rest on the Precambrian Mittiebah Sandstone.

Distribution: Mount Drummond and Ranken Sheet areas (Sheet 2). Crops out in rounded hills, commonly capped with laterite, in western part of Mount Drummond Sheet area, and in low rises in Ranken Sheet area. Generally poorly exposed; their presence commonly inferred from chert rubble on low rises.

Lithology: Mount Drummond Sheet area: white and cream siltstone and shale (silicified in places), chert and red friable medium-grained sandstone. Ranken Sheet area: limestone, oolitic limestone, coquinite, mudstone, shale, siltstone, and chert; grey and green dolomite in water well east of Alexandria homestead. Randal (1966a) reports that shale predominates in Burton Beds southeast of a prominent ridge of Mittiebah Sandstone. The Beds are usually strongly lateritized and there are few outcrops of unaltered sediments.

Thickness: 23 m in Mount Drummond Sheet area; maximum of 535 m (1750 ft) in Alexandria No. 1 Bore (Fig. 21).

Contacts: Unconformably overlie Mittiebah Sandstone and conformably overlie Peaker Piker Volcanics; top eroded.

Fossils (Öpik, 1956b): Abundant trilobites, brachiopods, sponges, echinoderms and hyolithids.

Age: Lower Middle Cambrian, Templetonian Stage (Öpik, 1967b).

Correlates: Probably Wonarah Beds and Anthony Lagoon Beds.

Description and Comment

Much of the limestone in the Burton Beds has been recrystallized, but the fossils and oolites have not been completely obliterated. Coquinites are common: one type contains trilobites and hyolithids cemented by sparry calcite; others contain brachiopods and echinoids, and have a matrix of fine-grained brown calcite. The scree and rubble is commonly silicified, but the original texture of the limestone has not been completely destroyed. In the oolitic limestones, the oolites have been replaced by a fine mosaic of chert, with coarser chert mosaics in the voids between the oolites.

In the few water bores, which have penetrated the full sequence, the thickness of the Burton Beds ranges from 90 to 530 m. The sediments are generally horizontal or nearly so. The Burton Beds have been faulted in parts of the Mount Drummond Sheet area, but in the Ranken Sheet area the beds are undisturbed.

Ranken Limestone

Derivation of Name: From Ranken River, a tributary of Georgina River. Öpik (1956b, p. 41) applied name to outcrops of oolitic and crystalline limestone in valley of Ranken River. Randal (1966a, 1967a) also included chert and dolomite. No type section described.

Distribution: Ranken and Avon Downs Sheet areas (Sheet 2). Outcrops limited to narrow meridional belt extending from Soudan, on Barkly Highway, north-northwest for about 30 km; most of them lie west of Ranken River.

Lithology: Thin and medium-bedded oolitic and crystalline limestone, silicified limestone, coquinite, chert, and minor dolomite. Ripple marks present; shell-in-shell structure common in accumulations of brachiopods and *Biconulites*.

Thickness: Not recorded; no outcrop thicker than 6 m.

Contacts: Base not exposed and not recorded subsurface; top eroded. Several kilometres of black-soil plains separate the outcrops of the Ranken Limestone from the Wonarah Beds cropping out to the west. To the east, dolomite rubble (the Camooweal Dolomite) is common on the black-soil plains. Öpik (1956b) considers that the fossils indicate that the top of the Ranken Limestone cannot be older than the Wonarah Beds, and that the two units probably intertongue. Öpik states that 'the Ranken Limestone rests on the Camooweal Dolomite'; Condon (1961, unpubl.) considers that the Ranken Limestone dips east at 1° to 2°, and that it appears to grade upward into the Camooweal Dolomite on the east bank of the Ranken River.

In fact the contacts between the Ranken Limestone and the Wonarah Beds or the Camooweal Dolomite have not been observed, and more recent work, summarized by Smith (1965a), shows that most of the Camooweal Dolomite is of Middle Cambrian age.

Fossils (Öpik, 1956b, p. 41): Abundant trilobites, brachiopods, cystids, hyolithids, and archaeocyathids.

Age: Lower Middle Cambrian, Ordian Stage.

Description and Comment

The Ranken Limestone is poorly exposed in scattered slabs, large blocks, and gravel on the black-soil downs. Limestone predominates; according to Randal (1966a) some of the limestone beds consist of pellets and fossil fragments set in a matrix of optically dense fine-grained calcite; terrigenous quartz, feldspar, and mica are present in the pellets. The sediments were deposited in shallow water, probably along a shore line.

In addition to the fossils listed above, Öpik (1956b, p. 41) records the presence of the upper Middle Cambrian trilobites *Asthenopsis* and *Papyriaspis* at the top of the Ranken Limestone in one locality, but states (p. 41) that they occur 'in the fragmented and re-cemented top of the Ranken Limestone', which he accepted as evidence of re-working of the upper part of the formation. Öpik cites as supporting evidence the occurrence of an upper Middle Cambrian fauna in a few limestone and chert boulders on the surface of the Camooweal Dolomite east of the Ranken River, and of a boulder containing *Amphoton* on the bank of the Ranken River south of the Barkly Highway; alternatively, they belong to the Camooweal Dolomite and show that in this locality it is upper Middle Cambrian in age. The residuals have not been mapped as a separate stratigraphic unit.

Undifferentiated Middle Cambrian

Several outcrops on Sheets 1 and 2 are shown as 'Undifferentiated Middle Cambrian'. Those on Sheet 1 have since been mapped (Randal, Brown, & Doutch, 1966, unpubl.) and the westernmost outcrop, near Brunchilly homestead, includes both the Precambrian Tomkinson Creek Beds and Middle Cambrian Gum Ridge Formation, whilst the other two are placed in the Anthony Lagoon Beds. The outcrops on Sheet 2 have not been mapped; they occur in the north-central part of the Ranken Sheet area (Randal, 1966a) and consist of blocks of coarsely crystalline dolomite with chert nodules which contain abundant hyolithids and fragments of trilobites and brachiopods. The lithology does not resemble that of the other Middle Cambrian units in the northern part of the basin, and the relationship between the undifferentiated Middle Cambrian sediments and the surrounding Camooweal Dolomite is unknown.

A sequence of 81 m (266 ft) of carbonate rocks was cored in Grg 16 (lat. 19°45′50″S, long. 136°51′23″E) below 11 m (37 ft) of Quaternary gravel and soil (Milligan, 1963, unpubl.). A summary of the log (Fig. 21) is given in Table 13 (Appendix).

The sequence below 60 m (200 ft) is partly similar in lithology to the Ranken Limestone and Burton Beds, either of which could be present in the core hole. Gatehouse (1967, p. 60) has found *Biconulites* in Core 27 (2.9 m; 220 ft 9 in-230 ft 2 in), *Biconulites* and Ptychopariid trilobites in Core 29 (3 m; 240 ft-250 ft 1 in), and lithistid sponge spicules in Core 35 (2.7 m; 290 ft 5 in-299 ft 2 in) and Core 36 (1.2 m; 299 ft 2 in-303 ft); the fauna is not diagnostic but is probably of early Middle Cambrian age.

Although the identity of the formations in the core holes has not been satisfactorily established, the hole does show that Middle Cambrian sediments are present in an area which Öpik (1956b, fig. 2) believed to be underlain by the Adelaidean or Lower Cambrian Camooweal Dolomite. The sequence between 11 and 30 m in the core hole may be Camooweal Dolomite, but at present it is considered that the boundary of this formation (Sheet 2) probably lies east of Grg 16.

Sandover Beds

Derivation of Name: From Sandover River (Sheet 3); outcrops extend from near river northwards to southeast foothills of Davenport Range. Named and described by Öpik (1956b, pp. 42-44); Smith et al. (1961) included unfossiliferous sandstone and conglomerate at base of section; Smith (1966) included fossiliferous limestone to west of area examined by Öpik. The sequence has not been defined as a formation because the upper contact is not exposed. No reference section has been nominated. Good sections of the basal sandstone and conglomerate can be seen west of Andagera Bore, and the limestone is exposed between Limestone Bore and the Ammaroo No. 1 well; the remainder of the sequence can be seen along the tracks from Arganara Bore to the Fitz and Andagera Bores (see loc. diag., Fig. 22).

Distribution: Elkedra Sheet area (Sheet 3). Crops out mainly between southern foothills of Davenport Range (about lat. 21°30′S) and Sandover River; some outcrops in southeast foothills of Davenport Range and in valleys within the range. Subsurface extent unknown; away from main outcrop areas only information available based on logs of a few water bores.

Lithology: Basal sandstone, with local lenses of conglomerate, succeeded by siltstone with interbeds of shale, limestone, and sandstone; in western part of outcrop area, limestone interbeds grade laterally into siltstone.

The sandstone is brown and pink, thin to medium-bedded, medium to coarse-grained, and ripple-marked, with local lenses of thick-bedded pebble, cobble, and boulder conglomerate. The siltstone is usually buff and white, silicified, thin to medium-bedded, and richly fossiliferous. It contains interbeds of buff and white fossiliferous shale, and minor limestone, sandstone, and chert. The limestone is grey and blue, thin-bedded to massive, and algal in part. It contains nodules of chert and interbeds of shale and siltstone.

In the Ammaroo No. 1 and No. 2 wells, the sequence includes hard grey argillaceous limestone; hard dark grey and black bituminous crystalline limestone interbedded with grey to black bituminous shale; dark grey, blue grey, and green-grey dolomitic shale; and sandstone and quartzite (Fig. 22).

Thickness: Estimated maximum thickness 225 m. The thickness of exposed sequences is difficult to measure because of poor exposure of the limestone beds and slumping in the siltstone beds. The thickness of the basal sandstone-conglomerate ranges from 2 to 36 m, and

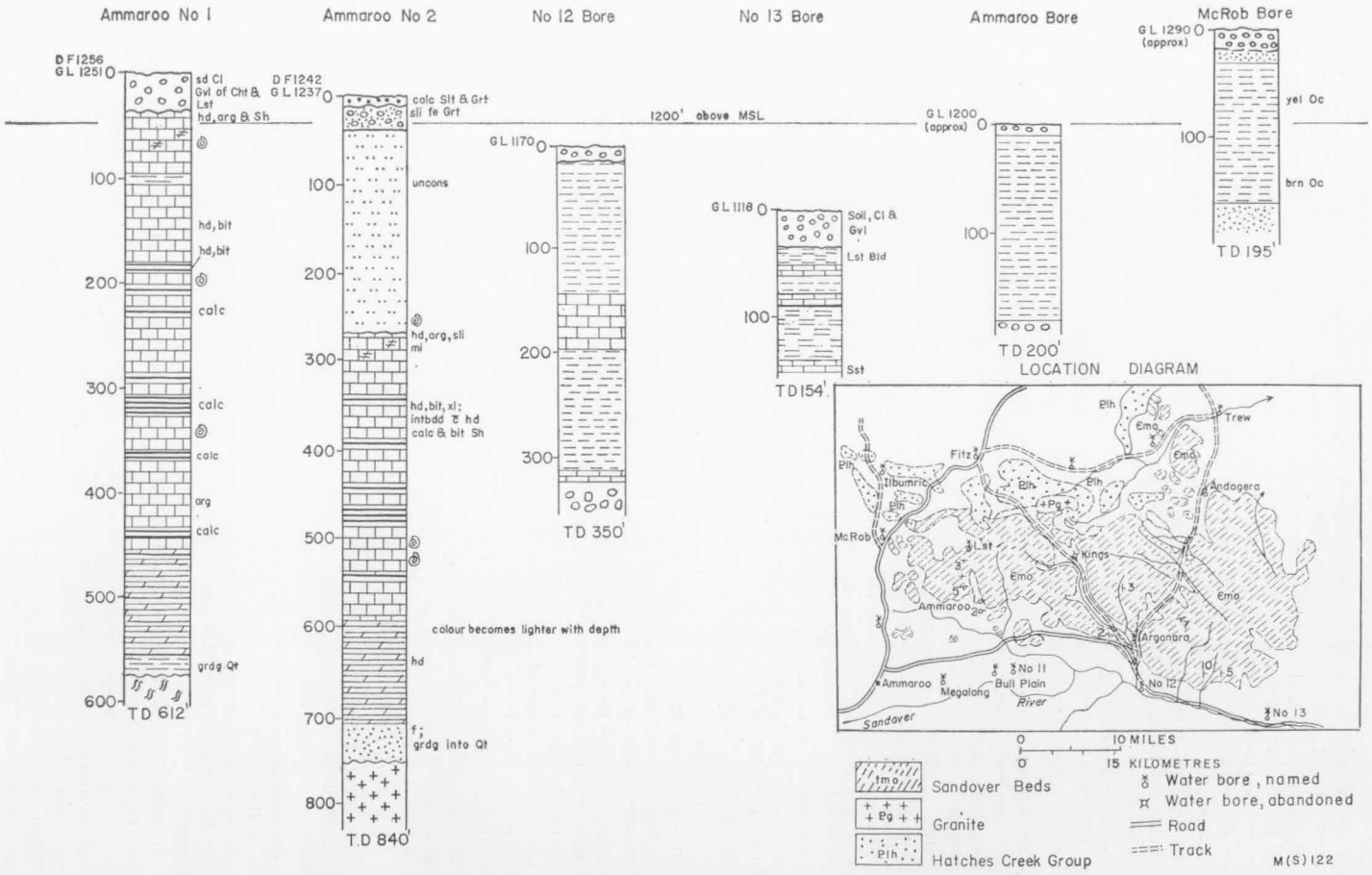


Figure 22. Stratigraphic sequences in Sandover Beds

the siltstone sequence is estimated to have a maximum thickness of at least 150 m; the limestone is at least 50 m thick at the surface.

In Ammaroo No. 1, the thickness of the Sandover Beds is 162 m (532 ft), and in the No. 2 well, 150 m (492 ft) (Fig. 22). Both wells began about 30 m below the top of the exposed sequence; the thickness in each well approximates the true thickness as the dip is low. In the southeastern foothills of the Davenport Range, and in valleys within the range, the thickness of the eroded Sandover Beds seldom exceeds 30 m.

Contacts: Basal sandstone-conglomerate rests unconformably on Arunta Complex and Hatches Creek Group, and on igneous rocks which intrude them; in Ammaroo No. 1 and No. 2 basal sandstone rests unconformably on Precambrian rocks. Where the basal sandstone-conglomerate is absent, the overlying siltstone rests unconformably on the Hatches Creek Group. The outcropping Sandover Beds are overlain by Cainozoic sediments.

Fossils: Contain rich and well preserved fauna. Öpik (1956b) listed a wide variety of trilobites and other fossils, some of which have since been described by Shergold (1969—Oryctocephalids) and Öpik (1968—Bradoriida); and the xystridurids are being described by Öpik (in prep.).

Age: Lower Middle Cambrian, Templetonian Stage (Öpik, 1967b); *Xystridura* Zone.

Correlates: Wonarah Beds (Öpik, 1956b, p. 43), lower part of Arthur Creek Beds, and Inca Formation in northwest Queensland (Öpik, 1956a).

Description and Comment

The basal sandstone-conglomerate sequence crops out well in mesas and in the scarps of low plateaux. The boulders, cobbles, and pebbles in the conglomerate consist of silicified sandstone similar to the sandstone in the Hatches Creek Group. In places, a sedimentary breccia, composed of large angular blocks of the underlying Hatches Creek Group and igneous rocks, is present. Smith et al. (1961, p. 16) record a 3-m bed of angular boulders of quartz sandstone and acid volcanic rocks at the base of the Sandover Beds 11 km north of Supplejack Bore, and grey siltstone is present near the base of the sequence in the Ammaroo No. 1 well (Farmout, 1963, unpubl.).

The thickness of the sandstone-conglomerate sequence ranges from 2 to 36 m in outcrop, but thicknesses exceeding 30 m are rare and most exposures are between 10 and 20 m thick. The gravel reported by drillers in the No. 12 and Arganara Bores, and the sandstone in the McRob Bore (Fig. 22), are here interpreted as part of the basal sequence of the Sandover Beds, but the specimens were not examined by geologists and none of the bores penetrated basement, unless the sandstone in the McRob Bore represents the Hatches Creek Group.

No fossils have been found in the sandstone-conglomerate sequence, but it is overlain conformably by fossiliferous siltstone.

The overlying siltstone sequence forms the bulk of the outcrop of the Sandover Beds. It crops out in low rounded hills deeply incised by creeks which follow the major joint system, and less deeply incised by numerous parallel streams at right angles. The siltstone is usually buff or white and has a distinctive drainage pattern on the air-photographs.

The siltstone beds are commonly silicified, and in some localities the bedding planes have been completely obliterated. The beds roll gently and dip in several directions, but east of Arganara Bore the regional dip is to the southeast, and to the west it is to the south or southwest. The absence of marker beds, the rolling dip, and the cover of rubble make it difficult to measure a complete outcrop section; several sections about 60 m thick have been measured, and the siltstone cropping out in the southeast is estimated to be 150 m. To this can be added about 53 m (175 ft) in Arganara Bore to give a total of about 200 m. Chips of brown, white, and yellow siltstone found in the spoil from several of the bores have aided the interpretation of drillers' logs of the bores shown on Figure 22. The logs shown are those with the more reliable data; of the other bores, Kings Bore (Fig. 22) is reported to have penetrated granite at 96 m (316 ft), and chips of Sandover Beds siltstone with agnostid trilobites from the Ilbumric and No. 12 and No. 13 Bores have been observed. Grey to black shale and limestone have been reported in both the Ammaroo No. 1 and No. 2 wells; this shale is probably the unweathered equivalent of the light-coloured siltstone-shale sequence seen on the surface, which was regarded by Condon (1961, unpubl.) as leached dololutite. The dolomitic shale recorded in the Ammaroo wells supports this conclusion. However, the presence of limestone outcrops indicates that the weathering and leaching processes in the Sandover Beds were complex.

The siltstone sequence in the Sandover Beds contains a rich fauna of well preserved specimens on the bedding planes. The fossils are extremely common in the lower parts of the sequence but less abundant in the higher.

The limestone beds are poorly exposed; they occur in the area bounded approximately by the McRob and Limestone Bores and the Ammaroo No. 1 well. The older beds are usually lateritized and silicified and their thickness is unknown; the younger beds, which are better exposed south of Limestone Bore, consist of blue and grey algal thin-bedded to massive limestone, with a rich fauna of trilobites, brachiopods, and hyolithids. This sequence is 53 m thick, and includes some concealed intervals where shale could be interbedded. The limestone appears to grade eastward into the siltstone sequence, and 3 km west of the Ammaroo No. 1 well it is overlain by 15 m of white micaceous siltstone, with chert and thin beds of silicified coquinite. In Ammaroo No. 1, the limestone is 126 m (412 ft) thick, and in Ammaroo No. 2, 97 m (320 ft) (Fig. 22).

The Sandover Beds have not been deformed or affected by intrusion. They have been affected by a few weak faults between the Arganara and Andagera Bores; the faults probably pre-existed in the Hatches Creek Group, and were rejuvenated during an orogeny which affected the sediments in the southern Georgina Basin in late Devonian or Carboniferous time. They mark the northernmost extent of the orogeny. The Sandover Beds have been strongly jointed, and this probably accounts for the availability of water in the otherwise unpromising siltstone sequence.

The subsurface extent of the Sandover Beds is unknown. South of the outcrop area they have not been identified beneath the Quaternary plains stretching from the Sandover River to the northern foothills of the Dulcie Range (Sheet 3); no information is available on the strata penetrated by Megalong, Bull Plain, and No. 11 Bores (Fig. 22). To the west, they are not known in outcrop between the Ammaroo-Elkedra road and the Stuart Highway (Sheet 3), although some unfossiliferous sandstone referred to the Upper Cambrian/Lower Ordovician Tomahawk Beds could belong to the Sandover Beds.

In the east and northeast, the Sandover Beds may be extensive in the subsurface and continuous with the Wonarah Beds and Gum Ridge Formation. Early Middle Cambrian sediments, equivalent in age to the Sandover Beds, have been penetrated in BMR 13 (Sandover) (Smith & others, 1967), and Trew Bore (Fig. 22) was drilling in green shale of the Sandover Beds or Hatches Creek Group at total depth (207 m; 678 ft). The BMR core holes Grg 3 and 3A (Sheet 3) were sited to penetrate the Sandover Beds or their equivalents but both were abandoned in Tertiary(?) sediments at 63 m (206 ft), and Grg 3A passed from Tertiary(?) sediments to probable Upper Cambrian dolomite at 67 m (220 ft), and was abandoned at 74 m (243 ft).

The richly fossiliferous black bituminous limestone and shale are probably good source beds for petroleum, and an early impetus to petroleum exploration in the Georgina Basin was provided by the discovery of methane and ethane in Discovery Bore on Ammaroo station in 1956 (Mackay & Jones, 1956, unpubl.; Sprigg, 1958). The Ammaroo No. 1 well was subsequently drilled 50 m to the southwest of Discovery Bore. Fluorescence was noted in cuttings and cores between 20 and 168 m (65-550 ft) in Ammaroo No. 1, and between 94 and 116 m (310-380 ft) and 183 and 201 m (600-660 ft) in Ammaroo No. 2. Cores of some bituminous beds gave a petroliferous odour when freshly broken and a small flow of gas was encountered at 124 m (406 ft.) in Ammaroo No. 2 (Farmout, 1963, unpubl.). These occurrences indicate the source-bed potential of the Sandover Beds, but porosity was very low and restricted to caverns in the limestone; no other exploratory tests have been made.

Arthur Creek Beds

Derivation of Name: From Arthur Creek, draining part of outcrop area in Huckitta Sheet area. Smith (1964a) named the Arthur Creek Beds and defined them as a sequence of fossiliferous shale, limestone, dolomite, and sandstone of Middle Cambrian age, which lies between the Lower Cambrian Mount Baldwin Formation and the Upper Cambrian Arrinthrunga Formation.

The name 'Beds' was used because the sediments are too poorly exposed to define formations, and because preliminary examination of the fauna suggests the presence of breaks in the sedimentary sequences (A. A. Öpik & J. G. Tomlinson, pers. comm.). No reference section has been nominated, but representative sections can be seen on and near the road from Lucy Creek homestead to the Jervois mines, on the plains south-southwest of Lucy Creek homestead, and west and southwest of the old Huckitta homestead (Sheet 3).

Distribution: Huckitta Sheet (Sheet 3). Discontinuous belt from northeast flank of Jervois Range to southeast foothills of Dulcie Range; and smaller belt extending west and southwest of old Huckitta homestead.

Lithology and Thickness: In eastern belt, Smith (1964a) has recognized three units (Appendix, Table 14).

Western belt comprises dolomite, limestone, sandstone, siltstone, and chert. Many of the carbonate rocks have been altered by weathering, and many of the beds have been strongly lateritized. The thickness probably ranges from about 150 to 300 m, as the position of the upper boundary is uncertain.

Contacts: In eastern and western belts apparently conformable on Mount Baldwin Formation, but palaeontological evidence indicates presence of disconformity; in eastern belt, Arrinthrunga Formation conformably overlies Arthur Creek Beds, but in west contact is concealed or occurs in apparently conformable sequence of carbonate rocks.

Fossils: Rich fauna still awaits complete examination. Tomlinson (*in* Casey & Tomlinson, 1956, pp. 62-6) identified representatives of the *Dinesus-Xystridura* (unit 1), *Pt. atavus* (unit 2), and *L. laevigata* (unit 3) Zones in the eastern belt, and Öpik (1970a) has described two new nepeid species. The fossils in the western belt still await determination.

Age: Middle Cambrian; *Dinesus-Xystridura, Ptychagnostus atavus,* and *Leiopyge laevigata* Zones; western belt not determined but probably of same age.

Correlates: Lower part of Sandover Beds; Marqua Beds.

Description and Comment

In the eastern belt, unit 1 usually crops out in isolated low mesas, with low dips except in fault blocks; the beds are usually silicified and in places have been replaced entirely by chert. A basal sandstone, up to 6 m thick, is present in some localities, but in others the shale-siltstone sequence rests apparently conformably on quartz sandstone of the Mount Baldwin Formation. The contact between unit 1 and the overlying unit 2 has not been observed.

Unit 2 occurs mainly between the Jervois Range and Arthur Creek, where it underlies open grassy plains. Some beds of gently dipping limestone crop out, but usually the only indication of the presence of unit 2 is the chips of limestone around rabbit burrows. Farther west, the limestone is exposed in fault blocks and has steep to overturned dips. Many of the limestones emit a petroliferous odour when freshly broken. The outcrop thickness is estimated at 75 m, but the poor exposures and gently rolling dips make it difficult to measure the thickness. BMR core hole Grg 6 penetrated most, but not all, of unit 2, and the log (Milligan, 1963, unpubl.; Fig. 23) shows mainly limestone, calcarenite, and calcilutite from 7 to 101 m (23-333 ft), and mainly siltstone from 101 to 208 m (333-683 ft) (TD). On lithological grounds the upper sequence appears to be unit 2, and the lower unit 1. However, the fauna in the cores has not been examined, and the probable gradation from siltstone and shale to limestone in unit 1 could complicate the identification of either unit by lithology alone.

The trends of limestone beds in unit 2 show up clearly on the air-photographs, and gentle domes and basins can be traced on the northwestern flank of the Jervois Range. The structures are difficult to map on the ground.

Unit 3 crops out in a few prominent dark brown mesas and low rises in the eastern area, but not west of longitude 136°E. Sandstone is predominant, but lateral gradation into limestone and dolomite is common, and it is probable that the sandstone represents large lenses in a carbonate sequence. Section HX33 was measured by the author about 5 km south of core hole Grg 6 (Sheet 3; Fig. 23; Appendix, Table 15).

About a kilometre west of section line HX33, flaggy blue limestone grades laterally, within a very short distance, into yellow-brown medium-grained sandstone which contains the upper Middle Cambrian trilobite *Dorypyge*.

Section HX51 (Fig. 23), measured by D. R. G. Woolley in a prominent mesa about 8 km northwest of Lucy Creek homestead, consists of 41 m (134 ft) of fossiliferous quartz sandstone with some thin interbeds of limestone near the base. In a mesa 3 km northwest of section HX51, Woolley has measured a thickness of 32 m of unit 3 (*in* Smith, 1964a), consisting of calcareous sandstone and quartz sandstone, with lenses and interbeds of limestone. Trilobites and brachiopods were collected 13 m above the base of the sequence, and A. A. Öpik (pers. comm.) states that their age is uppermost Middle Cambrian.

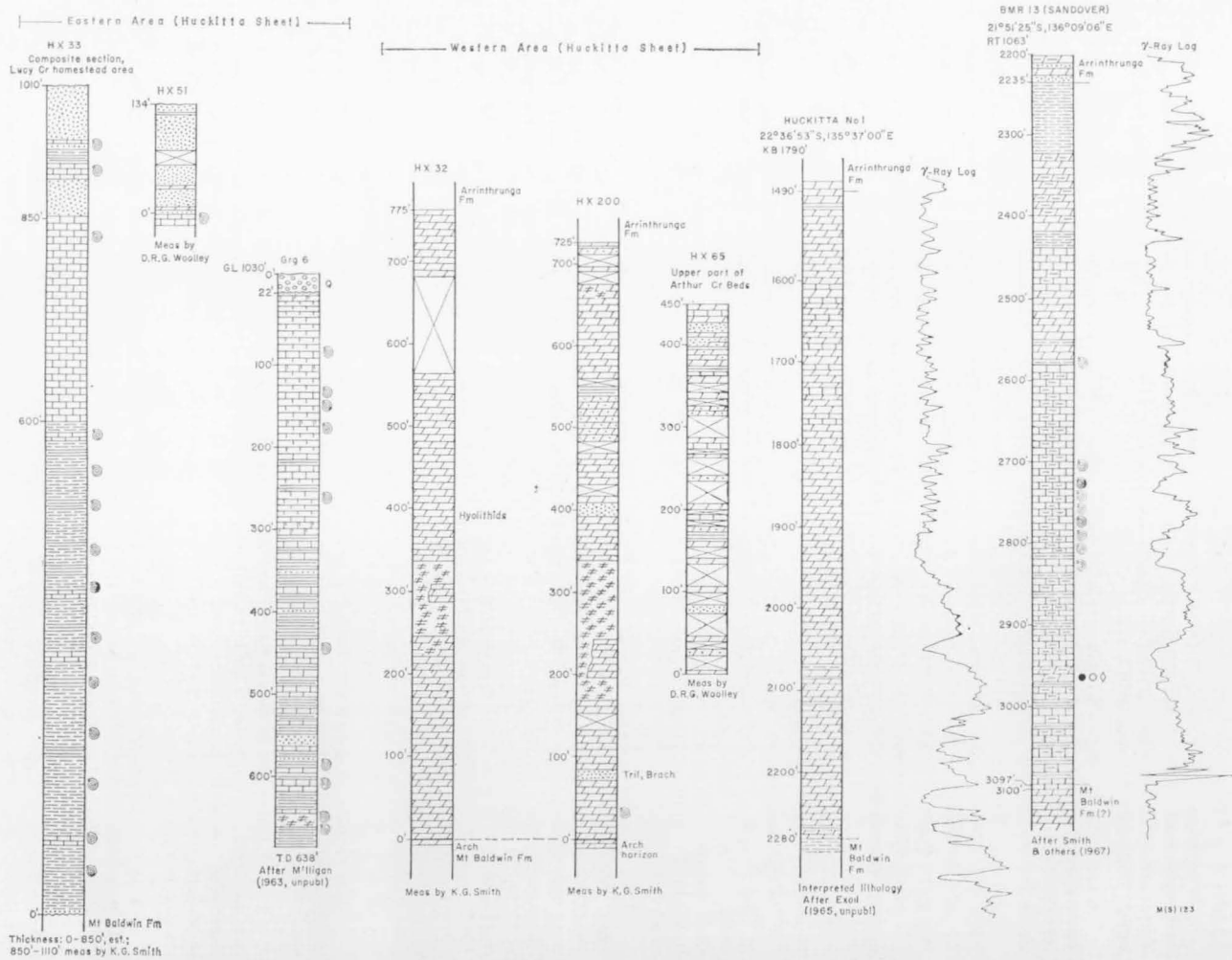


Figure 23. Stratigraphic sequences in Arthur Creek Beds

The sequence in the western belt of outcrop bears little resemblance to that in the eastern belt (Fig. 23); fresh rock consists mainly of dolomite, but most of the sequence has been lateritized and is composed of weathered carbonate rocks, chert, and ferruginous sandstone and siltstone, all of which are poorly exposed. Some soft yellow dolomitic siltstone is known, but outcrop is poor. Fossils are uncommon and the examination of those which have been found (all near the base of the sequence) has not been completed. The precise dating of fossils just above the base of the Arthur Creek Beds, and those in the top of the Mount Baldwin Formation, will be decisive in determining if a significant break in deposition occurs between the two units.

The measured sections of outcrop in the western area are shown in Figure 23, and the interpreted lithological logs of the Huckitta No. 1 well and BMR 13 (Sandover) are shown on the same figure. Dolomite constitutes most of the outcrop in localities HX32 and HX200, but towards the northwestern extremity of the outcrop area sandy dolomite, leached and ferruginized siltstone, and red-brown sandstone form most of the outcrop. Section HX65 shows some of this lithology, but it is only part of the sequence, and no reliable section has been measured in the lower beds.

Both the base and top of the Arthur Creek Beds are difficult to determine in the western area, because the top of the underlying Mount Baldwin Formation is commonly dolomitic, and the overlying Arrinthrunga Formation consists largely of dolomite. The base of the Arthur Creek Beds is placed immediately above a prominent bed of archaeocyathid-bearing dolomite of the Mount Baldwin Formation; this bed forms a prominent marker which can be traced for about 30 km, and it is 12 m stratigraphically below Middle Cambrian fossils reported by Casey & Tomlinson (1956). The upper boundary of the Arthur Creek Beds is placed at the change from yellow dolomite below to a sequence of purple, buff, and blue dolomite and red sandy siltstone above, which contains trilobites of lower Upper Cambrian age (A. A. Öpik, pers. comm.). The lithology in the basal part of the Arrinthrunga Formation is variable, but an approximate boundary with the Arthur Creek Beds can be drawn by tracing beds on air-photographs.

The Middle Cambrian sequence in the Huckitta No. 1 well is the first record of the subsurface lithology of the Arthur Creek Beds in the western area. No fossils were recorded in cores and cuttings, and though the base of the sequence is clearly defined, the position of the upper boundary is less certain. The gamma-ray log to about 580 m (1900 ft) shows little if any difference from that recorded in the Arrinthrunga Formation, but the lower part of this log has an entirely different character. Either, therefore, (i) the boundaries selected are correct, and the change in gamma-ray log characteristics is due to the increasing 'shale' content below 580 m (1900 ft); this is supported by the occurrence of black micaceous siltstone in Core 7; or (ii) the boundary between the Arrinthrunga Formation and the Arthur Creek Beds is at 580 m (1900 ft); this is supported by a decreased thickness of Arrinthrunga Formation in the well, but only partly supported by similar gamma-ray log characteristics, because it is difficult to distinguish between the different rock types in the well, as on the surface.

If the second alternative is correct, it can be inferred that the Huckitta Anticline may be a 'draped' structure, with a thin sequence of Middle Cambrian sediments over its crest. This raises the possibility of flank tests for oil and gas. If the log is correct as it stands, the Arrinthrunga Formation is 240 m thinner than in outcrop a few kilometres away, and this probably indicates a disconformity between the Arthur Creek Beds and the Arrinthrunga Formation at this locality.

The Arthur Creek Beds are not known in outcrop west of the Bundey River, although they could be concealed by sediments deposited in a late Upper Cambrian transgressive sea. To the east of the Jervois Range the beds do not crop out, but are probably continuous in that direction with the Marqua Beds.

In the north, the Arthur Creek Beds do not crop out, but may be continuous under the Arrinthrunga Formation, and the Middle Cambrian sequence penetrated in BMR 13 (Sandover) is tentatively correlated with the Arthur Creek Beds.

The lithology and gamma-ray log of the Middle Cambrian sequence in BMR 13 (Sandover) is shown on Figure 25. The sequence consists of limestone, siltstone and dolomite; it is not easily subdivided into units similar to those in the eastern outcrop area, and there is an increasing proportion of 'shale' in the lower part of the sequence. Gatehouse (*in* Smith et al., 1967) considers that the occurrence of *Pagetia significans* (Etheridge) and *Xystridura*

sp. indicates an age high in the lower Middle Cambrian for the interval from 840 to 863 m (2750-2830 ft). The fossils higher in the sequence (785 m; 2574 ft) are not diagnostic, but are assumed to be of Middle Cambrian age.

Marqua Beds

Derivation of Name: From Marqua homestead (lat. 22°49'S, long. 137°21'E), about 6 km northwest of nearest outcrops. Smith & Vine (1960, unpubl.) applied the name to the sequence of fossiliferous blue chert, silicified shale and siltstone, limestone, and calcareous sandstone between the Field River Beds and Arrinthrunga Formation in the Tobermory Sheet area (Sheet 4). Smith (1963a) has reported the same sequence in the Hay River Sheet area, and Reynolds (1968) noted outcrops in the western part of the Mount Whelan Sheet area of Queensland. A preliminary study of the fossils from the Marqua Beds indicates that there may be breaks in the sequence.

The reference section is on Marqua Station (lat. 22°53'S, long. 137°39'E) about 1 km north of the junction of tracks leading to Noakes Bore and Craigie Dam. The section is about 50 m west of an old track which leads north from this junction. The sequence is structurally disturbed, and the measured thickness is not considered reliable, but the section was chosen as the reference section because all the lithological units in the Marqua Beds are present, and because the area is easily accessible.

Distribution: Tobermory, Hay River, and Mount Whelan Sheet areas; Glenormiston Sheet area (subsurface only) (Sheet 4). Northern Territory: several small isolated areas southeast of Tarlton Range and east and southeast of Mount Ewing; larger areas east of Marqua homestead. Queensland: small area on west flank of Toomba Range. Subsurface: Northern Territory: BMR 12 (Cockroach); Queensland: Netting Fence No. 1.

Lithology: Blue and white chert, buff and white silicified shale and siltstone, blue, grey, and black fine-grained flaggy limestone, grey sandy limestone, and brown and cream medium-grained calcareous sandstone. Subsurface: light grey calcareous sandstone, light grey microcrystalline argillaceous limestone, and minor dark grey and black pyritic siltstone (BMR 12, Cockroach); light grey to dark grey siltstone, grey and fawn limestone, black micaceous shale, dolomitic limestone, and sandstone (Netting Fence No. 1).

Thickness: Reference section, 206 m; southeast of Tarlton Range, several measured sections total 282 m, but structure precludes estimation of thickness in concealed intervals. Over 390 m (1279 ft) in BMR 12 (Cockroach); at least 460 m (1500 ft) in Netting Fence No. 1 (dip 2°-3°, true thickness about 400 m; 1300 ft). It is not known whether the full sequence of the Marqua Beds is present in the Netting Fence No. 1 well.

Contacts: Unconformably on or faulted against Field River Beds. In Netting Fence No. 1 on granite dated at 1643 m.y. Overlain unconformably by Arrinthrunga Formation in outcrop and in BMR 12 (Cockroach). In Netting Fence No. 1 the dips suggest an unconformity between the Marqua Beds and the overlying Upper Cambrian sequences, but differences of less than 5° may be due to deviation of the hole.

Fossils: Tomlinson (*in* Casey & Tomlinson, 1956, p. 67) records trilobites and phosphatic brachiopods; Gatehouse (*in* PAP, 1965b, unpubl.) reports conodonts and phosphatic brachiopods from core at 1956 m in Netting Fence No. 1; Öpik (1961, p. 48) lists collection on west flank of Toko Range, referred by him to 'Devoncourt Limestone', but in fact in Marqua Beds. It is of *laevigata* II-III age, and rests on a chert-limestone sequence of lower *Pt. gibbus* and *Xystridura* age. This indicates a considerable time break in the sequence.

Age: Lower to Upper Middle Cambrian; *Xystridura* Zone to top of *L. laevigata* Zone.

Correlates: Arthur Creek Beds.

Description and Comment

The lower units of the Marqua Beds do not generally crop out strongly, but a band of blue chert at the base of the sequence is prominent in places; in some localities white leached and brown-red ferruginized siltstone crops out in mesas, but the beds are usually obscured by scree, and are difficult to distinguish from the Triassic Tarlton Formation. The higher beds consist mainly of limestone, which in places forms prominent ridges, but is commonly poorly exposed, although the pattern is evident on the air-photographs; the limestone usually supports a dense vegetation of gidyea, which shows up clearly on the air-photographs, but which also grows on the Adelaidean, Upper Cambrian, and Ordovician sediments in this area. Lenses of sandstone at the top of the Marqua Beds crop out in isolated mesas.

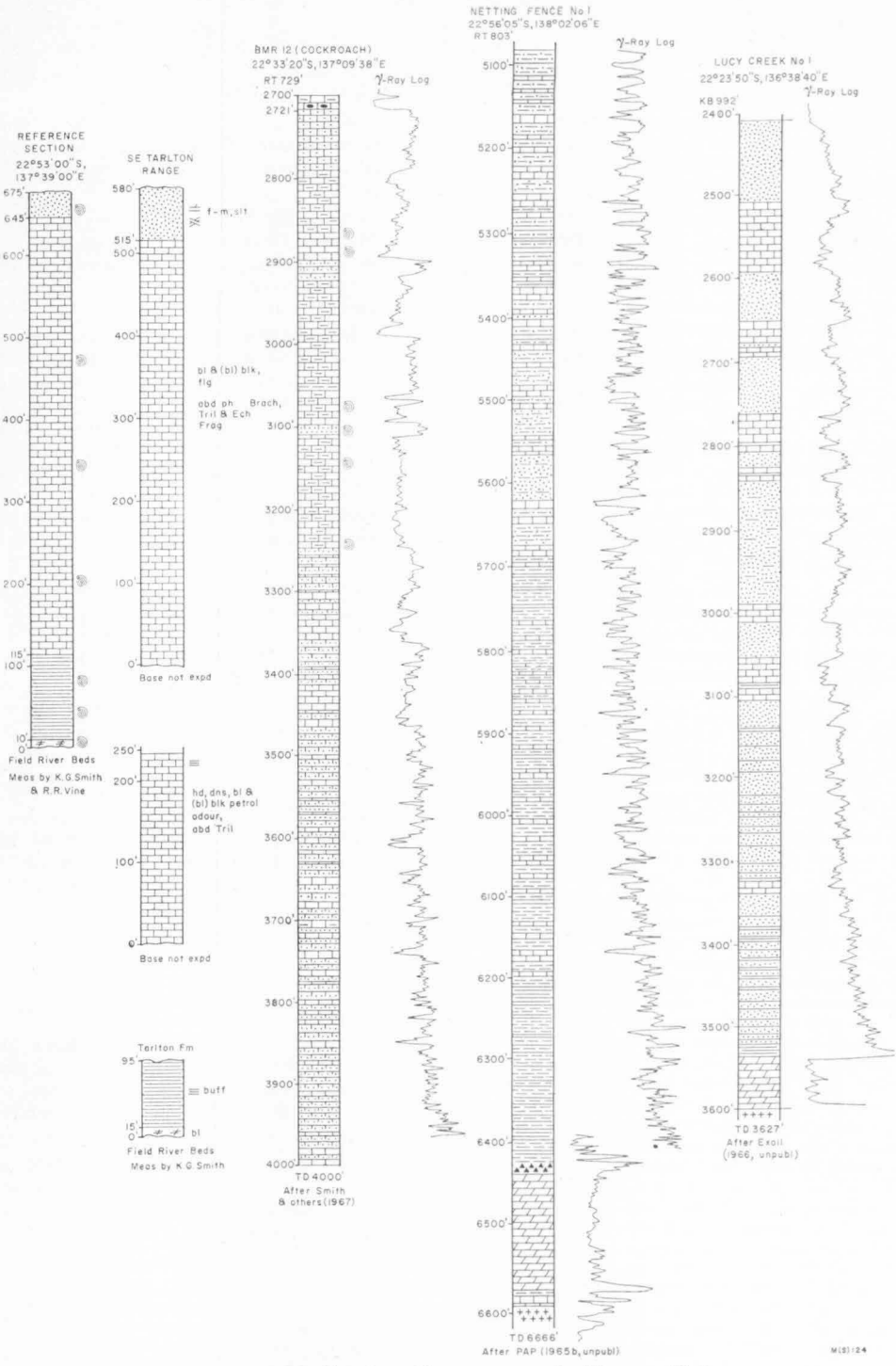


Figure 24. Stratigraphic sequences in Marqua Beds

In outcrop, the Marqua Beds resemble the Arthur Creek Beds in the eastern part of the adjoining Huckitta Sheet area. The reference section is given in the Appendix (Table 16) and Figure 24, and the units 1, 2, and 3 correspond lithologically with the subdivisions in the Arthur Creek Beds. The basal blue chert has not been observed in the Arthur Creek Beds, but its equivalent could be present. It is not always present in the Marqua Beds.

The sequence measured southeast of the Tarlton Range (Fig. 24) contains four lithological units which are similar to those of the reference section of the Marqua Beds, with the addition of 75 m of blue and blue-black laminated limestone which is not present in the reference section.

The sequences in BMR 12 (Cockroach) and Netting Fence No. 1 are shown in Figure 24; the sandstone of unit 3 has been interpreted in BMR 12 (Cockroach) as the interval 829 to 850 m (2721-2790 ft), and much of the section consists of calcareous sandstone and sandy and argillaceous limestone. Only a few fragments of fossils have been recovered. The beds are horizontal, and the thickness in the well represents the true thickness.

Netting Fence No. 1 penetrated the Marqua Beds from 1548 to 2009 m (5080-6590 ft), where the beds rest unconformably on Precambrian granite. The upper boundary in the well has not been precisely established, but Core 14 contains Upper Cambrian fossils (Gatehouse, *in* PAP, 1965b, unpubl.), and the boundary is placed at a lithological break between the limestone above the greywacke with limestone interbeds below, as determined by the operator. The Marqua Beds in Netting Fence No. 1 consist mainly of greywacke and interbedded limestone from 1548 to 1731 m (5080-5680 ft), limestone and interbedded siltstone from 1731 to 1957 m (5080-6420 ft), and dolomite from 1957 to 2009 m (6420-6590 ft). The company (PAP, 1965b, unpubl.) has used the names Netting Fence Formation and Thorntonia Limestone for the upper and lower parts of the sequence respectively, but I prefer the term Marqua for the whole sequence.

The subsurface extent of the Marqua Beds is unknown; they are assumed to be present on the eastern (downthrown) side of the Toomba Fault, but have not been identified east of the Netting Fence No. 1 well. They are also unknown north of BMR 12 (Cockroach), but are assumed to extend northwards and to be contiguous with a thin Middle Cambrian sequence reported in the Mulga No. 1 well (Alliance, 1965, unpubl.).

The Marqua Beds are not metamorphosed, but they have been affected by strong faulting during the Alice Springs Orogeny, and in many places have been faulted against some of the older units of the Field River Beds.

QUEENSLAND

Öpik (1956a, 1960, 1961) has published descriptions of all of the Middle Cambrian outcrops in the Queensland part of the Georgina Basin, and the descriptions which follow are based on his work, with minor additions from the published Explanatory Notes (in which Öpik was generally responsible for the sections on Palaeozoic geology), from unpublished material of later workers, and from the exploration wells and stratigraphic holes. Öpik (1956a, 1960) formally named all the units.

Beetle Creek Formation

Derivation of Name: From Beetle Creek, a small tributary of Templeton River, at longitude 139°18′E, latitude 20°36′S (Mount Isa Sheet). One of best known localities for Middle Cambrian rocks in Queensland. The lower part of the formation is known as the *Yelvertoft Bed* (David, 1932), which takes its name from Yelvertoft station, and has its type area at Halls Memorial (lat. 20°11′S, long. 138°53′E) on the Barkly Highway about 22 km northwest of Yelvertoft station.

Distribution: Camooweal, Mount Isa, Urandangi (Sheet 2), and Duchess (Sheet 4) Sheet areas. Erosional residuals near eastern margin of Georgina Basin, and outliers on basement.

Lithology: Siliceous shale, chert, siltstone, fine-grained sandstone, and thin interbeds of silicified limestone basal conglomerate in places; bituminous flaggy limestone reported in Duchess Sheet area (Carter & Öpik, 1963).

Thickness: 15 m at Beetle Creek; Yelvertoft Bed, 5 m (Öpik, Carter, & Noakes, 1961). Öpik (1960, p. 100) estimated thickness of 3 to 18 m, but Carter & Öpik (1963) estimated 'several hundred feet' in Duchess Sheet area. In Black Mountain No. 1, Phillips Petroleum Co. Ltd (1963, unpubl.) reported 148 m (487 ft) of sediments which, although unnamed, were regarded as probably equivalent to Beetle Creek Formation.

Contacts: Unconformable on Precambrian metamorphic rocks and Pilpah Sandstone. Öpik (1956a, p. 14) reported the presence at Beetle Creek of silicified *Collenia* and *Cryptozoon*-like bodies which are probably attached to the basement; they occur at the base of the formation and may belong to it or may represent residuals of an otherwise eroded 'sub-Cambrian' sequence.

The Beetle Creek Formation is overlain conformably and disconformably by the Inca Formation in some localities, but elsewhere it is overlain disconformably by other younger Middle Cambrian units, or occurs as residuals.

Fossils: Fauna comprehensively surveyed by Whitehouse (1936, 1939) and Öpik (1956a, 1960, 1968, 1970b). Shergold (*in* de Keyser, 1968, unpubl.) listed prolific fauna from Duchess Sheet area; fossils include trilobites, brachiopods, bradoriids, and hyolithids.

Age: Lower Middle Cambrian. Yelvertoft Bed is Ordian; top of formation is Templetonian.

Correlates: Sandover Beds, Wonarah Beds, and Thorntonia Limestone.

Description and Comment

The Beetle Creek is widely distributed in disconnected areas around the eastern margin of the Georgina Basin, but has not been identified subsurface. The formation is contemporaneous with and interfingers with the Thorntonia Limestone.

The overlying Inca Formation is horizontal or gently dipping, but is folded in the Duchess area (Sheet 4) and faulted in the Pilpah Range (Sheet 2).

The Beetle Creek Formation is the chief repository of phosphate deposits in northwest Queensland (see p. 56). De Keyser (1968, 1969a, both unpubl.) has described the formation in detail in connexion with phosphate deposition.

Border Waterhole Formation

Derivation of Name: From Border Waterhole, about 2½ km northwest of Highland Plains homestead, on State border at latitude 18°37'S. Named and briefly described by Öpik (1960); Carter & Öpik (1961) gave a more complete description, and Smith & Roberts (1963) have described outcrops in Northern Territory. No type section designated.

Distribution: Mount Drummond and Lawn Hill Sheet areas (Sheet 2). On downthrown (southern) side of Littles Range Fault, which extends from Queensland into Northern Territory (Sheet 2). Outcrops restricted to segment of fault zone, about 50 km long, where they occur in low rubbly ridges capped by laterite in places.

Lithology: Siliceous shale and associated chert rubble, overlain by dolomitic limestone with about 50 percent chert in places, and interbeds of chert and siliceous shale (Carter & Öpik, 1961). In Northern Territory (Smith & Roberts, 1963): white and cream siltstone, shale, chert, and minor limestone; pebble conglomerate at base of formation north of Lancewood Creek (not shown on Sheet 2).

Thickness: About 30 m in Queensland (Carter & Öpik, 1961); maximum of about 45 m in Northern Territory (Smith & Roberts, 1963).

Contacts: Unconformable on Precambrian rocks, and overlain conformably by Currant Bush Limestone. Carter & Öpik (1961, table 1) state that the Border Waterhole Formation rests on Camooweal Dolomite immediately west of the Queensland border; Smith & Roberts (1963, table 1; p. 12) state that in places the Currant Bush Limestone dips south under the Camooweal Dolomite; elsewhere in the Northern Territory the contact is faulted.

Fossils (Carter & Öpik, 1961): Trilobites and molluscs (monoplacophorids).

Age: Lower Middle Cambrian, Templetonian Stage.

Correlates: Beetle Creek Formation and Burton Beds.

Comment

This is one of the early Middle Cambrian sequences at the base of the Georgina Basin succession, which contains a *Xystridura* fauna. The beds are horizontal or gently dipping, except near faults; they are probably continuous subsurface with the Burton Beds, and may grade laterally into part of the Camooweal Dolomite. In outcrop there are two interpretations of the relationship between the Border Waterhole Formation and the Camooweal Dolomite; the field relationships and the logs of the stratigraphic holes in the Camooweal area suggest that the interpretation of Smith & Roberts (1963) is correct.

Thorntonia Limestone

Derivation of Name: From Thorntonia homestead (lat. 138°56'20"E, long. 19°30'00"S). Named and mapped by Öpik (1956a); no type section proposed.

Distribution: Lawn Hill and Camooweal (Sheet 2), Urandangi, Glenormiston, and Duchess (Sheet 4) Sheet areas. From near Lawn Hill (lat. 18°35'S, long. 138°24'40"E) southwards along east margin of basin and thence via Quita Creek area eastwards to Mount Birnie (lat. 21°38'S, long. 139°56'E). Main outcrop area, roughly between Lawn Hill and Thorntonia homestead, shown separately on Sheet 2; small discontinuous outcrops not distinguished on Sheets 2 and 4.

Lithology: Thick-bedded dolomitic limestone dolomite, and limestone with layers and nodules of chert; in places grading into siliceous shale, chert, siltstone, fine-grained sandstone, and silicified limestone of Beetle Creek Formation.

Thickness: Maximum thickness in outcrop estimated at 60 m (Öpik, 1956a), but usually much less. Carter & Öpik (1963) recorded 20 m in Duchess Sheet area, and Noakes et al. (1959) reported 9 to 21 m in Urandangi Sheet area. Amalgamated Petroleum Exploration Pty Ltd (1963b, unpubl.) reported Thorntonia Limestone in interval from 232 to 335 m (760-1100 ft) in Morstone No. 1 well.

Contacts: Unconformable on Precambrian basement and Lower Cambrian(?); overlain conformably by Inca Formation and Currant Bush Limestone.

Fossils (Öpik, 1956b, 1961, 1967b, 1970b; Shergold, *in* de Keyser, 1968, unpubl.): Trilobites, hyolithids, *Girvanella*.

Age: Lower Middle Cambrian, Ordian to Templetonian Stage.

Correlates: Beetle Creek Formation and lower part of Age Creek Formation.

Comment

The Thorntonia Limestone crops out over a wide area in the Lawn Hill/Camooweal Sheet areas, and as small residuals in many other areas marginal to the Georgina Basin. Öpik (1956a) used the name for all the discontinuous outcrops up to 250 km from the Thorntonia homestead area. The formation is usually richly fossiliferous, and is one of the basal sequences in the Georgina Basin. It is also the basal sequence of the succession in the Undilla Basin of Öpik (1960), who believed that it rests disconformably on the Camooweal Dolomite. In the Morstone No. 1 well, however, the Camooweal Dolomite is absent and the Thorntonia Limestone rests directly on Precambrian basement (Amalgamated, 1963b, unpubl.).

Inca Formation

Derivation of Name: From Inca Creek, a tributary of Buckley River, which drains large outcrop areas in Camooweal and Mount Isa Sheet areas. Named by Öpik (1956a).

Distribution: In low rolling hills, mesas and cliffs, and creek banks, in Camooweal and Mount Isa Sheet areas (Sheet 2); as a capping on mesas, and in cuestas and low rises in Duchess Sheet area (Sheet 4).

Lithology: In west: laminated siliceous shale and siltstone (bituminous when fresh), bands of chert and large lenses of impure flaggy and ellipsoidal limestone; Duchess Sheet area: lower part consists of siliceous shale with chert, siltstone, sandstone, and bituminous limestone; upper part composed of bituminous shaly limestone.

Thickness: Increases southwards, from 3 m near Thorntonia homestead to 150 m in Mount Isa Sheet area; thickest sequences near Mount Merlin (Duchess Sheet area)—600 m estimated by Carter & Öpik (1963). In Black Mountain No. 1 well, unnamed sequence correlated with Inca Formation is 540 m (1772 ft) thick (Phillips, 1963, unpubl.).

Contacts: In west: conformable on Thorntonia Limestone, but unconformable on Pilpah Sandstone and Riversdale Formation; Duchess Sheet area: unconformable on Precambrian basement and Mount Birnie Beds, and disconformable on residuals of Beetle Creek Formation.

Fossils (Whitehouse, 1939; Öpik, 1956a, 1970b; Shergold, *in* de Keyser, 1968, unpubl.): Mainly agnostid trilobites and sponge spicules.

Age: Middle Cambrian; *Pt. gibbus* and *Pt. atavus* Zones.

Correlates: Currant Bush Limestone.

Comment

The Inca Formation is contemporaneous with the Currant Bush Limestone. Öpik (1956a) reported that the 'rising' contact between the two formations 'dips' to the north, and that

the outcrops of the lower part of the Inca Creek Formation are therefore more abundant than those of the upper part.

The Inca Formation is widely distributed. The fossiliferous bituminous sediments may be source beds for petroleum.

In the west the Inca Formation is horizontal or gently dipping, but in the east the beds have been moderately folded and dips of 20° are common (Carter & Öpik, 1963).

Currant Bush Limestone

Derivation of Name: From Currant Bush Creek, a tributary of Harris Creek, about 16 km southwest of Thorntonia homestead.

Distribution: Camooweal, Mount Drummond, and Lawn Hill Sheet areas (Sheet 2). Main outcrops, near eastern margin of basin, extend southwards from Thorntonia area to Barkly Highway; small outcrops in fault blocks along northern margin of basin in Mount Drummond and Lawn Hill Sheet areas (Sheet 2).

Lithology: Northern Territory: thin-bedded cream to grey limestone with some sandy limestone, in places cross-bedded, and minor friable medium-grained sandstone (Smith & Roberts, 1963). Smith & Roberts also included the leached siltstone and shale at Lancewood Waterhole which Öpik (1960) named the Lancewood Shale. Farther east along the northern margin of the basin, Carter & Öpik (1961) have described a variable sequence of dark bituminous limestone, soft grey flaggy limestone, hard nodular limestone, massive thick-bedded dolomitic limestone and dolomite, in the upper parts of the formation. Near Thorntonia homestead and to the south, the sequence consists of bituminous flaggy limestone with oolitic, shaly, and marly interbeds.

Thickness: About 30 m in Northern Territory and possibly 150 m in Lawn Hill Sheet area; this latter figure regarded as doubtful by Carter & Öpik (1961) because of structural complexities. Thickness in outcrop in Camooweal and Mount Isa Sheet areas unknown, but Morstone No. 1 penetrated 116 m (380 ft) of Currant Bush Limestone in interval from 116 to 232 m (380-760 ft) (Amalgamated, 1963b, unpubl.).

Contacts: Main outcrop area: rests conformably on, and grades into, Inca Formation, and overlain conformably by V Creek Limestone; Northern Territory: underlain conformably by Border Waterhole Formation and overlain by dolomite regarded by Smith & Roberts (1963) as Camooweal Dolomite; Lawn Hill Sheet area (Carter & Öpik, 1961): conformably overlies Border Waterhole Formation and overlain by Mesozoic plant-bearing sandstone.

Fossils (Öpik, 1956a, 1970a): Agnostid and polymerid trilobites.

Age: Middle Cambrian; *Pt. atavus* to *Pt. punctuosus* Zones.

Correlates: Inca and Quita Formations and greater part of Age Creek Formation.

Lancewood Shale

The Lancewood Shale in the Border Waterhole area of the Northern Territory was named by Öpik (1960); it consists of deeply lateritized and indistinctly laminated sandy shale and siltstone which rest apparently conformably on the Currant Bush Limestone. Carter & Öpik (1961, table 1) include the Lancewood Shale in a stratigraphic table of the Lawn Hill Sheet area, but state that it occurs in the Northern Territory only; they give the thickness as 21 m; list the fauna as *Fouchouia, Peronopsis, Ptychagnostus,* and cystids; and describe it as 'apparently equivalent of part of Currant Bush Limestone'.

Smith & Roberts (1963) included the Lancewood Shale in the Currant Bush Limestone. Since the Lancewood Shale, as named and described by Öpik (1960) occurs only in the Mount Drummond Sheet area of the Northern Territory and has not been mapped as a separate unit there, it is not shown on Sheet 2.

V Creek Limestone

Derivation of Name: From V Creek, a small tributary of Harris Creek about 13 km east of Undilla homestead (lat. 19°37'S, long. 138°38'E).

Distribution: Camooweal and Mount Isa Sheet areas (Sheet 2). Belt trending southeast from Old Morstone to latitude 19°52'S (Camooweal Sheet area), and discontinuous outcrops between Barkly Highway and Buckley River in Mount Isa Sheet area. Usually crops out poorly in low rises and creek banks in south, but better developed in Undilla area in north.

Lithology: Blue and grey laminated sandy and marly limestone, with widely spaced interbeds of silicified limestone, cherty in upper part; lower part contains interbeds of calcilutite.

Thickness: 30 to 40 m in Undilla area; total of 30 m estimated in south (Öpik et al., 1961); thickness in Morstone No. 1 well, 99 m (325 ft), in interval from 17 to 116 m (55-380 ft) (Amalgamated, 1963b, unpubl.).

Contacts: In north: conformably overlies Currant Bush Limestone and conformably overlain by Mail Change Limestone, grades laterally into upper part of Age Creek Formation. In south: conformably overlies Inca Formation, and overlain conformably by Mail Change Limestone and Split Rock Sandstone.

Fossils (Whitehouse, 1936, 1939; Öpik, 1956a, 1961, 1970b): Abundant agnostid and polymerid trilobites, brachiopods, sponges; Öpik (1956a) described fauna as Acado-Baltic.

Age: Middle Cambrian; Zone of *P. nathorsti*.

Correlates: Upper part of Age Creek Formation and lower part of Split Rock Sandstone.

Comment

The V Creek Limestone is of small areal extent and has been deposited conformably on older units. Öpik (1960 p. 101) states that several thin interbeds in the V Creek Limestone are lithologically similar to the overlying Mail Change Limestone. In the subsurface, the V Creek Limestone is considerably thicker than indicated in outcrop.

Mail Change Limestone

Derivation of Name: From abandoned hut known as Mail Change (lat. 19°35'S, long. 138°30'E, approx.) about 15 km south of Old Morstone homestead.

Distribution: Camooweal and Mount Isa Sheet areas (Sheet 2). Similar to that of V Creek Limestone: northern belt trends southeast from Old Morstone homestead; southern belt comprises small outcrops between Barkly Highway and Buckley River. Forms low terraced hill in both areas.

Lithology: Blue and yellow mottled fine-grained thick-bedded limestone.

Thickness: Seldom exceeds 6 m; 4½ m (15 ft) in Morstone No. 1 well (Amalgamated, 1963b, unpubl.).

Contacts: Rests conformably on V Creek Limestone and overlain conformably by Split Rock Sandstone.

Fossils (Öpik, 1956a, 1970a): Brachiopods and occasional trilobites.

Age: Middle Cambrian; Zone of *P. nathorsti*.

Comment

The Mail Change Limestone is contemporaneous with the upper part of the Age Creek Formation and grades laterally into part of the Split Rock Sandstone.

Split Rock Sandstone

Derivation of Name: From Split Rock Waterhole (lat. 19°58'S, long. 138°29'E) about 3 km north of Barkly Highway.

Distribution: Camooweal and Mount Isa Sheet areas (Sheet 2). Crops out discontinuously in residuals between Undilla homestead area and Buckley River (included in Cm3 group of units on Sheet 2).

Lithology: Fine-grained quartz sandstone with interbeds of siltstone. Sandstone commonly cross-bedded; most outcrops strongly weathered.

Thickness: Maximum thickness 20 m, about 15 m common; 10 m (30 ft) reported in Morstone No. 1 (Amalgamated, 1963b, unpubl.).

Contacts: Conformably overlies V Creek Limestone and Mail Change Limestone in some localities; grades laterally into lower part of Mail Change Limestone; overlain unconformably by Lower Cretaceous Polland Waterhole Shale.

Fossils (Öpik, 1956a, 1960, 1970a): A rich fauna of trilobites.

Age: Middle Cambrian; Zones of *P. nathorsti* and *L. laevigata*.

Comment

The Split Rock Sandstone has a 'rising' contact against both the Mail Change and V Creek Limestones, and therefore has a wide stratigraphical range. It is one of the youngest Middle Cambrian sequences exposed on the eastern margin of the Georgina Basin. The beds are usually near-horizontal, but in places they have been disturbed by small faults.

Age Creek Formation

Derivation of Name: From Age Creek, a short tributary of O'Shanassy River. Type locality at confluence, about 6 km downstream from Old Morstone homestead. Öpik designated type locality (1954, unpubl.), published name (1956a), and defined formation (1960). Condon (1961, unpubl.) made additional observations, and Randal & Brown (1962b, unpubl.) have given a more detailed description of the formation and its relationship with the Camooweal Dolomite and other formations.

Distribution: Camooweal Sheet area (Sheet 2). Restricted to Morstone-Thorntonia area. Öpik et al. (1961) reported a single small outcrop (at lat. 20°11'S, long. 138°21'E) within a lateritic plain in Mount Isa Sheet area; on the Mount Isa 4-mile Map they show the outcrop as probably belonging to the Age Creek Formation, but did not include it in the accompanying stratigraphic table. On Sheet 2 the Age Creek Formation has been shown as a separate unit which includes the small outcrop in the Mount Isa Sheet area.

Lithology: 'A calcareous formation consisting of sandy clastic dolomite and limestone with interbeds of calcareous sandstone' (Öpik, 1960). Randal & Brown (1962b, unpubl.) and Brown (1962, unpubl.) give fuller descriptions of the lithology, and Randal & Brown (1962b, unpubl.) describe the formation as consisting of pellet dolomite, dolomite with pellets, crystalline two-tone dolomite, dolomitic limestone, and minor calcarenite, with some nodules and bands of chert. Randal & Brown also describe cross-bedding, which was also noted by Condon (1961, unpubl.).

Thickness: Öpik (1960) gives thickness of 1200 m; on Camooweal Sheet thickness of about 820 m shown in one cross-section and about 520 m in another. Randal & Brown (1962b, unpubl.) consider that the total thickness of the incomplete sections exceeds 1200 m in Ada Creek (this creek is named Marion Creek on the published topographic base maps of the Camooweal Sheet and is named accordingly on Sheet 2).

Contacts: Öpik (1956a; Camooweal Sheet, 1st Ed., 1961) considers Age Creek Formation to rest disconformably on Camooweal Dolomite, and as contemporaneous with, and interfingering with, parts of Thorntonia Limestone, Currant Bush Limestone, Inca Creek Formation, V Creek Limestone, and Mail Change Limestone. The palaeontological evidence indicates that these formations are contemporaneous, and the field evidence indicates that they interfinger with each other. Randal & Brown (1962b, unpubl.), however, believe that the Age Creek Formation and Camooweal Dolomite interfinger along the western boundary of the Age Creek Formation, and that they are contemporaneous, at least in part. Mesozoic sediments unconformably overlie the Age Creek Formation in some localities.

Fossils (Öpik, 1960, 1970a): Phosphatic brachiopods common; trilobites in some limestone interbeds.

Age: Middle Cambrian; *Xystridura* Zone to Zone of *Ptychagnostus nathorsti* (Öpik, 1960).

Correlates: Upper part of Thorntonia Limestone, Currant Bush Limestone, Inca Creek Formation, V Creek Limestone, lower part of Mail Change Limestone, and part, at least, of Camooweal Dolomite.

Discussion and Comment

The Age Creek Formation crops out mainly in rough karst structures, deeply incised by steep-sided creeks and rivers. The outcrops are typically blocky and separated by irregular joints up to 6 m deep. Away from watercourses the formation is less dissected, and forms plateaux covered by black soil. The formation is mainly thick and medium-bedded, but some massive and some thin beds may be present. The formation is usually cross-bedded, and some of the foresets are 15 m thick; the foresets are thin to thick-bedded, with dips of up to 30°, but mainly less than 10°. The cross-beds are more strongly developed in the coarser sediments. The cross-bedding and slumping towards sinkholes make it difficult to measure the dip in isolated outcrops.

In outcrop the Age Creek Formation is usually white or buff, with large pellets visible on weathered and fresh surfaces. The formation consists mainly of dolomite composed of large pellets, oolites, terrigenous material, and fragments of fossils, including algae. The rock commonly shows intergranular porosity because the fragments are generally cube cemented at points of contact. Brown (1962, unpubl.) states that the carbonate grains consist of pellets, oolites, and algal fragments, with the pellets well rounded, and the oolites usually recrystallized. The pellets are usually over 0.1 mm in diameter, and some exceed 2.0 mm; they are composed of dark microcrystalline dolomite and paler more coarsely

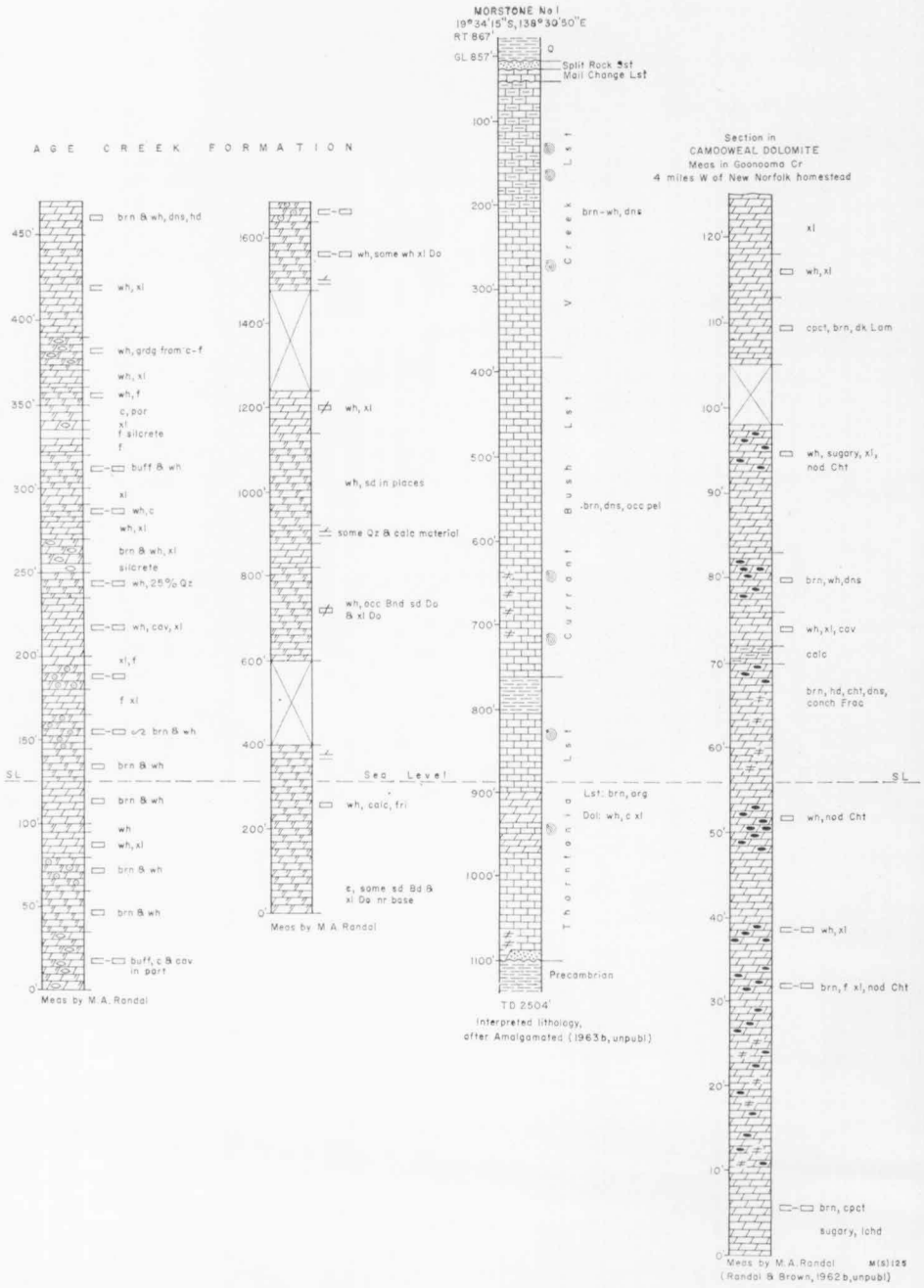


Figure 25. Measured sections in Age Creek Formation and Camooweal Dolomite, and Cambrian sequence in Morstone No. 1

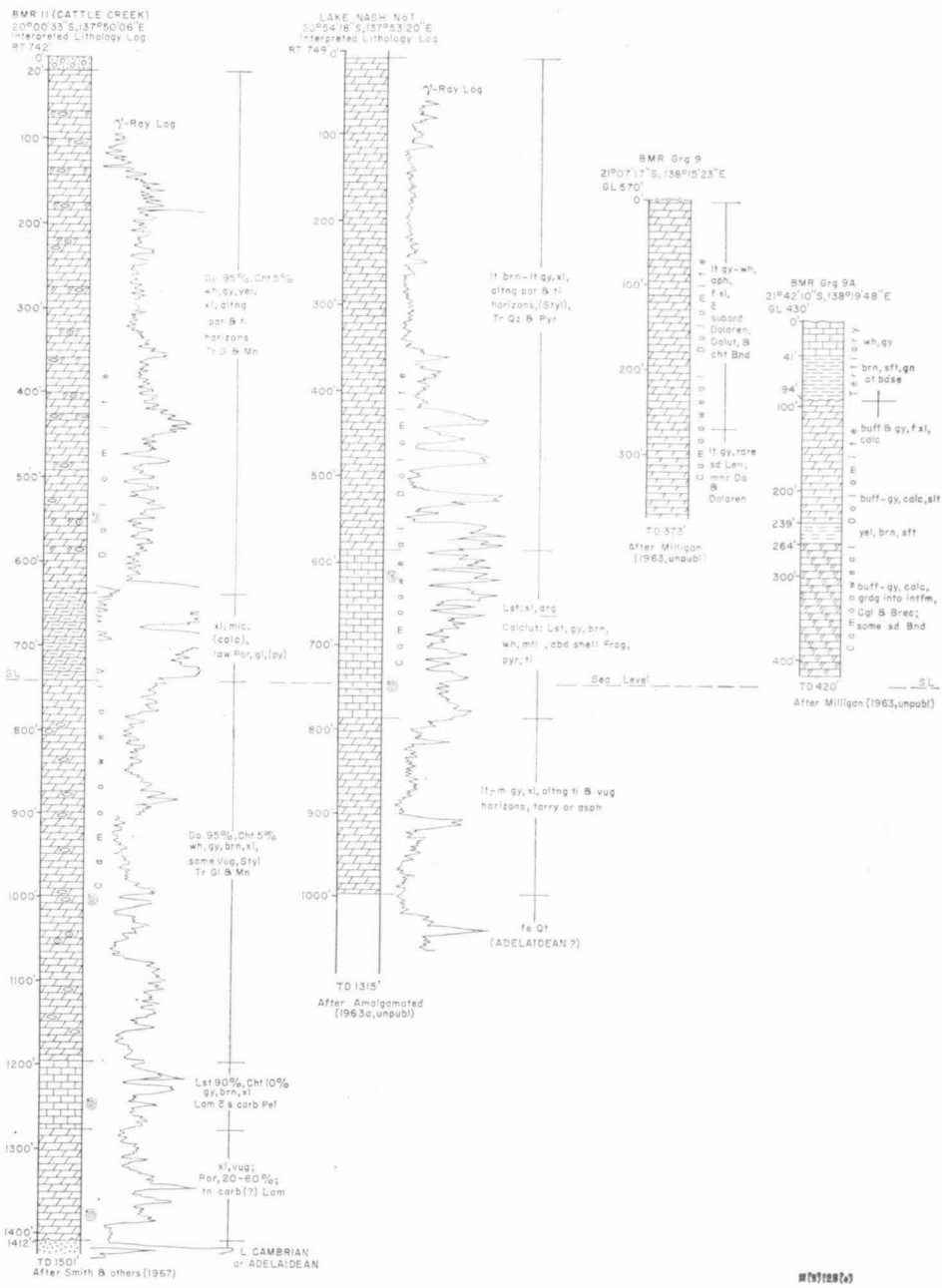


Figure 25. Measured sections in Age Creek Formation and Camooweal Dolomite, and Cambrian sequence in Morstone No. 1 (cont.)

crystalline dolomite. Composite pellets, consisting of small pellets, oolites, and fossils set in a dark matrix are known. Oolites are common, but their structure is seldom preserved; in thin section they can be identified by the circular arrangement of dolomite crystals, which may be slightly darker and finer in grain than the surrounding dolomite cement. The oolites have an average grainsize of 0.3 mm, are well sorted, and consistently even in size.

Brown states that terrigenous material is almost universal in the pellet dolomites of the Age Creek Formation, but is less common in the fine-grained thin-bedded fossiliferous limestone interbeds. The terrigenous material includes smaller grains (0.05 mm or less), which are common throughout the formation, and larger grains (over 0.1 mm), which are restricted to the western margin of the formation near Old Morstone homestead. The coarser terrigenous material consists of stained quartz grains, some of which contain needles of sillimanite(?); chert grains are common in the Ada Creek area. The finer terrigenous material consists of unstrained quartz, plagioclase, microcline, tourmaline, zircon, hypersthene, and garnet or spinel.

The pellet dolomites have a dolomite matrix, and the only rocks with a lime-mud matrix are the limestone layers composed of algal grains. The lenses of thin-bedded fossiliferous dolomite and dolomitic limestone within the foresets represent carbonate mud deposits.

The structure of the Age Creek Formation is obscured by the cross-bedding and some of the high dips (15°-20°) shown on the Camooweal Sheet, southwest of Old Morstone homestead, were probably measured on large foresets. The regional dip of the Age Creek Formation ranges from 2° to 5°, but the beds are apparently gently rolling. Randal & Brown (1962b, unpubl.) found several areas along the western outcrop belt where beds dip to the south or southeast, for example towards the Undilla Basin of Öpik (1956a, 1960), but some low south-westerly dips have been observed by Randal & Brown and by the present author, near the boundary of the Age Creek Formation and the Camooweal Dolomite. The Morstone No. 1 well did not penetrate the Age Creek Formation before reaching the base of the Middle Cambrian sequence at 340 m (1115 ft) (Amalgamated, 1963b, unpubl.). This suggests that there is no basin in the Undilla area, and that the regional dip of Middle Cambrian sequences is southwest, away from Precambrian basement into the Georgina Basin, or that there is a minor 'deep' in the Undilla area on the uneven Precambrian surface.

The estimated thickness of 1200 m for the Age Creek Formation may not be reliable because of the presence of large foreset beds. Some sections measured by Randal & Brown (1962b, unpubl.) are shown on Figure 25, together with the interpreted log of the Morstone No. 1 well.

The contact between the Age Creek Formation and the Camooweal Dolomite has been interpreted in several ways. Öpik (1956a) considers that the Camooweal Dolomite is of Lower Cambrian or Upper Proterozoic (Adelaidean) age, and that it formed an older meridional divide between the Middle Cambrian sequences in Queensland and the Northern Territory. Öpik clearly shows the stratigraphic position of the Camooweal Dolomite in his 1960 correlation chart. After Condon (1961, unpubl.) had identified cross-beds in the Age Creek Formation near Old Morstone homestead, Randal & Brown (1962b, unpubl.) studied the Age Creek Formation/Camooweal Dolomite boundary and the sequences on both sides of it. They concluded that: (i) A lithological boundary, traceable from Morstone homestead to Labortion Creek, approximates the boundary shown on the Camooweal 4-mile Geological Map (1961). To the east of the boundary, the sediments consist of pellet dolomite; near the boundary, pellet dolomite forms lenses within a crystalline dolomite, and to the west the sediments consist of cross-laminated white and mottled porous crystalline dolomite. (ii) The boundary extends northwards along the eastern side of the watershed between Nankivel Creek and Ada Creek, for example to the west of the approximate boundary shown on the Camooweal Sheet. (iii) Along the boundary, large tongues of detrital pellet dolomite (Age Creek Formation) are interbedded with lenses of crystalline dolomite (Camooweal Dolomite); immediately north of the northern boundary of Morstone station, interbeds of pellet dolomite commonly occur in crystalline dolomite (Camooweal Dolomite) and form characteristic rugged black outcrops which are easily distinguished on the air-photographs from the lighter-coloured crystalline dolomite. (iv) Interbeds of pellet dolomite in the Camooweal Dolomite were observed in Frith and Labortion Creeks, in small tributaries of Goonooma Creek (Sheet 2), and north of Norfolk homestead (Sheet 2).

Despite the slight westward shift of part of the boundary, there are two distinct rock bodies, one a pelletal dolomite (Age Creek Formation) and the other a crystalline dolomite

(Camooweal Dolomite); they intertongue along the boundary line shown on Sheet 2. Therefore, the age of the Camooweal Dolomite in this locality is Middle Cambrian.

Camooweal Dolomite

Derivation of Name: From Camooweal Township (lat. 19°55′15″S, long. 138°07′10″S). Öpik (1954, unpubl.) designated type area along Georgina River between Lake Mary, about 8 km north-northwest of Camooweal, and Lake Francis, about 3 km south-southwest of Camooweal. Both lakes are large waterholes in Georgina River. Named by Öpik (1956a), who also described its lithology, extent, and stratigraphical relationships.

Distribution: Camooweal, Mount Drummond, Ranken, Avon Downs, Mount Isa (Sheet 2) and Urandangi (Sheet 4) Sheet areas. Meridional belt along both sides of State border, from latitude 18°35′S to 21°S approximately, then southeastwards into Queensland almost to latitude 22°S. Bounded by the Ranken and Georgina Rivers in the west, and longitude 139°E in east.

The distribution is shown on Sheets 2 and 4; the boundaries are approximate and include the main outcrop areas and areas where the Camooweal Dolomite is assumed to underlie the black-soil plains where outcrops are sporadic. The distribution in the Northern Territory differs from that shown by Öpik (1956b, fig. 2) in accordance with the reduced distribution established by more detailed mapping. The distribution in Queensland is substantially the same as shown on the geological map of northwest Queensland (Carter, et al., 1961).

Lithology: 'Bedded dolarenite with nodules, stringers, and small lenticles of chert; some admixed fine quartz sand and interbeds of quartz sandstone occur at its base and locally thin beds of limestone and dolomitic limestone occur at various horizons' (Öpik, 1956a). Mainly white, or buff, light-brown, or cream. Randal & Brown (1962b, unpubl.) report interbeds and lenses of pellet dolomite in the Morstone Sheet area. The lithology of the outcrops is fairly uniform. Bedding ranges from thin to very thick, but thick and medium bedding is more common. Small-scale cross-bedding is also common.

Thickness: Complete sequence nowhere exposed: Carter & Öpik (1961) estimate about 150 m in Lawn Hill Sheet area; Smith & Roberts (1963) suggest 'several hundred feet' in Mount Drummond Sheet area; Öpik (1956a) estimated 250 to 300 m from interpretation of bore data; Randal & Brown (1962b, unpubl.) measured a part section of 38 m (Fig. 25); thickness of section attributed to Camooweal Dolomite is 430 m (1412 ft) in BMR 11 (Cattle Creek) and 301 m (987 ft) in Lake Nash No. 1.

Contacts: Interfingers with Age Creek Formation in Morstone area (Randal & Brown, 1962b, unpubl.); overlies and faulted against Middle Cambrian Currant Bush Limestone in Border Waterhole area (Smith & Roberts, 1963); overlies Lower Cambrian or Adelaidean basement in Lake Nash No. 1 (Amalgamated, 1963a, unpubl.); overlies fossiliferous Middle Cambrian limestone in BMR 11 (Cattle Creek) (Smith et al., 1967). Stratigraphical relationships indicate Middle Cambrian or younger age.

Fossils: None known in outcrop, but trilobites and brachiopods recorded in stratigraphic holes and water bores.

Age: Middle Cambrian, but may range into Upper Cambrian.

Discussion

The Camooweal Dolomite is of regional extent and is fairly uniform in lithology. The formation is poorly exposed except in the Camooweal Sheet area, where some cliff sections are known; elsewhere, it crops out in low benches and terraces. In much of the area, dolomite blocks and boulders protrude through the black-soil plains, and in some localities, it is difficult to distinguish between the cherty Camooweal Dolomite and the silicified Tertiary(?) dolomite and limestone. In the south, it is difficult to distinguish between the Camooweal Dolomite and the Upper Cambrian/Lower Ordovician Ninmaroo Formation.

In the Camooweal Sheet area, Brown (1962, unpubl.) found that the Camooweal Dolomite ranges from dolomite with pellets and intraformational pebbles to dense fine-grained crystalline dolomite. The pellets are usually about 0.05 mm in diameter, and are about the same size as grains of terrigenous material (quartz, feldspar, and rare heavy minerals) which are commonly present. The size of pellets increases towards the boundary with the Age Creek Formation.

The Camooweal Dolomite is commonly cavernous, with sinkholes on the surface; many caverns have been encountered in drilling operations, and most of the cores are vuggy. For

this reason, the Camooweal Dolomite yields abundant supplies of water which is generally suitable for stock and human consumption. The full potential of the formation has not been tested, as most of the bores were terminated at relatively shallow depths once supplies of 1000 to 2000 gallons per hour were obtained. BMR 11 (Cattle Creek) yielded up to 6000 gallons per hour by air lifting, but the tests were of short duration only.

The outcrop evidence that the Camooweal Dolomite is no older than Middle Cambrian is supported by boring. None of the wells or core holes passed through a Middle Cambrian sequence into Camooweal Dolomite. Nichols (1966, unpubl.) considers that some lithological characters of core hole Grg 9A (lat. 21°42′10″S, long. 138°19′48″E), in Camooweal Dolomite, correlate Upper Cambrian rocks in core hole Grg 14 (lat. 4°10′32″S, long. 137°21′46″E).

BMR 11 (Cattle Creek) and Lake Nash No. 1 began in Camooweal Dolomite and passed into fossiliferous Middle Cambrian rocks (Fig. 25) (Gatehouse, *in* Smith et al., 1967; A. A. Öpik, pers. comm.). Similarly, core hole Grg 16 (Fig. 21) spudded in Camooweal limestone, and Rocklands No. 33 Bore followed the same pattern.

The contact between the Camooweal Dolomite and the Precambrian or Lower Cambrian rocks has not been observed, and the lithology of the whole unit is uncertain. The position of the lower boundary of the Camooweal Dolomite in BMR 11 (Cattle Creek) and Lake Nash No. 1 is open to several interpretations: on lithological grounds the base would be placed at the base of the lowest beds above the limestone sequence, but the whole sequence above the Precambrian could be placed in the Camooweal Dolomite, with the limestone beds representing parts of the original sediments which have not been dolomitized.

Blazan Shale

Derivation of Name: From Blazan Creek, a tributary in headwaters of St Ronans Creek (Sheet 4). No type section designated.

Distribution: Urandangi Sheet area (Sheet 4). Restricted to small area in southeast (included in Cm3 group of units on Sheet 4).

Lithology: Siliceous shale with interbeds of sandstone and conglomerate at base.

Thickness: 60 m (Noakes et al., 1959); 36 m (Öpik, 1960).

Contacts: Disconformable on Thorntonia Limestone, filling canyons and gullies in its eroded surface; unconformable on Eastern Creek Volcanics and Sybella Granite, and conformably overlain by Quita Formation.

Fossils: Brachiopods and indeterminate agnostids.

Age: Upper Middle Cambrian (Noakes et al., 1959).

Comment

This is the basal formation of the upper Middle Cambrian sequence which disconformably overlies early Middle Cambrian formations in part of the eastern margin of the Georgina Basin. According to Öpik, the beds representing the Zones of *Pt. atavus* and *Hypagnostus parvifrons* (*Euagnostus opimus*) are missing below the base of the Blazan Shale.

Quita Formation

Derivation of Name: From Quita Creek, a large tributary of St Ronans Creek.

Distribution: Urandangi Sheet area (Sheet 4). Restricted to small areas in southeast. Noakes et al. (1959) traced the formation south from this area, but Reynolds (1965a) has not mapped it in the Glenormiston Sheet area.

Lithology: Siliceous shale and limestone, overlain by impure flaggy, marly, and sandy limestone with chert nodules.

Thickness: 55 m maximum.

Contacts: Conformable on Blazan Shale and disconformable on Thorntonia Limestone and Beetle Creek Formation; disconformably overlain by Steamboat Sandstone (Öpik, 1960).

Fossils (Öpik, 1960): Trilobites.

Age: Upper Middle Cambrian; Zone of *Pt. punctuosus*.

Correlates: Upper parts of Currant Bush Limestone and Inca Formation.

Comment

The Quita Formation crops out in low terraced hills; the dip seldom exceeds 3° to the south-southwest. In places it has been strongly faulted by crescentic faults of unknown age.

The formation is faulted against the Eastern Creek Volcanics in the southeast. Other observations on the Quita Formation are included in the discussion on the Steamboat Sandstone.

Steamboat Sandstone

Derivation of Name: From 'The Steamboat', a prominent mesa (lat. 21°55'S, long. 139°04'E; Sheet 4) capped by the formation. Type locality in Quita Creek area; no type section nominated.

Distribution: Urandangi and Glenormiston Sheet areas (Sheet 4). Southeast part of Urandangi Sheet area, southwards into northern part of Glenormiston Sheet area.

Lithology: Urandangi Sheet area: calcareous sandstone and quartz sandstone, with interbeds of sandy limestone and dolomite (Noakes et al., 1959); Glenormiston Sheet area: calcarenite, dolarenite, calcareous sandstone, calcilutite, and sandy calcilutite in lower part, and leached and weathered sandstone and minor siltstone beds in upper 25 m (Reynolds & Pritchard, 1964, unpubl.).

Thickness: 60 m (Öpik, 1960): 80 m+ (Reynolds & Pritchard, 1964, unpubl.).

Contacts: Disconformable on Quita Formation (Öpik, 1960); interfingers with lower part of Mungerebar Limestone in Glenormiston Sheet area; top eroded.

Fossils (Öpik, 1967a, 1970a): Wide variety of agnostid and polymerid trilobites.

Age: Upper Middle Cambrian; Zone of *L. laevigata*.

Comment

Noakes et al. (1959) state that the Steamboat Sandstone is 'visibly calcareous when fresh'; Reynolds & Pritchard (1964, unpubl.), who consider that the predominance of sandstone in the upper beds may be a weathering effect, report lateral changes from 'comparatively fresh sandy carbonate rock to weathered red, slightly ferruginous and kaolinitic? porous sandstone'. The changes from sandy limestone to sandstone could also reflect transgression and regression of the shoreline.

The sandstone in the upper part of the sequence is usually fine-grained, laminated or thin-bedded, well sorted, and silicified. The formation was faulted in pre-Mesozoic time, but has not been folded.

Noakes et al. (1950) mapped the Quita Formation to latitude 22°S, that is the boundary of the Urandangi and Glenormiston Sheet areas, but Reynolds & Pritchard (1964, unpubl.) did not map the Quita Formation south of this latitude and included the extensions from Urandangi Sheet area in the Steamboat Sandstone. The lower part of the Steamboat Sandstone is considered to be indistinguishable lithologically from the Quita Formation, and the validity of one of these two units as a formation is therefore in doubt.

Roaring Siltstone

Derivation of Name: From Roaring Bore (lat. 20°17'S, long. 140°05'E). No type section nominated, but Öpik (1961, p. 11) clearly intended section at Roaring Bore to be typical.

Distribution: Duchess Sheet area (Sheet 4). Small discontinuous outcrops in Selwyn Range area.

Lithology: Light grey friable laminated siltstone when fresh; on surface mottled siliceous siltstone and shale and interbedded sandstone (Carter & Öpik, 1963; de Keyser, 1968, unpubl.).

Thickness: 60 to 75 m.

Contacts: Unconformable on Cloncurry Complex and Lower Cambrian Mount Birnie Beds; overlain conformably by Devoncourt Limestone.

Fossils (Öpik, 1956a, 1960, 1961; Shergold, *in* de Keyser, 1968, unpubl.): Very abundant agnostid and polymerid trilobites, some brachiopods and bradoriids.

Age: Middle Cambrian; Zone of *Pt. cassis* (= *L. laevigata* I); may be younger away from main outcrop (Shergold, loc. cit.).

Comment

The Roaring Siltstone is the northern continuation of the shale facies of the Inca Formation (de Keyser, 1968, unpubl.) and is the basal unit of three upper Middle Cambrian formations in the Burke River Outlier of the Selwyn Range area (shown as Cm4 on Sheet 4).

It has been disturbed along several major faults, but away from the faults the dips are gentle. In common with other Cambrian formations near the eastern margin of the Georgina Basin, the outcrops are silicified and ferruginized.

Devoncourt Limestone

Derivation of Name: From Devoncourt Railway Siding, at latitude 21°09′25″S, longitude 140°11′55″E, about 10 km northwest of Devoncourt station. Type locality in Selwyn Range area; no type section proposed.

Distribution: Duchess Sheet area (Sheet 4).

Lithology: Grey sandy bituminous laminated and bedded limestone, with thin-bedded soft limestone interbeds (Carter & Öpik, 1963; de Keyser, 1968, unpubl.).

Thickness: 110 m in Selwyn Range and about 180 m farther north (Carter & Öpik, 1963); 180 to 210 m 11 km east of Duchess (de Keyser, op. cit.).

Contacts: Conformably overlies Inca Formation and Roaring Siltstone, unconformable on Thorntonia Limestone, faulted against Precambrian Cloncurry Complex, and overlain conformably by Selwyn Range Limestone and O'Hara Shale.

Fossils (Whitehouse, 1936, 1939; Öpik, 1956a, 1961; Shergold, *in* de Keyser, 1968, unpubl.): Wide variety of agnostid and polymerid trilobites.

Age: Upper Middle Cambrian; Zone of *Leiopyge laevigata* II and III (*agra* and *arepo* Zones) (Öpik, 1961).

Comment

The Devoncourt Limestone usually crops out poorly in pediments, and in terraced low hills in the north. It has been gently folded and dips steeply near faults. The formation has numerous slickensided fractures which dip at 10° to the east; they are apparently the result of thrusting and compression from the east, after the faulting had ceased.

Selwyn Range Limestone

Derivation of Name: From Selwyn Range, east of Duchess. No type section nomniated.

Distribution: Duchess Sheet area (Sheet 4). Selwyn Range area only; does not crop out north of Devoncourt homestead, nor south of Selwyn Railway Siding.

Lithology: Light-coloured flaggy calcilutite with chert nodules, and regular interbeds of soft marly limestone (de Keyser, 1968, unpubl.).

Thickness: 30 to 35 m.

Contacts: Conformable on Devoncourt Limestone and overlain disconformably by Upper Cambrian O'Hara Shale.

Fossils: Shergold (*in* de Keyser, 1968, unpubl.) records very sparse fauna from single locality. No other fossils have been reported.

Age: Upper Middle Cambrian and lowest Upper Cambrian (the 'Zone of Passage' of Öpik, 1967a).

Comment

The Selwyn Range Limestone crops out in low terraces and as rubble on low rises. Dips are steep near faults, but low elsewhere. The formation exhibits numerous slickensided fractures, dipping east at 10°, similar to those in the underlying Devoncourt Limestone.

Mungerebar Limestone

Derivation of Name: From land division within Ardmore station. Type area 'From Chummy Tank northwest for 6 miles towards Andy [lat. 22°18′S, long. 138°55′E] and Chummy dry bores; this is across the strike of the beds which dip low to southeast' (Casey, 1959).

Distribution: Glenormiston Sheet area (Sheet 4). North-central part of Glenormiston Sheet area only; crops out in belt from McCabe Knob (lat. 22°23′S, long. 138°54′E) in west to Smoky Creek in east; a few outcrops farther east near Cottonbush Creek.

Lithology: Mainly grey and dark grey well bedded sandy limestone, and limestone beds containing many chert biscuits; dolomitic limestone and oolitic limestone in some outcrops (Casey, 1959; see also Öpik, 1967a).

Thickness: Estimated maximum of 30 m; 20 m measured in continuous sequence.

Contacts: Overlies Steamboat Sandstone, but lower beds interfinger with it; overlain disconformably by Ninmaroo Formation, and by Mesozoic and Cainozoic sediments.

Fossils: Rich trilobite fauna described by Öpik (1967a); conodonts also recorded (Jones, 1961).

Age: Mainly Mindyallan (lowest Upper Cambrian), but oldest beds are Middle Cambrian (Öpik, 1960, 1967a).

Description and Comment

The outcrops are low and discontinuous, but Reynolds & Pritchard (1964, unpubl.) have recorded a section, just west of McCabes Knob, which is representative of the upper beds (see Appendix, Table 17).

The Mungerebar Limestone is overlain disconformably by red and white sandstone and siltstone, up to 10 m thick, mapped as the leached local basal beds of the Ninmaroo Formation; but Reynolds & Pritchard (1964, unpubl.) point out that these beds could belong to a separate formation between the Mungerebar Limestone and Ninmaroo Formation.

In the Netting Fence No. 1 well, which penetrated an almost complete sequence of the Cambrian and Ordovician sediments, 81 m (265 ft) of Mungerebar Limestone was reported in the interval from 1247 to 1328 m (4090-4355 ft) (PAP, 1965b, unpubl.). The sediments were described as calcarenite and calcilutite, with traces of oolites. No fossils were recorded, and on lithological grounds, J. N. Casey (pers. comm.) has expressed some doubt on its identification with the Mungerebar Limestone. Nevertheless, the gamma-ray log shows a distinctive unit in the interval. The well is about 110 km southwest of outcrops of the formation, whose presence is unknown in the subsurface between the two localities.

Unnamed Middle Cambrian Sequence in the Subsurface

Phillips Petroleum Co. Ltd (1963, unpubl.) drilled Middle Cambrian rocks in the Black Mountain No. 1 and Beantree No. 1 wells, and the French Petroleum Co. (Aust.) Pty Ltd (FPC, 1965c, unpubl.) drilled Middle Cambrian in The Brothers No. 1 well. None of the sequences has been named.

Black Mountain No. 1 Well (688 m; 1569-3828 ft)

Pomegranate Limestone (Upper Cambrian) overlying

540 m (1569-3341 ft). *Limestone,* light grey, buff to dark brownish grey, cryptocrystalline, argillaceous, silty in part; interbedded with *shale,* grey to dark grey to black, calcareous, micromicaceous in part, pyritic and glauconitic in part; calcite veins common.

148 m (3341-3828 ft). *Limestone,* argillaceous; *shale,* calcareous, grading down into *siltstone,* brownish grey to red, siliceous, sandy in part, calcareous between 3790 and 3828 feet (12 m); abundant black chert from 3360 to 3776 feet (127 m). Cores show bituminous limestone.

Mount Birnie Sandstone (Lower Cambrian) below.

The total thickness of Middle Cambrian in the well is 688 m (2259 ft), but dips in the cores average about 10° and the true thickness is less.

The fossils recovered are indeterminate (J. G. Tomlinson, pers. comm.); therefore the interval is assigned to the Middle Cambrian because it lies below known Upper Cambrian rocks and above a sequence placed in the Lower Cambrian on lithological grounds.

Beantree No. 1 Well

41 m (1604-1740 ft). *Limestone,* grey, hard, dense, shaly and silty; *limestone,* brown, hard, coarsely crystalline (7 m; 1620-1644 ft); phosphatic brachiopods.

Rests on adamellite

Middle Cambrian fossils were found in Core 3 (3 m; 1635-1645 ft) and McKellar (*in* Phillips, 1963, unpubl.) identified lower Upper Cambrian fossils in Core 2 (3 m; 983-993 ft); the well completion report states that part of the sequence above 488 m (1604 ft) may be of upper Middle Cambrian age. In any event, if the sequences assigned to Middle Cambrian in both the Beantree No. 1 and Black Mountain No. 1 wells are even approximately correct, the results show a considerable thinning from Black Mountain No. 1 westward to Beantree No. 1, which was drilled on a Precambrian 'high' which presumably extends south from the Cloncurry Complex.

The Brothers No. 1 Well

The well penetrated a probable Cambrian sequence from 351 to 1272 m (1153-4173 ft) (TD), although part of the sequence above 374 m (1227 ft) at least may be Lower Ordovician. Late Upper Cambrian or early Lower Ordovician conodonts were found in Core 2

(7 m; 1222-1245 ft), late Upper Cambrian conodonts in Core 3 (6 m; 1406-1426 ft), and early Middle Cambrian *Biconulites* in Core 10 (6 m; 4153-4173 ft) (Jones, *in* FPC, 1965c, unpubl.). No fossils were found in the cores and cuttings between 435 and 1266 m (1426-4153 ft), within which interval the boundary between Upper and Middle Cambrian lies. The whole sequence has been divided on lithological grounds and electric log characteristics into 5 units; brief lithological descriptions of each unit are given below, regardless of age, to obviate repetition later.

Unit 5. 42 m (1153-1292 ft): mainly *limestone,* grey to grey brown, non-porous, but fractured and water-bearing; stylolitic; minor interbeds of *clay,* grey, plastic.

Unit 4. 262 m (1292-2152 ft): interbedded *limestone,* grey to grey-brown, fine-grained, contorted, fractured, and *shale,* grey, fissile, micaceous.

Unit 3. 103 m (2152-2490 ft): dominantly *shale,* grey, compact, fissile, slightly calcareous; thin interbeds of *limestone,* grey, impure.

Unit 2. 454 m (2490-3980 ft): 357 m (2490-3662 ft): interbedded *limestone,* grey, fine-grained, compact, contorted, and *shale,* grey, fissile, micaceous. 97 m (3662-3980 ft): dominantly *shale;* minor interbeds of *limestone,* grey pyritic. The top of unit 2 is at the main break in the Cambrian sequence in the well, marked by resistivity change and an increase in velocity on the sonic log.

Unit 1. 59 m (3980-4173 ft): interbedded *limestone* and *shale* at top; grading into *limestone* at base, massive, grey to dark grey, fossiliferous (*Biconulites*).

The total thickness of probable Cambrian in this well is 924 m (3003 ft). The sequence is mainly flat-lying, or gently dipping, but some thin intervals above 490 m (1600 ft) are contorted.

Upper Cambrian

The description of the Upper Cambrian rock units excludes the late Upper Cambrian sequences, which are described later as Cambro-Ordovician.

NORTHERN TERRITORY

Arrinthrunga Formation

Derivation of Name: From Arrinthrunga Creek, a prominent tributary of Arthur Creek, which rises on southeast flank of Dulcie Range and flows through higher part of sequence. Type section at latitude 22°41′15″S, longitude 135°40′E, near northwest end of Elyuah Range.

Principal Reference: Smith (1964a).

Distribution: Huckitta, Elkedra (Sheet 3), Tobermory, Hay River Sheet areas (Sheet 4). Narrow belt in southwest foothills of Dulcie Range, and broad belt between southeast tip of Dulcie Range and longitude 136°30′E; approximately, northwards almost to Ooratippra homestead. The formation has not been identified either in outcrop or subsurface west of Ooratippra Creek and west of Mount Ultim. East of the Huckitta Sheet area, the formation crops out discontinuously in an arcuate belt extending from southeast of the Tarlton Range to Marqua homestead (Sheet 4), and continues southeast in narrow belts, on the eastern side of the Craigie Fault; a few discontinuous outcrops extend into Queensland, along the eastern side of the Toomba Fault.

The formation has been identified in BMR 13 (Sandover) and BMR 12 (Cockroach) and is probably present in the Netting Fence No. 1 well.

Lithology: Predominantly crystalline dolomite, algal dolomite, oolitic and pelletal limestone, and dolomite, with interbeds of siltstone and sandstone. Red and green siltstone is common in the middle part of the sequence, and thin interbeds of quartz sandstone are common throughout, but usually crop out poorly. One quartz sandstone has been delineated as a separate member—the *Eurowie Sandstone Member.*

Thickness: Maximum measured is 975 m, east of Yam Creek (Huckitta Sheet area); averages about 900 m in much of Huckitta Sheet area; thins eastward to about 600 m in Tarlton Range/Toko Range area, for example 681 m (2236 ft) in BMR 12 (Cockroach).

Contacts: Conformably overlies Middle Cambrian Arthur Creek Beds in Lucy Creek station area, but elsewhere position of lower contact uncertain; unconformable(?) on Mount Baldwin Formation in Elyuah Range; in east, apparently conformable on Marqua Beds, and in many places faulted against Adelaidean Field River Beds. Overlain disconformably or

apparently conformably by Tomahawk Beds in west, and apparently conformably by Ninmaroo Formation in east.

Fossils: Fossils are rare and are known only in two outcrops (Fig. 26). The oldest fossils are trilobites of lower Upper Cambrian age (A. A. Öpik, pers. comm.), the fossils near the middle of the formation are brachiopods and hyolithids which could not be removed undamaged from the rock, and those near the top are trilobites which have not been positively identified. No fossils have been obtained from the stratigraphic holes and exploratory wells.

Age: Upper Cambrian; age indicated by stratigraphic position between Middle Cambrian Arthur Creek Beds and Marqua Beds and late Upper Cambrian/Lower Ordovician Tomahawk Beds and Ninmaroo Formation. The range in Upper Cambrian time has not been established.

Correlates: Part of Meeta Beds and Georgina Limestone.

Description and Comment

The type section of the Arrinthrunga Formation includes only about one-third of the sequence, but it demonstrates the lithology of the carbonate rocks and interbedded siltstone and sandstone which are typical of the formation in the western and central parts of the Huckitta Sheet area. It is not possible to select a section in the Huckitta Sheet area where the top and bottom beds are clearly exposed, and which includes the Eurowie Sandstone Member. Since the selection of the type section (in 1958), the development of new pastoral areas and the drilling of stratigraphic holes have provided better access to good sections of the formation in the Huckitta homestead/Elyuah Range area, and these sections, which are thicker than the type section, also amply illustrate the lithology.

In the type section of the Arrinthrunga Formation, the sequence is steeply dipping and overturned, but the outcrop is good; the measured sequence is detailed in Smith (1964a, p. 41).

In the eastern part of the Huckitta Sheet area, the Arrinthrunga Formation may be subdivided into four units, which in descending order are:

Unit 4. Hard brown dolomite, some prominent interbeds of blue and blue-black oolitic and algal limestone, minor interbeds of thin quartz sandstone, red and green siltstone, and buff soft fine-grained dolomite.

Unit 3. Brown quartz sandstone with ripple marks and halite casts—the Eurowie Sandstone Member.

Unit 2. Poorly outcropping blue oolitic limestone, blue algal limestone, buff dolomite, thin quartz sandstone, minor red and green siltstone; numerous concealed beds, probably consisting of siltstone (on evidence from water bores).

Unit 1. Hard thick and medium-bedded brown and dark brown dolomite with chert nodules, and minor quartz sandstone. This unit crops out strongly.

Although there are many changes along the strike from limestone to dolomite and from dolomite to quartz sandstone, particularly in unit 4, the broad division of units is easily recognizable in the eastern Huckitta Sheet area, and can also be recognized, in part, in the eastern part of the Tobermory Sheet area. However, unit 3 is not known in the western part of the Huckitta Sheet area, or in the Tobermory Sheet area, where, in general, outcrops contain more limestone and less dolomite than the sequence in the Huckitta Sheet area; the interpreted log of BMR 12 (Cockroach), however, shows a preponderance of dolomite (Fig. 26).

An important lithological variation from unit 1 occurs in the western part of the Huckitta Sheet area, in the localities of the composite section; here the base is not exposed, but lower beds of the formation consist of platy blue limestone with interbeds of red siltstone and sandstone. This part of the sequence may be older than the normal basal dolomite of unit 1, or it may be low in unit 2, which does not crop out well. In either case, its presence may indicate a disconformity between the Arrinthrunga Formation and underlying sequences.

The total thickness of units 1 to 4 in the eastern part of the Huckitta Sheet area has not been measured, because of the poor outcrop of unit 2; it is estimated at 900 m. The sequences in surface sections and well sections are shown on Figure 26. The only hole which has penetrated the complete sequence is BMR 12 (Cockroach), but BMR 13 (Sandover) provided a good record of unit 2, as outlined in the eastern part of the Huckitta Sheet area, and BMR core hole Grg 7 provided valuable lithological information on the lower part of unit 2 and the upper part of unit 1, while Grg 8 cored a higher part of unit 2. The Huckitta No. 1 well commenced 250 m (820 ft) stratigraphically below the top of the Arrinthrunga Formation and provided a record of the subsurface sequence in the western part of the

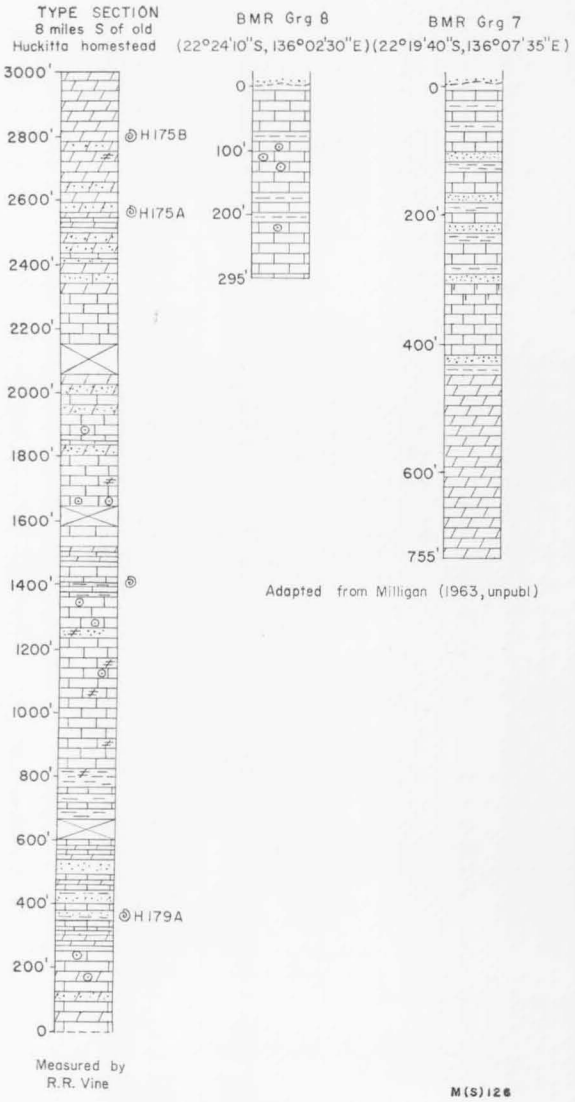


Figure 26. Stratigraphic sequences in Arrinthrunga Formation

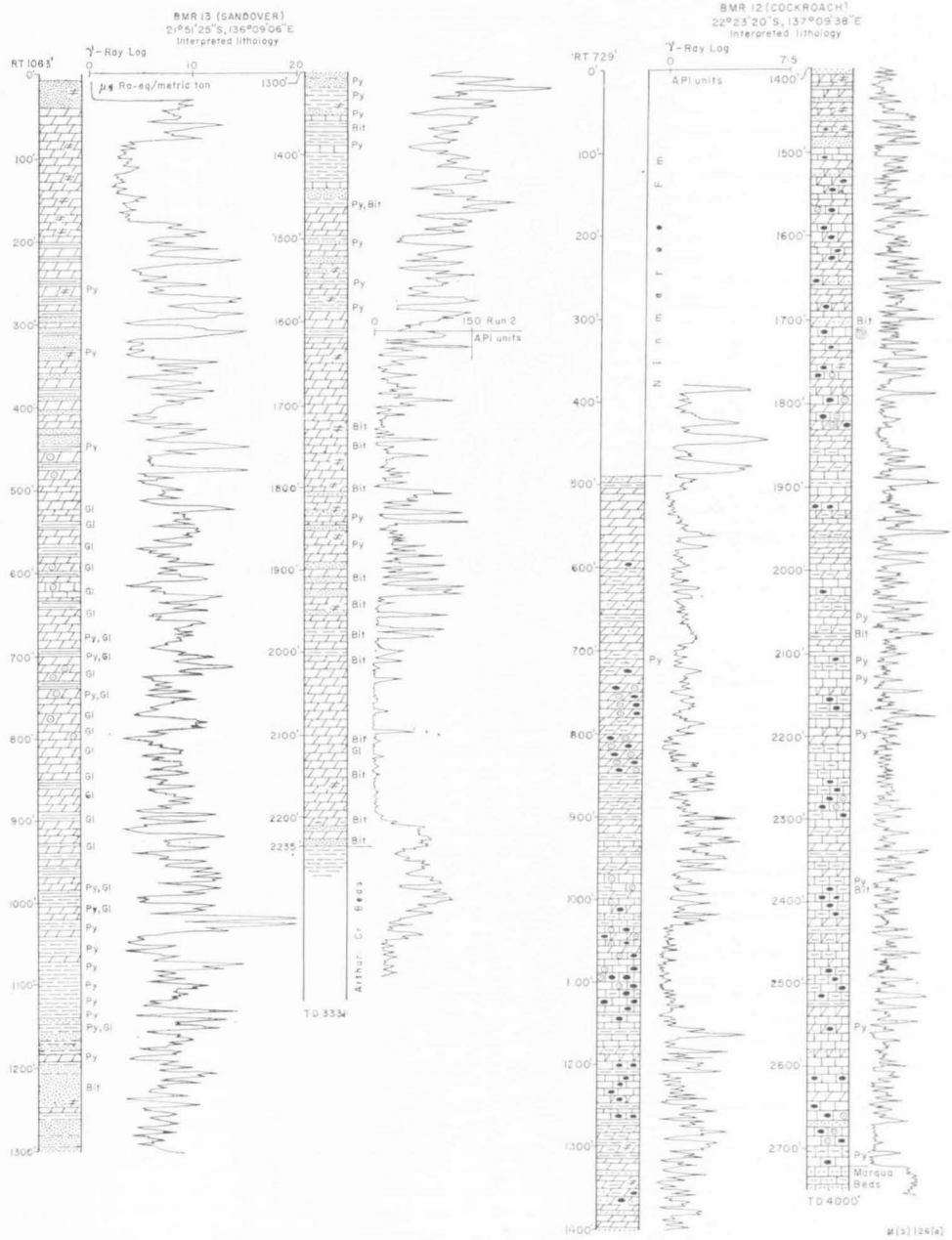


Figure 26. Stratigraphic sequences in Arrinthrunga Formation (cont.)

Huckitta Sheet area. The Arrinthrunga Formation has not been recorded in the Netting Fence No. 1 well, but a dominantly carbonate sequence in the interval 726 to 1548 m (2381-5080 ft) below the Ninmaroo Formation, is best placed in the Arrinthrunga Formation.

The contacts of the Arrinthrunga Formation with the underlying and overlying sequences are generally difficult to define, because of the structural complexity and poor exposures, or because it is difficult to select a boundary between units in which carbonate rocks predominate. In most places, the formation rests apparently conformably on Middle Cambrian units, but in the Elyuah Range it rests disconformably on either the Mount Baldwin Formation or Arthur Creek Beds. In this locality, the Arthur Creek Beds have not been mapped, but in places rubble of unfossiliferous chert and soft yellow sandstone, which might belong to the Arthur Creek Beds, lies on the surface between the Mount Baldwin Formation and the Arrinthrunga Formation. Elsewhere, towards the northwestern end of the range, but southeast of Grant Bluff, the Arrinthrunga Formation appears to lie on the Mount Baldwin Formation, though actual contacts have not been observed. The evidence for a disconformity in the Elyuah Range is dependent on the correct identification of the Arrinthrunga Formation there, but the sequence is lithologically similar to the lower part of the formation to the northeast.

There is ample evidence northwest of Huckitta homestead that the Cambro-Ordovician Tomahawk Beds have transgressed several older units, but in the Huckitta area itself, in a deeper part of the basin, the contact between the Arrinthrunga Formation and Tomahawk Beds appears to be conformable and gradational, although the sandstone at the base of the Tomahawk Beds could indicate a change in the environment. Farther east in the Lucy Creek area, the reduction in the thickness of the top unit of the Arrinthrunga Formation may be due to erosion; another erosional break is indicated around BMR 13 (Sandover), where the Tomahawk Beds overlie beds high in unit 2 of the Arrinthrunga Formation. In the Tobermory, Hay River, and Mount Whelan Sheet areas the Arrinthrunga Formation is succeeded by other carbonate formations, and the boundary is difficult to define. In all areas, insufficient palaeontological data are available to determine the length of the breaks at the base or top of the Arrinthrunga Formation.

In the subsurface, the Arrinthrunga Formation is widely distributed, and it is almost certainly contiguous with the Meeta Beds, which are correlated lithologically with the lower part of the formation. However, the extent of the formation to the west of Ooratippra Creek, and farther southwest to Mount Ultim, is uncertain. The formation has not been identified in outcrop to the west of this line, nor has it been identified subsurface, although it may be concealed beneath Cambro-Ordovician sediments or Quaternary sand and alluvium. Depth to basement in the Barrow Creek and Alcoota Sheet areas is unknown, but the aeromagnetic contours in the Huckitta Sheet area (Fig. 6) have a regular northwesterly trend, generally in conformity with the surface outline of the Dulcie Syncline. The complete removal of about 1000 m of Arrinthrunga Formation would have a marked effect on these contours; the Dulcie Sandstone and Tomahawk Beds continue to the northwest without much reduction in thickness, so the closing of the 6000-foot contour and the convergence of the 4000-foot contour may indicate reduction in thickness of the Arrinthrunga Formation towards the northwest. Nevertheless, the available geological information is:

(1) Core hole Grg 1, which was sited to penetrate the Arrinthrunga Formation or Arthur Creek Beds, cored Cainozoic sediments from surface to 35 m (0-116 ft), and a sequence of sandstone with interbedded siltstone and oolitic limestone from 35 to 64 m (116-210 ft) (TD). A. A. Öpik (pers. comm.) considers that a brachiopod recovered at 63 m (208 ft) is not older than Upper Cambrian. The sequence bears some lithological resemblance to both the Tomahawk Beds and Arrinthrunga Formation, but the only fossil recovered is not diagnostic.

(2) A water bore about 8 km southeast of Mount Ultim penetrated about 65 m of soft yellow siltstone, with some sandstone interbeds. This sequence almost certainly belongs to the Arthur Creek Beds, and consequently there is little room for the Arrinthrunga Formation unless its strike is transverse to that of the Dulcie Syncline. The bore was redrilled about 1962 and logged by D. R. G. Woolley (BMR). The new bore was located 50 m north of the first bore; it penetrated 9 m (30 ft) of Cainozoic sediments followed by 65 m (220 ft) of quartz sandstone, claystone, and siltstone which does not fit the known sequence in the Arrinthrunga Formation, but may belong to the Arthur Creek Beds.

(3) Core hole Grg 2, on the north side of the Dulcie Syncline, penetrated friable quartz sandstone, lithologically identical with the Devonian Dulcie Sandstone, and was abandoned at 108 m (354 ft).

(4) Core hole Grg 5, also on the north side of the Dulcie Syncline, penetrated Quaternary sand from the surface to 53 m (0-173 ft), and then a sequence of limestone, oolitic limestone, sandstone, and siltstone from 53 to 137 m (173-450 ft) (TD). This sequence has some lithological similarities to both the Tomahawk Beds and Arrinthrunga Formation; trilobites found at 53 to 54 m (175 ft 6 in-177 ft 3 in) are not older than Upper Cambrian (Tomlinson, *in* Milligan, 1963, unpubl.), and are not diagnostic of either the Tomahawk Beds or Arrinthrunga Formation.

(5) About 26 km northwest of core hole Grg 2, low outcrops of oolitic unfossiliferous limestone underlie, in part, fossiliferous Upper Cambrian sandstone of the Tomahawk Beds, and have tentatively been included in the Tomahawk Beds; these are the only known outcrops which might be part of the Arrinthrunga Formation.

(6) The northwestern limit of the Arrinthrunga Formation between Ooratippra homestead and Mount Ultim is parallel to the trend of a major Precambrian fault which may have been reactivated after Arrinthrunga but before Tomahawk Beds time, with the downthrown side to the southeast; subsequent erosion may have caused some thinning on the uplifted northwestern side before the late Upper Cambrian transgressive seas covered the area. However, there is no evidence of such a fault in the Adelaidean and Lower Cambrian sediments and Precambrian rocks on the southern flank of the Dulcie Range.

(7) As no core hole has commenced in the Tomahawk Bed sequence, and as they have not been penetrated in any of the stratigraphic holes or exploratory wells, it is impracticable to compare the sequences in Grg 1 and Grg 5, and in the outcrops 26 km northwest of Grg 2, with the known sequence in outcrop. However, the transgression of the Tomahawk Beds over older rocks, particularly northwest of Huckitta homestead, strongly suggests that the sequences in Grg 1 and Grg 5 belong to the Tomahawk Beds. The Arrinthrunga Formation may lie below them, but the core holes may not be deep enough to verify this.

Oolites and algae are abundant in the Arrinthrunga Formation, particularly in the upper part of unit 2 and the lower part of unit 4. The algae are usually in dome-shaped colonies, and each dome consists of many individual 'rods' of *Collenia*. Algae are well displayed about 6 km southeast of Lucy Creek homestead, near the track leading from the homestead to the Tarlton Downs/Jervois road. Low but prominent mounds of algal limestone crop out in the bed of a shallow stream on the right-hand side of the track. Larger algal colonies about 3 m across are exposed in Eurowie Creek, but access is difficult. Lead was found by a prospector in the upper algal part of the Arrinthrunga Formation, about 13 km east of Arapunyah homestead, in 1960, and was subsequently tested and abandoned by Consolidated Zinc Pty Ltd (1961, unpubl.) (see p. 49).

The main structural feature in the Arrinthrunga Formation is the faults trending northwest, with east block down. In the Dulcie and Toomba Range areas the faults are known to be younger than Upper Devonian and it is assumed that most, if not all, of the other faults are of the same age. Some of the faults are up to 100 km long with throws of about a thousand metres; the throw cannot be determined accurately because of lack of information on the erosion of the Adelaidean rocks, for example along the Toomba Fault near the Queensland border. Several small drag folds, both anticline and synclines, are associated with the faults; but the movements have had only a slight affect on the Arrinthrunga Formation. The most prominent surface folds are the Huckitta Anticline and an unnamed dome about 13 km to the east, but the data on the Huckitta No. 1 well, on the Huckitta Anticline, indicates that the beds may be compacted over an Adelaidean ridge.

Eurowie Sandstone Member

Derivation of Name: From Eurowie Yard (lat. 22°29′S, long. 135°54′50″E), on west bank of southern branch of Eurowie Creek (Smith, 1964a). Type locality in Eurowie Yard area; no type section measured because of irregular dip readings and incomplete sequences.

Distribution: Huckitta Sheet area (Sheet 3). Restricted to almost continuous belt from about latitude 22°10′S, longitude 136°E, southward for 80 km to about 8 km east of Picton Spring, at about latitude 22°35′S.

Lithology: Red-brown medium-grained laminated to thin-bedded quartz sandstone, with some beds of fine-grained quartz sandstone and siltstone near base; sandstone grades upwards into dolomite. Abundant ripple marks, small-scale cross-beds, halite casts, mud cracks, and mud pellets are present.

Thickness: From 15 to 30 m.

Contacts: Sharp conformable contact with underlying limestone and dolomite, but upper part usually grades vertically, and in places laterally, into dolomite.

Fossils: Barren.

Age: Upper Cambrian.

Description and Comment

The weathered red-brown Eurowie Sandstone Member has a dark conspicuous pattern on the air-photographs. The fresh sandstone is white. The halite casts consist of cubic hollows in dolomitic sandstone and dolomite. The member crops out in low rises and as rock and rubble on the surface of the carbonate rocks.

The Eurowie Sandstone Member has no known equivalent elsewhere within the Arrinthrunga Formation. In the northeastern part of the Huckitta Sheet area the formation contains many lenses of ripple-marked quartz sandstone, many of which grade laterally into dolomite, but none of them is at the same stratigraphical level as the Eurowie Sandstone Member.

Meeta Beds

Derivation of Name: From Meeta Bore (lat. 21°27'S, long. 137°15'E) on main road between Argadargada and Lake Nash homestead (Nichols, 1966b, unpubl.). No reference section measured because of discontinuous outcrop, but reference area consists of arcuate belt extending from about 6 km west to about 6 km north of Meeta Bore. Neither the base nor the top of the sequence is exposed and the term 'Beds' has therefore been preferred.

Distribution: Northeast part of Elkedra Sheet area (Sheet 3); most of northern half and part of southern half of Sandover River Sheet area (Sheet 4); southern part of Avon Downs Sheet area (Sheet 2); and perhaps central-eastern part of Frew River Sheet area (Sheet 1).

Lithology: Mainly dolomite, with interbeds of quartz sandstone and siltstone; fragments of chert, commonly oolitic and pelletal on surface; some oolitic limestone beds.

Thickness: Complete sequence unknown, but probably over 300 m in most localities; 225 m (739 ft) in BMR core hole Grg 4, 219 m (720 ft) in Grg 14, and 275 m (902 ft) in water bore G2 on Lake Nash station, 16 km northwest of Meeta Bore; 316 m (1036 ft) in an unsuccessful water bore, about 16 km southwest of Meeta Bore. None of the core holes or water bores reached the base of the sequence.

Fossils: Recrystallized gastropods, of probable Upper Cambrian age, 21 km west-southwest of Georgina Downs homestead (Nichols, 1964, unpubl.); algae in dolomite beds in Argadargada station area.

Age: Upper Cambrian. Lithology correlated with part of Arrinthrunga Formation. Part of the Meeta Beds in the north could be Middle Cambrian, but the only evidence for this is the presence of Middle Cambrian limestone in the Lake Nash No. 1 well, below a dolomite which dips south towards, if not under, the Meeta Beds.

Correlates: Units 1 and 2 of Arrinthrunga Formation, and perhaps part of Camooweal Dolomite (basis of correlation of detailed sequences in core holes Grg 14 and Grg 9A; Nichols, 1966b, unpubl.).

Description and Comment

The Meeta Beds usually crop out poorly in low rises which are commonly covered with chert rubble. In the east, rises are separated by black-soil plains with protruding blocks of dolomite and thin layers of quartz sandstone rubble; in the west, in the Elkedra Sheet area, outcrops are mainly confined to a series of ridges trending southwest from Annitowa homestead; the ridges are separated by spinifex-covered sand plain, except for small areas north and west of the homestead, where dolomite blocks protrude through the brown-soil plains. Sandstone crops out in small rises and low benches. The low rises and ridges of buff and white dolomite and oolitic and pelletal chert in the Avon Downs Sheet area are continuous with the outcrops in the Sandover River Sheet area, and are tentatively included in the Meeta Beds because the lithology resembles that of the Meeta Beds rather than the fossiliferous Wonarah Beds to the north.

The dip is usually irregular, owing to slumping, particularly in the quartz sandstone; but some low southerly dips have been observed in the ridges southwest of Annitowa homestead. The low irregular dip and discontinuous outcrops make it difficult to determine the stratigraphy and thickness.

Nichols (1964, unpubl.) described the Meeta Beds in the Sandover River Sheet area as buff microcrystalline and medium to coarse crystalline dolomite; buff microcrystalline and cryptocrystalline dololutite; buff pelletal and intraclastic, medium to well sorted, medium to thick-bedded dolarenite; buff oolitic and quartzose dolarenite; buff algal dolomite; buff intraclastic dolarenite, with large intraclasts 2 to 3 cm long; brown, medium to coarse-grained, ripple-marked, cross-bedded, medium to well sorted quartz sandstone; and some dolomitic sandstone. In the Elkedra Sheet area, Smith (1966) described the sequence in the ridges east of Annitowa homestead as dolomite, chert, and brown friable quartz sandstone, overlain by buff and light grey finely crystalline limestone and oolitic limestone, with interbeds of soft grey calcareous sandstone; blocks of brown dolomite occur on the plains to the north and west of the homestead. In the ridges to the southwest, buff and white dolomite predominates,

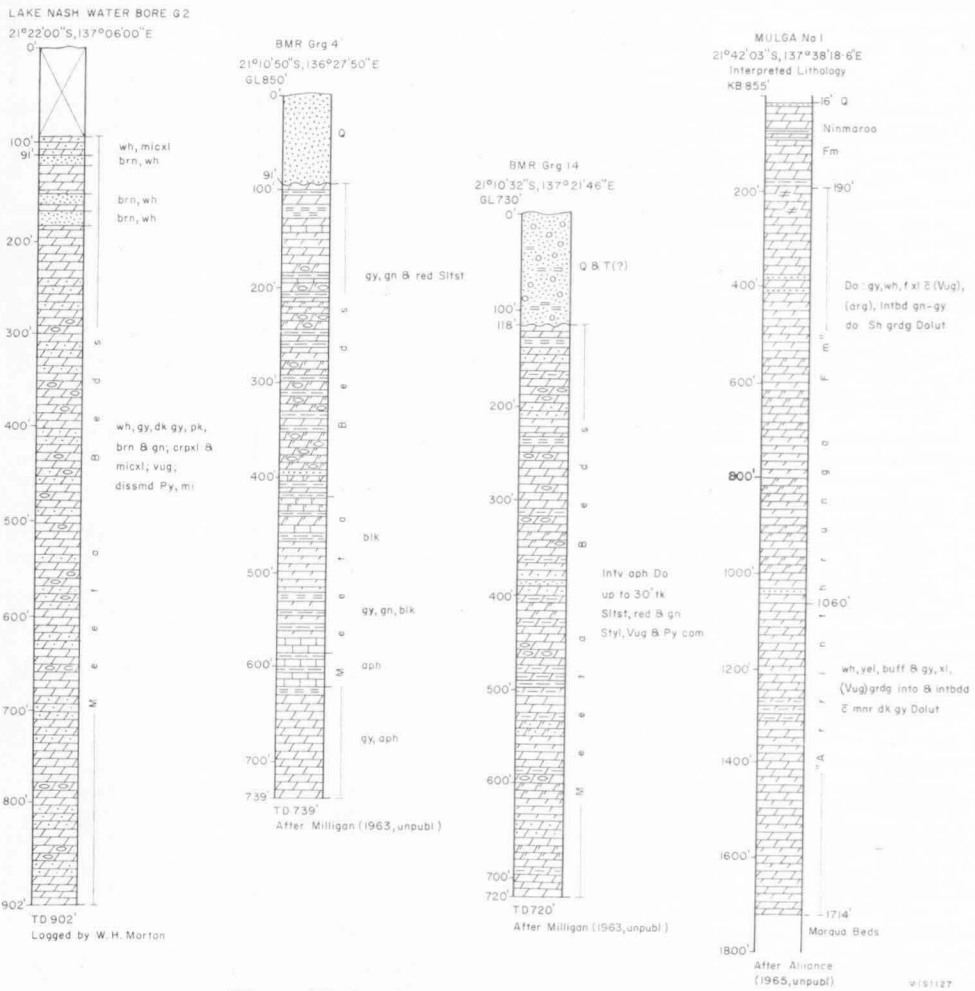


Figure 27. Stratigraphic sequences in Meeta Beds

but near the southwestern extremity of the ridges there are numerous beds of green and purple siltstone and some interbeds and lenses of quartz sandstone. One prominent lens of quartz sandstone is 23 m thick; it is white (when fresh), medium to coarse-grained, friable, clean, and ripple-marked.

Only an approximate boundary can be drawn between the Meeta Beds and the overlying Tomahawk Beds. The boundary between the Meeta Beds and the Ninmaroo Formation, in the western part of Sandover River Sheet area, is drawn approximately between two dolomite sequences, one of which (the Ninmaroo Formation) grades laterally into fossiliferous sandstone of the Tomahawk Beds.

Subsurface information on the Meeta Beds has been obtained in BMR core holes Grg 4 and Grg 14 (Milligan, 1963, unpubl.) and presumably also in the Mulga No. 1 well, although the sequence below the Ninmaroo Formation is named the Arrinthrunga Formation in the completion report (Alliance, 1965, unpubl.). The unpublished logs of several water bores drilled in 1963 provide valuable supporting information on the subsurface sequence (Resident Geologist, Alice Springs, pers. comm.). Core from Grg 4 has been examined petrologically by Fehr (1963, unpubl.) and from Grg 14 by Nichols & Fehr (1964, unpubl.). The logs of Grg 4, Grg 14, and the appropriate part of the Mulga No. 1 well, together with the log of water bore G2 on Lake Nash station, are shown on Figure 27.

QUEENSLAND

Pomegranate Limestone

Derivation of Name: From Pomegranate Creek, a tributary of Burke River, which rises about 30 km southwest of Selwyn (Öpik, 1960, pp. 101-2). Type locality at 'Pomegranate Creek, Chatsworth Station, south of Cloncurry, northwestern Queensland' (Lexique Stratigraphique internationale, 1962, 52, p. 117). No type section nominated.

Distribution: Duchess and Boulia Sheet areas (Sheet 4). Main outcrops in Duchess Sheet area occupy about 900 sq km; outcrops of few square kilometres known in De Little Range in Boulia Sheet area. Formation identified in interval from 229 to 478 m (752-1569 ft) in Black Mountain No. 1 and from 92 to 488 m (303-1604 ft) in Beantree No. 1 (Phillips, 1963, unpubl.).

Lithology: Light-coloured crystalline bituminous flaggy and laminated limestone, grey sandy limestone, intraformational breccia, some chert nodules; in subsurface: light grey hard dense microcrystalline and cryptocrystalline silty and argillaceous limestone, with thin interbeds and laminae of grey-black calcareous micaceous shale.

Thickness: 30 m estimated in Pomegranate Creek area where base not exposed (Carter & Öpik, 1963); 15 m in outcrop and probably 90 m in water bores in De Little Range area (Casey & others, 1960, unpubl.); 249 m (817 ft) in Black Mountain No. 1 and 397 m (1301 ft) in Beantree No. 1 (Phillips, 1963, unpubl.).

Contacts: Base not exposed; overlain by, and interfingers with, O'Hara Shale; in Black Mountain No. 1 and Beantree No. 1 wells rests on unnamed sequences of probable lower Middle Cambrian age.

Fossils (Öpik, 1963, 1967; Tomlinson, *in* Phillips, 1963, unpubl.): Trilobites and brachiopods.

Age: Upper Cambrian, Idamean Stage (Öpik, 1963); a diachronous upper contact through several zones.

Correlates: Lower part of O'Hara Shale and Georgina Limestone(?).

Description and Comment

The outcrops of the Pomegranate Limestone in the Duchess Sheet area are low, discontinuous, and gently undulating, and are probably repeated by small-scale faulting; only the upper part of the sequence is exposed and no type section has been nominated. In the Boulia Sheet area, outcrop is also poor. In both areas, the O'Hara Shale conformably overlies the Pomegranate Limestone and in some localities the two formations interfinger. The Pomegranate Limestone has been named from surface sections which are thin compared with the thickness in the Black Mountain No. 1 and Beantree No. 1 wells.

In Beantree No. 1, the Cretaceous Wilgunya Formation unconformably overlies the Pomegranate Limestone and an unnamed lower Middle Cambrian limestone underlies it. The selection of the base of the Pomegranate Limestone is presumably based on electric log characteristics, which show a marked change at 488 m, and is supported in part by the presence of coarsely crystalline limestone below. Lower Middle Cambrian fossils have been identified in Core 3 (3 m; 1635-1645 ft) (Mackellar, *in* Phillips, 1963, unpubl.). The Pomegranate Limestone thickens from the Black Mountain No. 1 well to the Beantree No. 1 well, whereas the Middle Cambrian sediments thin out between these localities.

O'Hara Shale

Derivation of Name: From O'Hara Gap station (lat. 21°25'S, long. 140°05'E) in northwest Queensland (Öpik, 1956a).

Distribution: Confined to small discontinuous areas in Burke River valley, between Devoncourt and Chatsworth homesteads, in Duchess Sheet area; also occurs in northwest part of Boulia Sheet area.

Lithology: Micaceous laminated well bedded pink and red shale and siltstone, with thin sandstone interbeds and some chert interbeds (Öpik, 1960; Carter & Öpik, 1963); Casey & others (1960) record interbeds of conglomerate.

Thickness: Up to 60 m preserved (Carter & Öpik, 1963).

Contacts: Conformably overlain by Chatsworth Limestone in Black Mountain No. 1, but most outcrops overlain by Cretaceous or Cainozoic sequences: in places O'Hara Shale conformably overlies and interfingers with Pomegranate Limestone.

Fossils (Öpik, 1961, 1963, 1967a): Wide variety of trilobites and some brachiopods.

Age: Lower Upper Cambrian, Mindyallan and Idamean Stages (Öpik, 1967a).

Description and Comment

The O'Hara Shale crops out as cappings to mesas and plateaux and usually weathers red, brown, or pink. The shale and siltstone are well laminated. It has been tectonically disturbed along with other Palaeozoic formations in the Burke River Structural Belt, but the dip is always gentle except near faults.

The subsurface extent of the O'Hara Shale is unknown; it has been identified in the Black Mountain No. 1 well, but in Beantree No. 1 the Pomegranate Limestone is overlain by Mesozoic sediments and the O'Hara Shale is not present, although the upper part of the Pomegranate Limestone may be laterally equivalent to it. The O'Hara Shale is 49 m (162 ft) thick in Black Mountain No. 1 and consists of dark grey micaceous silty slightly calcareous shale with laminae of brownish grey calcareous siltstone (Phillips, 1963, unpubl.). No diagnostic fossils were obtained.

Chatsworth Limestone

Derivation of Name: Chatsworth station on Duchess and Boulia Sheet areas (Casey, 1959). Type area at latitude 22°03'S, longitude 140°18'E.

Distribution: Duchess and Boulia Sheet areas (Sheet 4). North, northwest, and east of Chatsworth homestead in Duchess Sheet area; 26 km east-northeast of Digby Peaks, and at Black Mountain, Mount Ninmaroo, and near Dribbling Bore in Boulia Sheet area.

Lithology: Grey and dark grey calcarenite and calcilutite, with minor calcareous sandstone, coquinite beds, and intraformational breccia. Predominantly thin-bedded and laminated, with minor cross-bedding. Öpik (1960) reported dolomite in the sequence, but Carter & Öpik (1963) do not mention it.

Thickness: 158 m in type section, but base and top not exposed (Casey, 1959); Casey & others (1960, unpubl.) report: near Dribbling Bore, 60 m; Mount Datson, 200 m; Mount Ninmaroo, 115 m; Black Mountain, 320 m. The base is not exposed at these localities, but the Black Mountain No. 1 well penetrated the underlying O'Hara Shale at 180 m (590 ft) (Phillips, 1963, unpubl.). The combined surface and subsurface sections at Black Mountain indicate a complete thickness of 450 m. Öpik (1960) gives the total thickness as about 600 m.

Contacts: Rests conformably on O'Hara Shale and conformably overlain by Ninmaroo Formation (Casey, 1959); disconformably overlies Middle Cambrian Inca Formation.

Fossils: Abundant trilobites and brachiopods (Öpik, 1956a, 1960; Carter & Öpik, 1963). Conodonts from Black Mountain, Mount Ninmaroo, and Mount Datson studied by Druce & Jones (1970).

Age: Upper Cambrian (Franconian and Trempealeauan, Öpik, 1960).

Description and Comment

The formation generally crops out poorly in the Duchess Sheet area, but it crops out better in a chain of isolated peaks in the Boulia Sheet area. Casey & others (1960, unpubl.) have described the type section (Fig. 28) of the Chatsworth Limestone (see also Appendix, Table 18).

In Black Mountain No. 1, the Chatsworth Limestone was reported as argillaceous very fine-grained limestone, parts of which are silty and parts glauconitic, and interbeds of micaceous, calcareous shale (Phillips, 1963, unpubl.). The limestone of the upper part of the sequence exposed at the surface is coarser, and is sandy rather than argillaceous (Casey & others, 1960, unpubl.) (Appendix, Table 19).

The Chatsworth Limestone has been folded and faulted along the Black Mountain/Mount Ninmaroo/Mount Datson line of outcrops; it is downthrown at least 300 m to the east.

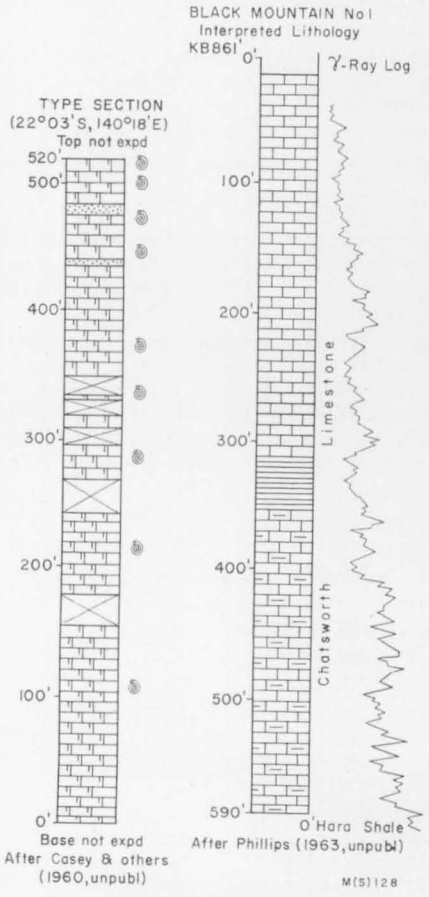


Figure 28. Stratigraphic sequences in Chatsworth Limestone

Gola Beds

Derivation of Name: County of Gola, 10 km north of St Lucia homestead (lat. 22°38'S, long. 140°30'E) (Casey, 1959).

Type area: Two small inliers in Momedah Anticline; no type section designated.

Distribution: Boulia Sheet area (Sheet 4); type area only.

Lithology: Calcarenite and calcilutite.

Thickness: Estimated maximum 45 m exposed.

Contacts: Base not exposed; eroded top overlain unconformably by Lower Cretaceous Longsight Sandstone.

Fossils: Trilobites, including rich agnostid fauna (Öpik, 1960; Shergold, 1971); conodonts (Druce & Jones, 1970).

Age: Late Upper Cambrian.

Description and Comment

The Gola Beds crop out poorly in low vegetated rises in two elongated inliers; the beds protrude occasionally through soil cover, but crop out reasonably well where dips are steep, near the axis of the Momedah Anticline. The anticline is a post-Cretaceous structure, and Casey & others (1960, unpubl.) state that there is field evidence of an earlier anticline structure at the northern end of the northernmost outlier of Gola Beds.

Druce & Jones (1970) suggest rather tentatively that the Gola Beds may be correlated with the upper part of the Chatsworth Limestone.

Georgina Limestone

Derivation of Name: From Georgina River; no type area or type section designated. Öpik (1960) used the name in its present context, but Ogilvie (*in* Whitehouse, 1931) first proposed the name for a sequence of fossiliferous limestone 'in and around the basin of the Georgina River'; Whitehouse (1936) used the name Georgina Series for limestone in this area and his usage was continued by David (1950, 1, pp. 115-8) and by the compilers of both the Geological Map of Queensland (1953) and the Geological Map of Australia (1953). Öpik (1956a) objected to the usage on the grounds that the term Georgina Series was too broad and indistinct and that it included both Middle and Upper Cambrian rocks together with unfossiliferous dolomite—the Camooweal Dolomite. He stated that it should be restricted to either Upper Cambrian limestone in the Glenormiston station area, or the Camooweal Dolomite. In 1960, he restricted the name Georgina Limestone to a thin limestone sequence south of Glenormiston homestead, and (1963) stated that the fossiliferous Middle Cambrian inliers could not be distinguished lithologically from it; Reynolds (1964b, unpubl.) mapped the formation southwards to the Mount Whelan Sheet area.

Distribution: Glenormiston and Mount Whelan Sheet areas (Sheet 4). Small areas south of Glenormiston homestead, in Glenormiston Sheet area, and larger adjoining areas to south in Mount Whelan Sheet area.

Lithology: Flaggy grey sandy limestone with several breccia interbeds (Öpik, 1960) in upper part; dark bituminous limestone with shale partings and light grey aphanitic limestone in lower part which crops out in Glenormiston Sheet area only (Öpik, 1963). According to Reynolds (1965a) the sequence in the Glenormiston Sheet area consists of hard laminated and thin-bedded blue-grey and brown calcilutite and sandy calcilutite, with cross-beds and ripple marks; soft white marl; oolitic limestone; intraformational breccia; two-tone limestone; sandy limestone; and calcareous sandstone. Reynolds (1968) believed that two lithologically distinct units were also present in the Mount Whelan Sheet area, and that the outcrops of the older sandy beds occurred along anticlinal crests.

Thickness: Maximum of 30 m in Glenormiston (Reynolds, 1965a) and Mount Whelan Sheet areas.

Contacts: Disconformably overlain by Ninmaroo Formation; base not exposed.

Fossils: Öpik (1963) described fossils belonging to Zone of *Leiopyge laevigata* (late Middle Cambrian); and Zones of *Glyptagnostus stolidotus, Corynexochus plumula* and *Erixanium sentum* (Idamean) in Mount Whelan Sheet area, and Zone of *Glyptagnostus stolidotus* (Mindyallan) in Glenormiston Sheet area.

Age: Late Middle Cambrian to early Upper Cambrian.

Description and Comment

The outcrops and fossils of the Georgina Limestone indicate a period of erosion before the Ninmaroo Formation was deposited. In 1963 Öpik included Middle Cambrian beds in the Georgina Limestone, but this information has not been incorporated on Sheet 4, where it is shown as Upper Cambrian.

The subsurface extent of the Georgina Limestone is unknown, but it crops out in the eastern limb of the Toko Syncline and probably continues into the trough; on the western limb of the syncline, the Georgina Limestone has not been recognized, but part of the Arrinthrunga Formation and perhaps the upper part of the Marqua Beds are regarded as time equivalents. The thickness of the Georgina Limestone is unknown; Tysons No. 1 Bore

(15 km south of Glenormiston homestead) commenced in the formation and penetrated 550 m (1810 ft) of limestone (Öpik, 1960). Reynolds (1968) re-interpreted a report of Jack (1895), which presumably referred to Tysons No. 1 Bore, and suggested that the Georgina Limestone could be about 330 m thick. The Papuan Apinaipi Petroleum Co. Ltd (1965b, unpubl.) reported 521 m (1709 ft) of Georgina Limestone in the interval from 726 to 1247 m (2381-4090 ft) in the Netting Fence No. 1 well, where the formation lies between the Ninmaroo Formation above and the Mungerebar Limestone below; the dips suggest the Georgina and Mungerebar Limestone are unconformable. Core 14 (3 m; 4910-4920 ft) contains early Upper Cambrian fossils of the Idamean Stage (possibly in the Zone of *Glyptagnostus reticulatus*) in a bituminous limestone with black shale laminae (Gatehouse, *in* PAP, 1965b), which is shown on the well logs as the Steamboat Sandstone. Thus the stratigraphic interpretations of parts of Netting Fence No. 1 may be incorrect. I have included the sequence in the interval from 726 to 1548 m (2381-5080 ft) in the Arrinthrunga Formation.

Mungerebar Limestone

The Mungerebar Limestone, which ranges in age from Middle to Upper Cambrian, has already been described, on pages 102-3.

CAMBRO-ORDOVICIAN

The Tomahawk Beds and the Ninmaroo and Kelly Creek Formations are described separately from other Upper Cambrian and Lower Ordovician sequences. The Tomahawk Beds range in age from Upper Cambrian to Lower Ordovician, and contain equivalents of both the Ninmaroo and Kelly Creek Formations.

Tomahawk Beds

Derivation of Name: From Tomahawk Yard (lat. 22°26′S, long. 135°48′45″E) (Smith, 1964a). Reference section in Point Spring area (lat. 22°37′30″S, long. 135°50′E) at southeast end of Dulcie Range.

Distribution: Huckitta, Alcoota, Barrow Creek, and Elkedra (Sheet 3) and Sandover River and Tobermory Sheet areas (Sheet 4). Crops out in narrow belt with moderately steep dips along southwest flank of Dulcie Range; on northeast flank dips are generally very low. Extend northwards discontinuously from Dulcie Range towards Davenport Range: in northeast part of Huckitta Sheet area, and on Elkedra, Sandover River, and Tobermory Sheet areas, Beds form extensive sheet, except near faults and on limbs of sharp folds.

Lithology: Huckitta Sheet area: essentially basal sandstone with interbeds of siltstone grading laterally and vertically into dark brown and grey-brown dolomite, grey limestone, grey and brown sandstone, and green siltstone; succeeded by grey and brown sandstone with brown sandy dolomite. Sequence on Elkedra, Sandover River, and Tobermory Sheet areas generally similar, but northwest of Bundey River much more sandstone and less carbonate rock, and white leached siltstone. In foothills of Davenport Range, on Barrow Creek and Elkedra Sheet areas, some beds of sandstone and conglomerate tentatively included in Tomahawk Beds.

Contacts: Conformable with Arrinthrunga Formation in central part of Huckitta Sheet area, but faulted or disconformable elsewhere. Northwest of Bundey River, transgress several Precambrian formations; in Sandover River Sheet area, probably disconformable on Meeta Beds, and grade into Ninmaroo Formation in east; in Tobermory Sheet area equivalent to Kelly Creek and Ninmaroo Formations.

The Tomahawk Beds are conformably overlain by the Nora Formation in part of the Dulcie Range, and unconformably by the Dulcie Sandstone over most of the Huckitta, Alcoota, and Barrow Creek Sheet areas.

Fossils: Abundant trilobites, pelecypods, brachiopods, and ribeirioids (Tomlinson, *in* Casey & Tomlinson, 1956). All the fossils came from the lower part of the sequence which was subsequently mapped as the Tomahawk Beds. Tomlinson regarded them as middle Upper Cambrian (Franconian), but considered one other trilobite resembling *Tellerina,* from a downfaulted block on the southwestern side of Arthur Creek and north of Mount Playford (Huckitta Sheet area), to be of late Upper Cambrian (Trempealeauan) age.

Age: Upper Cambrian—Lower Ordovician (A. A. Öpik & J. G. Tomlinson, pers. comm.).

Correlates: Part of Ninmaroo Formation and part of Kelly Creek Formation.

Description and Comment

The type of outcrop varies considerably according to the lithology and tectonic setting. Along the southwestern flank and part of the northeastern flank of the Dulcie Range, the beds crop out in low rounded hills and cuestas, which are commonly covered with rubble. Northwest of the Bundey River, the Tomahawk Beds crop out in low peaks, low terraces, and mesas. In the northeastern part of the Huckitta Sheet area, the southeastern parts of the Elkedra and Sandover River Sheet areas, and the northern part of Tobermory Sheet area, the Tomahawk Beds crop out in a plateau dissected and eroded into mesas and sharp peaks. In the remainder of the Tobermory Sheet area, the beds generally crop out poorly in low hills with some strong benches of carbonate rock.

The Tomahawk Beds usually have a low dip, but along much of the southwestern flank of the Dulcie Range and along part of the northeastern flank, the beds are intricately folded, mainly by slumping; the sequence is commonly repeated as many as four times in the one hill. Beds of prominent dark brown dolomite indicate the order of succession, and enable the thickness to be measured accurately.

The reference section (HX30; Appendix, Table 20) was measured and described in Smith (1964a) and is shown in Figure 29, together with other representative sections.

Smith divided the sequence of the reference section into the following units:

Unit 3: 260 feet (79 m) *Sandstone*, grey and brown; *dolomite*, sandy, brown.

Unit 2: 200 feet (61 m) *Dolomite*, dark-brown; *limestone*, grey; some *sandstone*, grey, glauconitic.

Unit 1: 186 feet (57 m) *Sandstone*, grey; interbeds of *siltstone*, green.

Unit 2 is prominent near the southeastern tip of the Dulcie Range and can be traced on the southwestern flank of the range, northwestwards to section HX28, and almost to the Bundey River. To the west of the river, the unit does not crop out and the exposed sequence consists mainly of quartz sandstone or quartz greywacke, with a few beds of weathered dolomite; these sequences are shown in sections HX54, AX3, and BX7. The fossils in sections HX54 and BX7 have not yet been examined in full, and the sequence may represent almost the complete sequence of Tomahawk Beds, ranging from Upper Cambrian to Lower Ordovician, with the carbonates of unit 2 grading laterally to psammites; or a thick development of psammites of unit 3; or a thick development of psammites of unit 1; or a thicker development of units 1 and 2 combined.

From the eastern side of the Spring Range to the northwestern tip of the Dulcie Syncline and southeastwards along the northeastern flank of the syncline, the Tomahawk Beds consist mainly of sandstone and siltstone (with oolitic limestone in one locality in the Barrow Creek Sheet area) and the fossils are all of Upper Cambrian age (A. A. Öpik & J. G. Tomlinson, pers. comm.). Section EX5 is representative of most of the outcrops, although the exposures there are thicker than usual, and the beds are strongly slumped. Towards the southeastern end of the Dulcie Syncline, the sequence resembles that of the reference section, and includes Lower Ordovician sediments.

Some poorly outcropping sequences in the northern parts of the Elkedra and Barrow Creek Sheet areas are referred tentatively to the Tomahawk Beds; they consist of sandstone and interbedded siltstone and a few outcrops of green-grey limestone. The sediments are unfossiliferous, but have been included in the Tomahawk Beds on lithological grounds. They generally have a low regional dip, but are strongly slumped at many localities. Where the beds are not slumped and siltstone is absent, the sequence resembles the basal sandstone of the Middle Cambrian Sandover Beds, and it is possible that both the Tomahawk Beds and the Sandover Beds crop out in close proximity. The cobble, pebble, and boulder conglomerates in the foothills of the Davenport Range are also tentatively referred to the Tomahawk Beds. They are unfossiliferous, but in a few places are topographically above, and almost certainly stratigraphically above, the Middle Cambrian Sandover Beds in water bores. They do not contain boulders, cobbles, pebbles, or fragments of Sandover Beds, and all the phenoclasts consist of well rounded fragments of quartz sandstone similar to those found in the Hatches Creek Group. These outcrops are unlikely to be Middle Cambrian, and probably represent the basal deposits of the Upper Cambrian transgression; on this basis they have been mapped tentatively as Tomahawk Beds. The possibility that the beds are of Mesozoic age cannot be discounted because there are conglomerates in the Mesozoic sediments to the east.

Section EX1 is representative of much of the Tomahawk Beds cropping out in the northeastern Huckitta, southeastern Elkedra, southern Sandover River, and northern Tober-

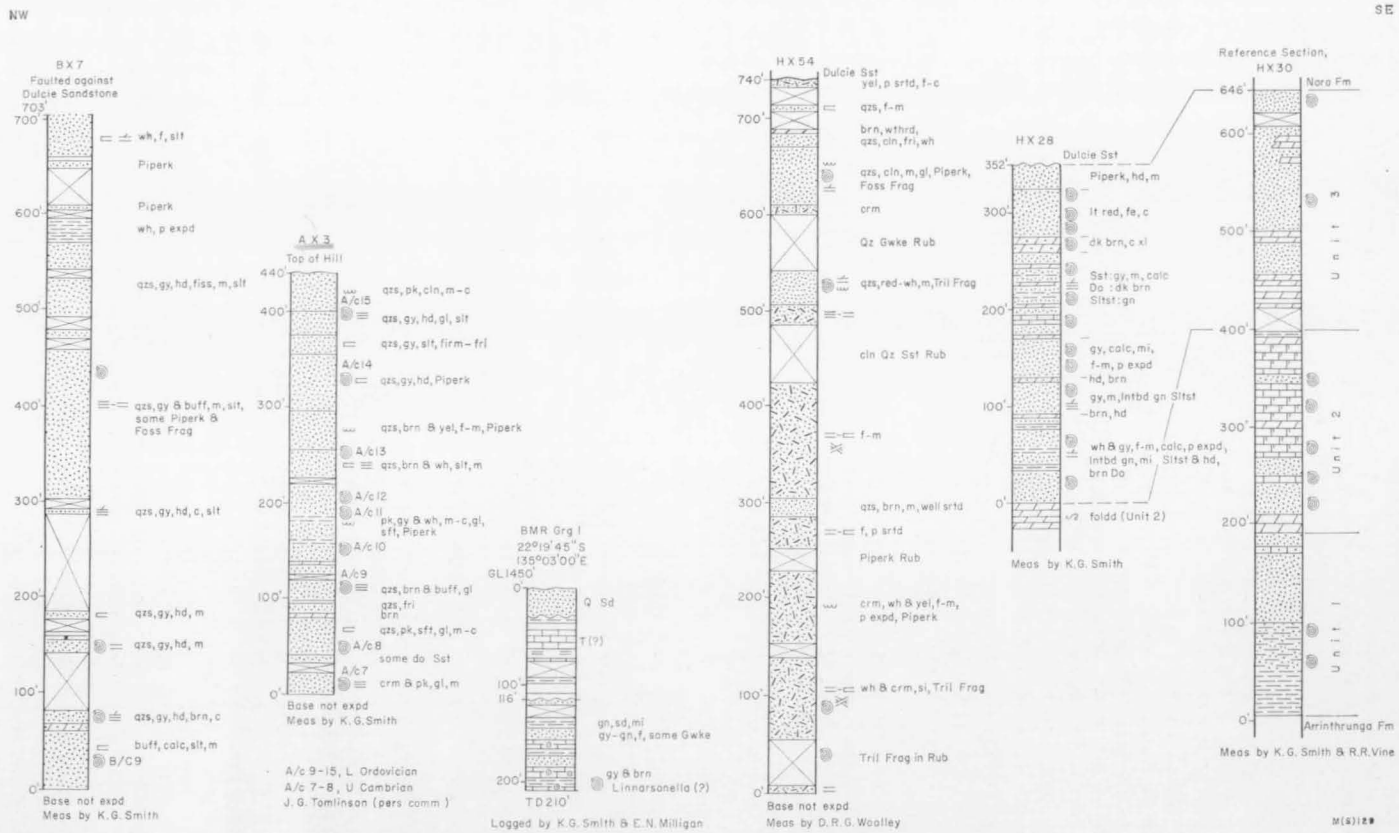


Figure 29. Stratigraphic sequences in Tomahawk Beds (cont.)

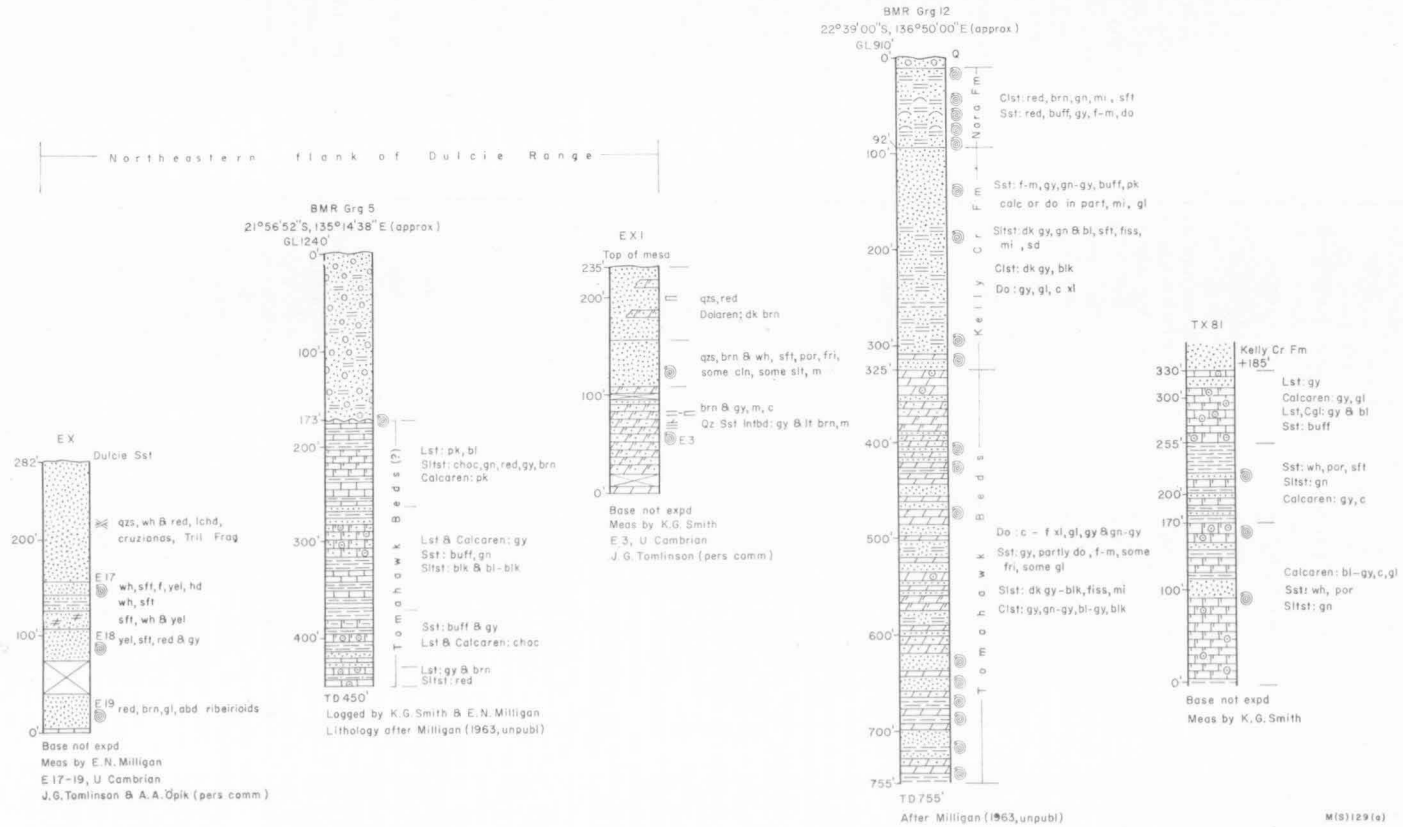


Figure 29. Stratigraphic sequences in Tomahawk Beds (cont.)

mory Sheet areas. Rapid lateral gradations between sandstone and dolomite are common, and equivalent outcrops in close proximity commonly appear red-brown (sandstone) and dark brown or black (dolomite and dolarenite) when viewed from a distance and on the air-photographs. The regional dip is generally low, but the beds, particularly the sandstone and sandy siltstone, are strongly slumped. The Tomahawk Beds contain a rich fauna, mainly trilobites and ribeirioids, but all are of Upper Cambrian age (A. A. Öpik & J. G. Tomlinson, pers. comm.) and no Lower Ordovician sediments are known.

In places, unit 3 of the reference section is identical in lithology with the Kelly Creek Formation, but it is not a mappable unit on the 1:250,000 scale. In parts of the Tarlton Range in the Tobermory Sheet area the Kelly Creek Formation can be separated from the Tomahawk Beds; elsewhere it is possible to separate the Ninmaroo Formation from the lower part of the Tomahawk Beds. In the Tarlton Range area, the Upper Cambrian/Lower Ordovician sequence consists of carbonate rocks, sandstone, and siltstone; many of the beds have been leached and lateritized, and the leaching of the sandy carbonate rocks gives a misleading impression of the proportion of sandstone in the sequence.

The approximate boundary between the Tomahawk Beds and Ninmaroo Formation marks the broad division between the fossiliferous psammite in the west and the less fossiliferous carbonate in the east. This is not a simple lateral change as the formations interfinger.

The Kelly Creek Formation can be mapped around the Tarlton Range, but to the northwest the effects of weathering and the gradation from carbonate rock to sandstone make it impossible to separate the Kelly Creek Formation, and the whole sequence has been mapped as Tomahawk Beds.

In the southeast, in the Tobermory Sheet area, the Tomahawk Beds lens into mappable units, but to the northwest they may provide a subsurface link between the Georgina and Wiso Basins. Such a connexion can only be inferred at present; an Upper Cambrian fossil was recovered from dolomite at a depth of 94 m (310 ft) in Grg 18 (Milligan, 1963, unpubl.) and Lower and Middle Ordovician sediments are known in the Lander River Sheet area of the Wiso Basin (Milligan, Smith, Nichols, & Doutch, 1966, unpubl.). However, no Upper Cambrian sediments are known there, although some of the sediments are lithologically similar to those tentatively included in the Tomahawk Beds in the northeastern part of the Barrow Creek Sheet area.

Ninmaroo Formation

Derivation of Name: From Mount Ninmaroo (lat. 22°31′S, long. 140°17′E). Whitehouse (1936, p. 60) used the name Ninmaroo Limestone for thick sequence of limestone at Black Mountain, Mount Ninmaroo, and Mount Datson. Casey (1959) subsequently named the lower part of the sequence at Black Mountain the Chatsworth Limestone, and renamed the remainder the Ninmaroo Formation because towards the Queensland border roughly equal proportions of dolomite and limestone, and some sandstone, are present. Type section at Black Mountain in Boulia Sheet area (lat. 22°32′S, long. 140°18′E).

Distribution: Boulia, Glenormiston, Mount Whelan, Urandangi, Duchess, Sandover River, Tobermory, and Hay River Sheet areas (Sheet 4).

Lithology: Calcarenite, commonly dolomitic and sandy, dolarenite, calcilutite, intraformational breccia, dolomite, limestone, and calcareous sandstone in Boulia area (Casey & others, 1960, unpubl.); dolomite, sandy dolomite, limestone, calcilutite, dolomitic sandstone, oolitic limestone, algal limestone, calcarenite, and marl in Glenormiston/Mount Whelan area (Pritchard, 1960); calcarenite, quartz sandstone, siltstone, dolarenite, limestone, and oolitic limestone in Tobermory Sheet area (Smith, 1965b); dolomite, dolarenite, and dololutite in Sandover River Sheet area (Nichols, 1964, unpubl.); marl, sandstone, shale, limestone, and dolomite in Urandangi Sheet area (Noakes et al., 1959); and limestone, dolomite, and marl in Duchess Sheet area (Carter & Öpik, 1963). The outcrops generally consist of calcarenite and dolarenite in the Boulia and Duchess Sheet areas, and dolomite, dolarenite, and calcarenite in the western outcrop areas (Fig. 30).

Thickness: 670 m at Mount Ninmaroo, 595 m at Black Mountain, and 370 m at Mount Datson (Casey & others, 1960); more than 370 m in Glenormiston Sheet area (Reynolds & Pritchard, 1964, unpubl.); 340 m (1120 ft) in Netting Fence No. 1 (PAP, 1965b, unpubl.); about 300 m in western flank of Toko Syncline (Smith & Vine, 1960, unpubl.); and more than 130 m in Sandover River Sheet area (Nichols, 1964).

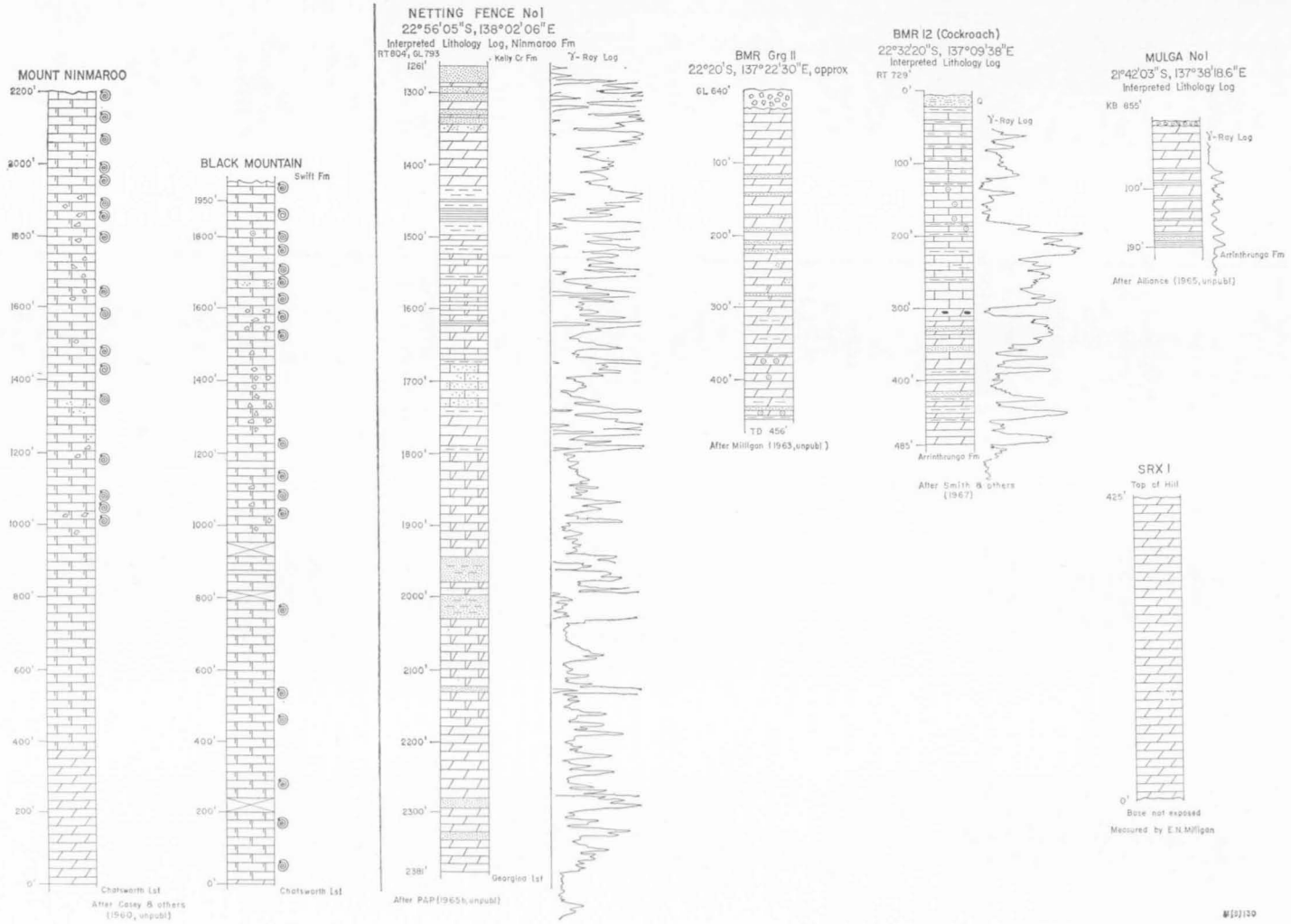


Figure 30. Stratigraphic sequences in Ninmaroo Formation

Contacts: Conformable on Chatsworth Limestone, unconformable on Mount Birnie Beds, disconformable on Mungerebar and Georgina Limestones, and disconformable(?) on Arrinthrunga Formation and Meeta Beds; grades laterally into lower part of Tomahawk Beds and overlain unconformably by Swift Formation, and conformably by Kelly Creek Formation. Along the Toomba Fault, the Ninmaroo Formation is downfaulted against the Adelaidean Field River Beds.

Fossils: Richly fossiliferous; trilobites, ribeirioids, and brachiopods recorded from lower part (Tomlinson, 1959, unpubl.; Öpik, 1960), and ribeirioids, brachiopods, and gastropods from upper part (Öpik, 1960). Druce & Jones (1968, 1970) record conodonts from Black Mountain, Mount Ninmaroo, and Mount Datson sections.

Age: Late Upper Cambrian to Lower Ordovician (Trempealeauan-Tremadocian).

Description and Comment

The Ninmaroo Formation covers a wide area in the southeastern part of the Georgina Basin. It crops out in a narrow belt along the Burke River Structural Belt in the east, and in a broad belt west of longitude 139°30′E. Casey (1959) renamed the formation in the eastern belt, and the name has also been adopted for the sediments in the west, although deposition is not completely continuous: for example Beatrice No. 1 passed from Mesozoic rocks directly into Pomegranate Limestone.

Eastern Belt. The Ninmaroo Formation forms large hills in places and low benches in others; it commonly crops out sporadically in grey-soil plains. The main outcrops occur in faulted asymmetrical anticlines. The sequences at Black Mountain and Mount Ninmaroo (Casey & others, 1960, unpubl.) are given in Tables 21 and 23 (Appendix).

The intraformational breccias in the sequence at Black Mountain and Mount Ninmaroo are common in the upper half of most of the sequences in the eastern belt; they consist of angular and subangular fragments of calcarenite or calcilutite, which are elongated along the bedding, set in a matrix of calcarenite or marl which is commonly oolitic. The fragments appear to have been derived from the underlying beds (Casey et al., 1960).

The Ninmaroo Formation has been folded into asymmetrical anticlines with steeper eastern flanks. Later faults along or near the crests are downthrown to the east, and at Black Mountain and Mount Ninmaroo cut the fold axes. To the east and west of the structural zones, the Ninmaroo Formation is generally horizontal.

Brown (1961, unpubl., summarized by Casey, 1968, and Druce & Jones, 1970) divided the formation into six units (see Druce & Jones, op. cit., figs 2-4) and Druce & Jones have studied the conodont faunas and erected zones for the Tremadocian part of the sequence.

The units are:

Member 1—the basal unit, consisting of cross-bedded dolomite at Black Mountain and Mount Ninmaroo, and sandy dolomite at Mount Datson.

Member 2—the first richly fossiliferous unit (nautiloids and ribeirioids), of variable lithology, consisting of calcarenite, calcilutite, two-tone limestone, dolomite, cross-bedded limestone, intraformational conglomerate, oolitic and chert nodules. It is present on Black Mountain, Mount Ninmaroo, and Mount Datson.

Member 3—characterized by the higher proportion of two-tone limestone, and minor calcarenite, intraformational conglomerate, and 'marl'. It is present at Black Mountain, Mount Ninmaroo, Mount Datson, and Digby Peaks.

Member 4—distinguished by large thicknesses of intraformational conglomerate; its base is marked by detrital, often cross-bedded limestone, overlying the last persistent two-tone limestone of member 3. It is recognizable at Black Mountain, Mount Ninmaroo, Mount Datson, and Digby Peaks.

Member 5—characterized by massive white crystalline crinoidal limestone, interbedded with 'marl', oolitic calcarenite and intraformational conglomerate. The top of this unit, west of Mount Ninmaroo and Black Mountain, is marked by a distinctive massive bed which contains nautiloids, polyzoans, sponges, and brachiopods. Member 5 also contains algae and ribeirioids, and is also present at Black Mountain and possibly at Black Ridge.

Member 6—consists of cherty dolomitic limestone and silicified yellow siltstone, and contains trilobites (asaphids, dikelocephalids, and leiostegiids), brachiopods, gastropods, sponge spicules, and algae. It is present at Black Mountain, Mount Ninmaroo, and Black Ridge. Brown (1961, unpubl.; fide Casey, 1968) reports that massive beds of member 5 commonly occur interbedded with member 6. He interprets the sponge bed at the top of member 5 as a bar separating two facies—an open-water facies (member 5) from a lagoonal facies (member 6).

The Ninmaroo Formation crops out in low rises, terraced hills, and plains; the dip is generally low, except in slump structures and near the Craigie and Toomba Faults. The combination of gentle dip, strong joint patterns, and alternating hard and soft beds gives rise to low stepped hills with a pronounced bastion aspect.

The formation generally dips towards the Toko Syncline, but the combination of poor outcrop, low rolling dips, and repetition of similar beds makes it difficult to determine the relative stratigraphic position of most of the outcrops; the problem can only be resolved by adequate palaeontological control. To the east of the Georgina River, the outcrops are poor and discontinuous, and the base of the sequence is seldom exposed. However, the contact with the Mungerebar Limestone is exposed, and Reynolds & Pritchard (1964, unpubl.) regard the rim of leached and weathered sandy and silty beds, up to 9 m thick, around the southern margin of the Mungerebar Limestone, as the local base of the Ninmaroo Formation.

Western Belt. To the west of the Georgina River, in the Toko Range area, Pritchard (1960) subdivided the Ninmaroo Formation into five members; one of these has now been mapped as the Kelly Creek Formation and the others are retained in the Ninmaroo Formation. Öpik (1963) states that the Ninmaroo Formation rests on the eroded surface of the lower part of the Georgina Limestone, north of the 23rd parallel, and Reynolds & Pritchard (1964, unpubl.) state that these outcrops are the oldest part of the Ninmaroo Formation in the area. They are exposed only around a core of Georgina Limestone, in an anticline 13 km west of Glenormiston homestead, and in scarps below the Mesozoic sediments at the eastern end of the Ten Mile Hills.

Four members (units Cu2, Cu3, Cu/Ol4, and Ol5) have been described by Pritchard (1960); and Reynolds & Pritchard (1964, unpubl.) have given slightly fuller descriptions (see also Druce & Jones, 1970).

Member 1 consists of thick to massive sets of white, grey-brown, and brown, fine to medium-grained, laminated, thin and medium-bedded dolarenite, with a little fine and medium-grained dolomitic sandstone and sandy dolomite. Blue thin-bedded calcilutite interbeds are present in the top and bottom parts of the member. The thickness is estimated at 60 m, and algae are the only fossils.

Member 2 consists mainly of hard calcilutite; it is estimated to be 75 m thick, and algae are the only fossils. The sequence consists of roughly bedded two-tone (grey-brown and grey-blue) calcilutite, in sets up to 3 m thick; thin-bedded, grey-brown, and grey-blue calcilutite, white marl, thin-bedded medium-grained calcarenite, intraformational calcilutite conglomerate, and algal colonies.

Member 3 extends from the west and north of the Ten Mile Hills to Linda Downs homestead and around to the western side of the Toko Range. It consists mainly of alternating hard and soft sediments, but only the hard beds crop out. They consist of laminated, thin and medium-bedded, brown and white, fine to coarse-grained dolarenite, and laminated to thin-bedded, fine-grained, well sorted, well rounded dolomitic quartz sandstone, in sets up to 5 m thick. The thickness is estimated to be 60 m. Öpik (1960) has assigned the nautiloids and trilobites present to the late Upper Cambrian.

Member 4 flanks both sides of the Toko Range and consists of sets up to 3 m thick of laminated and thin to medium-bedded two-tone limestone, laminated and thin-bedded brown calcilutite and sandy calcilutite, fine-grained calcarenite and sandy calcarenite, and calcareous sandstone. The thickness is estimated to be 120 m; the member contains nautiloids, ribeirioids, and gastropods similar to those in the Tremadocian part of the Ninmaroo Formation in the Boulia area. Algal colonies are abundant.

The total thickness of members 1 to 4 is estimated at 315 m. On the western flank of the Toko Syncline, Smith & Vine (1960, unpubl.) measured a thickness of 255 m, which they do not regard as reliable because of the structural complexity. The lithology of the Ninmaroo Formation, to the west of the Toko Syncline, has been discussed in the description of the Tomahawk Beds, and the main difference from Pritchard's (1960) description is in the lower units, where tongues and lenses of quartz sandstone and dolomitic sandstone are common. The boundary between the Ninmaroo and Arrinthrunga Formations is not easy to select in the Tobermory Sheet area unless these lenses of sandstone are present. Likewise, the boundary between the Ninmaroo Formation and the Meeta Beds in the Sandover River Sheet area is not easily mapped, but the Meeta Beds can be distinguished by the presence of oolitic chert which is not found in the Ninmaroo Formation. Both sequences consist mainly of dolomite and dolarenite, but the Meeta Beds contain numerous beds of quartz sandstone.

The relationship between the eastern and western belts is still uncertain for lack of detailed palaeontological control in the latter. J. N. Casey (pers. comm.) has suggested a very tentative correlation as follows:

Member 1 of the eastern belt correlates with members 1 to 3 of the western (1 and 3—Cu2 and Cu/Ol4—are probably identical);

Members 2 to 4 of the eastern belt are missing in the west;

Member 5 of the eastern belt correlates with member 4 of the west;

And member 6 of the east is missing in the west (it is lagoonal).

The subsurface extent of the Ninmaroo Formation is unknown in Queensland, but is known well in the Northern Territory. In Queensland, the continuity of the beds in the subsurface between the eastern and western belts has not been established. However, the Ninmaroo Formation almost certainly occurs in the southeastern extension of the Toko Syncline, as shown by the results of a BMR seismic survey (Robertson, 1965, unpubl.): the survey showed a strong reflector, with a velocity of 5500 m per second, at a depth of about 3350 m in the syncline near Pulchera Waterhole (lat. 22°56′S, long. 138°35′E), and traced northeastward to shot point 247, near Yarandilla Yard (lat. 23°43′S, long. 138°56′E), where it underlay Cretaceous sediments. A hole drilled at shot point 247 penetrated about 90 m of Cretaceous sediments above a dolomite-siltstone sequence from which P. J. Jones identified Lower Ordovician conodonts similar to those in the Ninmaroo Formation.

This reflector probably represents the Ninmaroo Formation; its thickness is unknown, but the seismic data indicate that the Palaeozoic section in the Toko Syncline may be about 4300 m thick, which is much thicker than the 1800 m in outcrop on the flanks of the syncline in the Tobermory Sheet area. Reynolds (1968) has estimated that the thickness of the Ninmaroo Formation in the western limb of the Toko Syncline, near the southernmost outcrops, is 730 m, but he did not regard the estimate as reliable.

Eastward from Yarandilla Yard, the extent of the Ninmaroo Formation is unknown in the subsurface, and to the southeast the formation was not encountered in The Brothers No. 1 or Marduroo No. 1 wells (FPC, 1965c, unpubl.).

Kelly Creek Formation

Derivation of Name: From Kelly Creek, which rises in foothills of Toko Range in Northern Territory, and flows east to join Pituri Creek (Casey, *in* Smith, 1965b).

Type Area: Hills on both sides of Bloodwood Creek, 13 km north of No. 8 Dam on Tobermory station (lat. 22°45′S, long. 137°45′E). Type section (see Appendix) on Gaphole Creek (lat. 22°58′S, long. 137°54′22″E) on west flank of Toko Syncline.

Distribution: Crops out in Tarlton, Toko, and Toomba Ranges, mainly on flanks of Toko Syncline.

Lithology: Quartz sandstone, calcareous sandstone, siltstone, dolomite, calcarenite, and coquinite with lenses of white chert.

Thickness: 168 m in type section; 120+ m in Toomba Range, 75 m in Tarlton Range; and 110 m (361 ft) in Netting Fence No. 1 (Fig. 31).

Contacts: Conformably overlies Ninmaroo Formation; disconformably overlain by Coolibah Formation in Toko Range, and by Nora Formation in Tarlton Range.

Fossils: Abundant nautiloids, trilobites, brachiopods, ribeirioids, and gastropods; fauna not described.

Age: Lower Ordovician (J. G. Tomlinson, pers. comm.).

Correlates: Upper part of Tomahawk Beds in Tarlton Range/Dulcie Range area, Northern Territory; Swift Formation in Boulia area, Queensland.

Description and Comment

The Kelly Creek Formation is restricted to the southwestern part of the Georgina Basin, and apart from a small area in and near the Tarlton Range, all the outcrops are in the limbs of the Toko Syncline. In the northwestern and northeastern parts of the syncline, the formation is usually poorly exposed in low rubble-covered hills, but some good exposures occur in mesas. On the southwestern side, where the dips are steeper, it is well exposed in the scarp on the eastern side of the Tarlton Range, and in isolated mesas near the southeastern end of the range.

In the Toko Range, the lower part of the Kelly Creek Formation consists mainly of sandstone and the higher beds of carbonate rocks (see Appendix, Table 23).

Both the Netting Fence No. 1 well and core hole Grg 12 penetrated the Kelly Creek Formation. In Netting Fence No. 1, about 13 km east of the type section, the Kelly Creek Formation is 110 m (900-1261 ft) thick and consists of dolomitic limestone, dolomite, and quartz sandstone (PAP, 1965b, unpubl.). The composite log records sandstone and dolomitic sandstone at the top of the Ninmaroo Formation, and it is possible that this part of the sequence belongs to the Kelly Creek Formation. I consider that the base of the Kelly Creek Formation could be placed at 451 m (1480 ft), but there is no palaeontological evidence to indicate which interpretation is correct.

To the southeast of the type section, in the Hay River Sheet area, the Kelly Creek Formation consists of dolomite and calcarenite, without the basal sandstone beds. The outcrops are in an area of structural complexity, and the lower part of the sequence may have been faulted out. Farther southeast, in the Mount Whelan Sheet area, the lower part of the Kelly Creek Formation consists of sandstone and the upper part of dolomite; the thickness is estimated at 80 m (Reynolds, 1968).

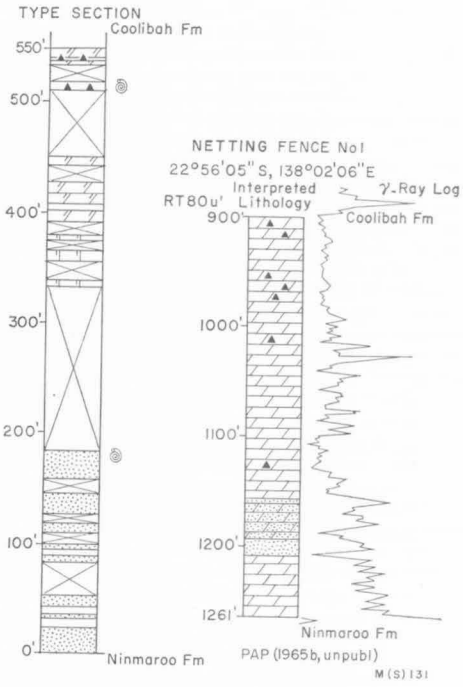


Figure 31. Stratigraphic sequences in Kelly Creek Formation

On the eastern limb of the Toko Syncline, the Kelly Creek Formation consists of 'thin-bedded and laminated, fine-grained dolomitic quartz sandstone which is in places glauconitic; and laminated to medium-bedded grey-brown dolomite and white marl' (unit 0l-6 of Pritchard, 1960). Pritchard estimated the thickness to be 75 m along the Mulligan River (Mount Whelan Sheet area). In the eastern outcrop area, Reynolds (1968) reported that the Kelly Creek Formation appeared to be disconformable on the older part of the Ninmaroo Formation; the disconformity is also indicated by an occurrence of Kelly Creek Formation on the Georgina Limestone. Thus, although the Ninmaroo and Kelly Creek Formations appear to be conformable in the Northern Territory and parts of Queensland, a disconformity may be present in the easternmost outcrops.

In the Tarlton Range, the Kelly Creek Formation consists mostly of calcareous micaceous sandstone, with interbeds of dolomite, sandy dolomite, green siltstone, and some calcarenite. Glauconite is common in many of the beds, and fossils are abundant, although less numerous than in the Toko Range. The beds are gently dipping, except near the Tarlton Fault, and northwest of the range the formation grades laterally into the Tomahawk Beds. Part of the formation crops out well in several benches, which can be followed for several kilometres along the scarp of the Tarlton Range. The sequence is considerably thinner than in the Toko Range, and is generally about 80 m thick.

To the west of the Tarlton Range, the Kelly Creek Formation has been identified in core hole Grg 12 (Milligan, 1963, unpubl.); it is preserved in a downfaulted block which is covered by soil to the west.

Lower Ordovician

Swift Formation

Derivation of Name: From Swift Hills, latitude 22°00′00″S, longitude 140°01′E. Named by Casey (1959). Type area is Swift Hills (see Appendix).

Distribution: Boulia and Duchess Sheet areas (Sheet 4). From western side of Black Mountain, northwestwards in narrow belt to a few kilometres beyond Swift Hills on Duchess Sheet area.

Lithology: Bedded chert with interbeds of siltstone, sandstone, silicified coquinite, and limestone.

Thickness: About 20 m; 6 to 9 m exposed in Duchess Sheet area.

Fossils: Trilobites, brachiopods, and graptolites.

Age: Lower Ordovician (Carter & Öpik, 1963; Casey, 1959).

Correlates: Kelly Creek Formation.

Contacts: Unconformably overlies Ninmaroo Formation in northern part of Boulia Sheet area and probably in Black Mountain area also (Casey, 1959); unconformable on Middle Cambrian Beetle Creek Formation in Duchess Sheet area (Carter & Öpik, 1963); overlain unconformably by Mesozoic and Cainozoic sediments.

Description and Comment

In the type area the formation crops out as low rounded hills with a small scarp on the eastern side, and south of Digby Peaks the outcrop forms a broad divide with dendritic streams deeply incised in steep-sided valleys (Casey et al., 1960, unpubl.). To the west of Black Mountain, the formation crops out in low rounded foothills cut by steep-sided flat-floored valleys. In the Duchess Sheet area the formation crops out in plains and pediments (Carter & Öpik, 1963).

The section in the type area is 20 m thick, and consists of laminated siltstone and sandstone at the base, and 8 m concealed sequence, and laminated chert above (Appendix, Table 24).

The contact between the Swift Formation and the Ninmaroo Formation can be seen at various localities between 1 and 12 km southeast of Digby Peaks. It is an erosional contact: chert of the Swift Formation lies on a karst surface of Ninmaroo. It is also transgressive, the angle of unconformity being about 1°. Casey & others (1960, unpubl.) assign only minor significance to the break; but Öpik (1960) and Carter & Öpik (1963) regard it as the expression of the main tectonic movement in the Burke River Structural Belt.

The thickest known sequences of the Swift Formation crop out in the Swift Hills and Digby Peaks. At Digby Peaks it is about 18 m thick; the lower half consists of chert and coquinite bands, interbedded with graptolite-bearing siltstone, and the upper half consists predominantly of thin-bedded chert. There is a marked decrease in the amount of detrital quartz in the Swift Formation from north to south.

Lower Middle Ordovician

Toko Group

The geographical term Toko has been used in several names for Ordovician rocks in western Queensland, but its present usage dates only from 1966. Whitehouse (1936) used the name Toko Series for Ordovician sediments west of Boulia; this was a modification of his earlier (1930) Glenormiston Series, because most of the Glenormiston area was under-

lain by Cambrian sediments and he wished to denote Ordovician rocks only. On the Geological Map of Queensland (1953) the name Toko Group is used for Ordovician rocks southwest of a line joining Linda Downs homestead and Mount Idamea, that is, for rocks above the Ninmaroo Formation as delineated on Sheet 4 of this Bulletin. The sequence above the Ninmaroo Formation had not been divided into formations, and Casey (1959) proposed the name Toko Beds pending further subdivision. Pritchard (1960) followed Casey's usage, and described five units (Ol 7-8, Om 9-11) in the Toko Beds, but he did not name them.

Casey (*in* Smith, 1963a) stated, 'The name Toko will be used as *Toko Group,* which will consist of the Kelly Creek, Coolibah, Nora, Carlo, and Mithaka Formations; the base of the group (i.e., base of Kelly Creek Formation) overlies the Ninmaroo Formation with an unconformity'. The formations are equivalent to units Ol 6-8 and Om 9-10 of Pritchard (1960); Pritchard's unit Om 11 was deleted (it is now named the Cravens Peak Beds) and his older unit Ol 6 was included.

After further field checks, Casey (*in* Smith, 1965b) removed the Kelly Creek Formation from the Toko Group, because the palaeontological evidence indicated a break between it and the overlying Coolibah Formation. Thus Casey's Toko Group consists of four units—the Coolibah Formation, Nora Formation, Carlo Sandstone, and Mithaka Formation. This definition is followed in this Bulletin. The age of the group ranges from Lower to Middle Ordovician; it is underlain disconformably by the Kelly Creek Formation and overlain unconformably by the Siluro(?)-Devonian Cravens Peak Beds. The component formations of the group have been mapped westwards from the Toko Range to the Tarlton and Dulcie Ranges.

Coolibah Formation

Derivation of Name: From Coolibah Dam, on Tobermory station, Northern Territory (lat. 22°49′S, long. 137°44′E) (Casey, *in* Smith, 1965b).

Type area: From 6 to 10 km north of No. 8 Dam on Tobermory station (lat. 22°45′S, long. 137°45′E), on road from Tobermory homestead to Craigie Dam.

Distribution: Tobermory, Glenormiston, Hay River, Mount Whelan Sheet areas (Sheet 4). In belt parallel to scarp of Toko Range, at a distance of 1 to 3 km from scarp; also in southeast extensions of Toko Range; not present in Tarlton Range.

Lithology: Grey and white limestone, sandy limestone, calcilutite, dolomite, and marl, with lenses of white chert.

Thickness: 7.5 to 15 m in type area; 55 m at Gaphole Creek; about 110 m in Mount Whelan Sheet area, Queensland; 36 m (117 ft) in Netting Fence No. 1 (PAP, 1965b, unpubl.).

Contacts: Probably disconformable on Kelly Creek Formation and overlain conformably by Nora Formation.

Fossils: Nautiloids, gastropods, sponges, and ribeirioids. (See Tomlinson, 1971, for description of operculum of *Teiichispira.*)

Age: Lower Ordovician (A. A. Öpik & J. G. Tomlinson, pers. comm.).

Description and Comment

The Coolibah Formation is the basal unit of the Toko Group. It usually crops out poorly in low hills and strike ridges parallel to the Toko Range, and continues along strike to the southeast in the Toomba Range on the southwestern limb of the Toko Syncline, and in unnamed hills and ridges on the southeastern limb. Dips are low, except along the Toomba Fault, where they range from 45° to 90°, and the beds are overturned in places.

The limestone and chert usually crop out better than the other rock types, and have a white or light-coloured pattern on the air-photographs. The chert commonly contains fossils, mainly gastropods. Poor outcrop precludes measurements of reliable sections, although most of the sequence can be observed at Gaphole Creek (Tobermory Sheet area) and M. A. Reynolds (pers. comm.) has measured a thickness of 110 m in the Toomba Range (Mount Whelan Sheet area).

P. W. Pritchard (pers. comm.) measured an incomplete section on the Toko Syncline, and his lithological descriptions clearly show the oolitic nature of the limestone.

The Netting Fence No. 1 well penetrated the Coolibah Limestone in the interval from 239 to 274 m (783-900 ft). The sequence consists mainly of white and grey fine-grained stylolitic limestone, with chert bands; three thin shale bands were also recorded (PAP, 1965b, unpubl.).

Nora Formation

Derivation of Name: From Nora Gap in Northern Territory, at latitude 22°45′S, longitude 137°56′E. Named by Casey (*in* Smith, 1963a).

Type area: West side of Toko Range, for 3 km north and south of Halfway Dam (lat. 22°53′S, long. 137°49′E). No type section described.

Distribution: Tobermory, Hay River, Glenormiston, Mount Whelan Sheet areas (Sheet 4). In scarp of Toko, Toomba, and Tarlton Ranges, and in southeast part of Dulcie Range.

Lithology: Olive-brown and dark brown dolomite and coquinite near base, succeeded by olive, yellow, grey, and purple siltstone and sandy siltstone, and green and brown fine-grained glauconitic sandstone.

Thickness: About 60 m in northern and northeastern part of Toko Range, increasing to about 120 m in southwest limb of Toko Syncline; in Netting Fence No. 1 well, 114 m (373 ft) (approx. true thickness); in Tarlton Range, 60 m; in Dulcie Range, 113+ m.

Contacts: Apparently conformable on Coolibah Formation and conformably overlain by Carlo Sandstone in Toko Syncline; in Tarlton Range, apparently conformable on Kelly Creek Formation (disconformity indicated by preliminary palaeontological evidence); disconformable on Carlo Sandstone at The Pinnacles, near Tarlton Downs homestead (Smith, Vine, & Milligan, 1961, unpubl.); in Dulcie Range, overlain unconformably by Devonian Dulcie Sandstone and overlies Tomahawk Beds conformably.

Fossils: Lower part contains rich but undescribed fauna of pelecypods, brachiopods, nautiloids, trilobites, gastropods, and Bryozoa; shelly fossils uncommon in upper part of formation, but tracks and trails abundant.

Age: Middle Ordovician (A. A. Öpik & J. G. Tomlinson, pers. comm.).

Description and Comment

In the scarps of the ranges, much of the Nora Formation is covered by scree from the overlying Carlo Sandstone, and good exposures are found only in the steep-sided gullies draining the scarps. The older beds crop out better at the base of the Toko Range, where the dolomite and coquinites are generally well exposed, and also in the Tarlton Range. Exposures in the Dulcie Range are generally poor.

The Nora Formation is Pritchard's (1960) unit Ol 8; Pritchard (*in* Reynolds & Pritchard, 1964, unpubl.) described the sequence 3 km north of Linda Creek, on the northeastern side of the Toko Range (Appendix, Table 25).

In the Netting Fence No. 1 well the Nora Formation is 110.5 m (373 ft) thick (410-783 ft) (see Appendix, Table 26).

In the Tarlton Range the scarp consists predominantly of siltstone and claystone which grade upwards into fine-grained sandstone; coquinites are common near the base and persist as thin interbeds throughout most of the formation (see Appendix, Table 27).

In the Dulcie Range the Nora Formation is mostly concealed by scree. Smith (1964a) reported the sequence as a continuation of HX30, the reference section of the Tomahawk Beds (see Appendix, Table 28). Towards the northwestern part of its outcrop in the Dulcie Range the Nora Formation is only about 25 m thick.

Some of the beds of the Nora Formation in the Dulcie Range contain iron, and some in the Toko Range contain phosphatic nodules; these occurrences are discussed on pages 48-9.

Carlo Sandstone

Derivation of Name: From Carlo station, which extends westwards from netting fence near Mulligan River into Simpson Desert; named by Casey (*in* Smith, 1963a).

Type Area: 3 km south of Carlo homestead, where formation crops out in four parallel ridges, trending northwest, and dips to southwest. No type section measured.

Distribution: Tobermory, Hay River, Glenormiston, Mount Whelan Sheet areas (Sheet 4). Top 6 m of Toko Range scarp; continues southeast on both limbs of Toko Syncline; rim of scarp in Tarlton Range.

Lithology: Thick and medium-bedded fine to medium-grained quartz sandstone with ripple marks and flute casts; in Tarlton Range, clay pellets common in lower half, prominent bed of clay pellets at base in Toko Range area; few thin beds of siltstone in lower part of sequence.

Thickness: About 60 m in type area and in much of northeastern and northern parts of Toko Syncline. On southwest limb of Toko Syncline Carlo Sandstone thickens to southeast: about 75 m thick near Gaphole Creek, 90 m at Queensland border, increases to 150+ m in southeast; 18-35 m in Tarlton Range, where top is eroded.

Contacts: Conformably overlies Nora Formation and conformably overlain by Mithaka Formation in Toko Syncline; in Tarlton Range, rests apparently conformably on Nora Formation except in one locality on northernmost hill of The Pinnacles near Tarlton Downs homestead, where probable disconformity indicated by scour-and-fill structures; top eroded in most places on Tarlton Range, but overlain conformably by Mithaka Formation in places.

Fossils: Nautiloids, brachiopods, pelecypods, and worm tracks and trails; mostly in upper half; fauna undescribed.

Age: Middle Ordovician (A. A. Öpik & J. G. Tomlinson, pers. comm.).

Description and Comment

Despite its apparently resistant composition, the Carlo Sandstone is generally poorly exposed in the scarps, and most of it is covered by scree. Southeast of Gaphole Creek the

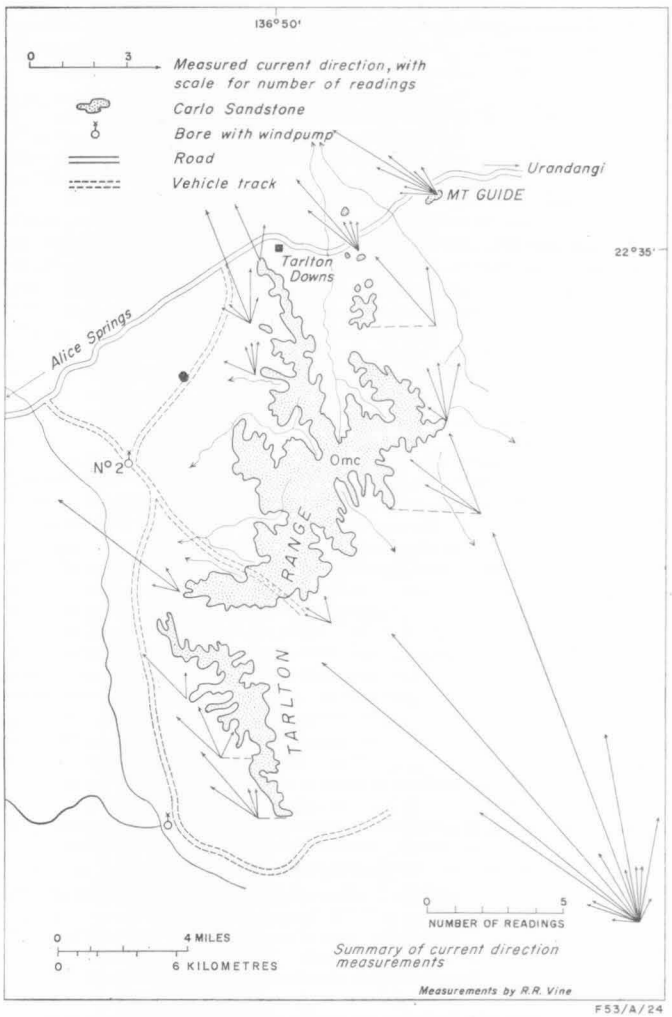


Figure 32. Current directions in Carlo Sandstone, Tarlton Range

formation crops out well where streams have cut across the steeply dipping beds, but elsewhere the beds are seldom seen on the bevelled surface of the Toomba Range. It is difficult to measure complete sections of the Carlo Sandstone because the upper part seldom crops out well.

The Carlo Sandstone is Pritchard's (1960) unit Om 9, which he described as 'medium to thick-bedded, brown and white, fine to medium-grained quartz sandstone, with cross-bedded sandstone containing clay-pellets at the base. The upper part of the unit is massive'. Pritchard (*in* Reynolds & Pritchard, 1964, unpubl.) measured the sequence in the lower part of the Carlo Sandstone in section G261, which is a continuation of his section in the Nora Formation (see Appendix, Table 29).

A more complete section, 85 m thick, has been measured by the writer in a prominent gap in the Toomba Range near the Northern Territory border. Neither the base nor the top of the formation is exposed and the sequence consists of quartz sandstone, with clay pellets prominent in the lowermost 15 m; some beds of red clean friable sandstone are present, and most of the sequence is cross-bedded.

In Netting Fence No. 1, the only well to penetrate the Carlo Sandstone, the thickness is 125+ m (0-410 ft) and the lithology is 'mostly medium-grained, well-sorted quartz sandstone, generally clean and porous but also with yellow ferruginous or white clay matrix in some beds' (PAP, 1965b, unpubl.).

R. R. Vine has measured a complete sequence of the Carlo Sandstone in the Tarlton Range, 10 km south of Tarlton Downs homestead, where the formation is 37 m thick (see Appendix, Table 30).

Smith, Vine, & Milligan (1961, unpubl.) have examined the Carlo Sandstone in the Tarlton Range and found that the direction of the currents during deposition was from the southeast, although local variations occur. The measurements were made on festoon bedding and lamination, flute casts, current ripple marks, and current lineations, and the directions observed at each locality are shown on Figure 32.

Mithaka Formation

Derivation of Name: From Mithaka Waterhole, 200 m west of Queensland border (lat. 22°53'S, long. 138°E). Named by Casey (*in* Smith, 1963a).

Type area: On track from Wheelaman Bore (lat. 22°52'S, long. 138°16'30"E) to Cravens Peak (unsuccessful) bore (22°57'S, 138°07'E) and 1.5 km northeast to top of scarp to south.

Distribution: Tobermory, Glenormiston, Hay River, and Mount Whelan Sheet areas (Sheet 4). Relatively broad belt in centre of Toko Syncline (southeast corner of Tobermory Sheet area and southwest corner of Glenormiston Sheet area) and intermittently to southeast, along both limbs of Toko Syncline; residuals on Tarlton Range.

Lithology: Brown and grey gypsiferous siltstone and sandstone, white glauconitic quartz sandstone, gypsiferous green shale, calcareous siltstone, and some thin coquinite.

Thickness: 60 to 120+ m in Toko Syncline; 20+ m in Tarlton Range; no complete sequence measured.

Contacts: Conformable on Carlo Sandstone and overlain unconformably by Cravens Peak Beds in Toko Syncline; in Tarlton Range, conformable on Carlo Sandstone, but top eroded.

Fossils: Trilobites, nautiloids, and sponges (*Receptaculites*) common, pelecypods and brachiopods less abundant; conodonts reported by P. J. Jones (*in* Reynolds & Pritchard, 1964, unpubl.) from more than 80 shot-hole samples collected by Phillips Petroleum Co. Ltd (1961, unpubl.) during the Springvale-Toko seismic survey; tracks and trails common.

Age: Middle Ordovician (A. A. Öpik & J. G. Tomlinson, pers. comm.).

Description and Comment

The Mithaka Formation is Pritchard's (1960) unit Om 10, which he described as 'sets up to 30 feet thick of thin-bedded brown and white quartz sandstone which in places is glauconitic, interbedded with gypsiferous green shale'. No complete sequence of the Mithaka Formation has been observed; in the Toomba Range it is almost completely concealed in valleys up to 300 m wide, separating ridges of Carlo Sandstone and Cravens Peak Beds; blue-grey siltstone has been noted in a few water bores. The best exposures are in the Tobermory and Glenormiston Sheet areas, where the sequence consists of soft brown gypsiferous siltstone inter-

bedded with brown and white laminated and thin-bedded quartz sandstone and green shale. The proportion of sandstone increases towards the top, and some coquinite also occurs in the upper part of the formation. All the thicknesses measured form only a small proportion of the sequence; the thickness of the concealed part has been estimated. No reliable subsurface information is available on the Mithaka Formation.

A few residuals of the Mithaka Formation on the top of the Tarlton Range consist of strongly lateritized fossiliferous siltstone with a few sandy laminae; the thickness ranges from 2 to 20 m.

Siluro-Devonian

No fossiliferous Silurian rocks are known in the Northern Territory, but the Cravens Peak Beds in western Queensland may be of Silurian age. They occur in the southwestern part of the Glenormiston Sheet area, and may extend southeast under the Mesozoic and Cainozoic sediments which conceal the southeastern part of the Toko Syncline. Jones (*in* Reynolds & Pritchard, 1964, unpubl.) reported coelolepidid fish scales in the Cravens Peak Beds, which indicate an Upper Silurian/Lower Devonian age. They and other specimens have since been studied in detail by Tomlinson (1968).

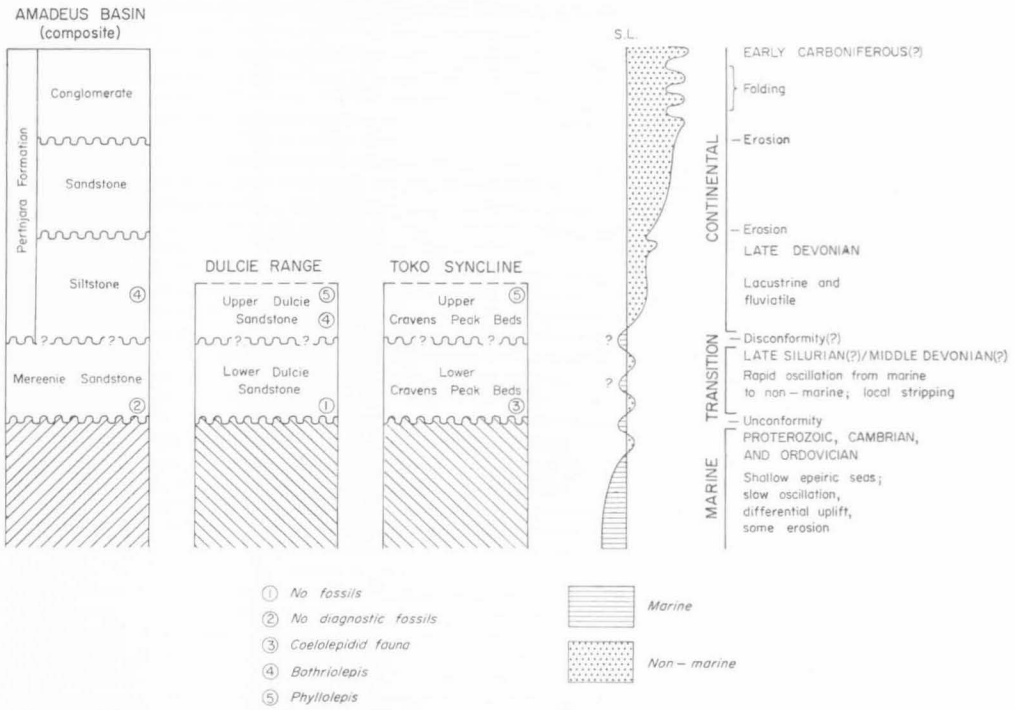


Figure 33. Correlation of post-Ordovician sediments in central Australia (After Tomlinson, 1968)

Cravens Peak Beds

Derivation of Name: From Cravens Peak Holding (Queensland Lands Department Map No. 68), between Northern Territory border and Toko Range in west Queensland, from just north of latitude 23°00′S to latitude 23°22′S. Named by Reynolds (*in* Smith, 1965b).

Distribution: Glenormiston, Mount Whelan, and Hay River Sheet areas (Sheet 4). Confined mainly to Cravens Peak Holding, with narrow belt along east edge of Toomba Range into Northern Territory, and small outcrops near Northern Territory border, south of Mithaka Waterhole.

Lithology: Red-brown quartz sandstone, with mud pellets in some beds and some pebble, cobble, and boulder conglomerate.

Reference Section: About 100 m east of Toomba Bore (lat. 23°05′S, long. 137°59′E) on Hay River Sheet area, Northern Territory; top of section within few metres of Queensland border.

Thickness: 420 m in reference section but base and top not exposed (see Appendix, Table 31); 120+ m near southeast end of Toomba Range (Reynolds, 1968).

Contacts: Unconformable on Mithaka Formation in Toomba Range; unconformable on Toko Group and Kelly Creek Formation near Mulligan River northwest of Carlo homestead; overlain unconformably by Permian(?), Mesozoic, and Cainozoic rocks.

Fossils: Placoderms on surface; coelolepidid fish scales in subsurface.

Age: Siluro(?)-Devonian (see Fig. 33).

Description and Comment

The Cravens Peak Beds constitute the sequence designated Om 11 by Pritchard (1960) and 'Middle Ordovician Undifferentiated' by Smith (1963a). Mapping of the sequence has now been completed, and the fossils found disprove an Ordovician age.

In the northernmost outcrops, and on the eastern side of the Toko Syncline and in its centre, the Cravens Peak Beds crop out poorly in low rises which are commonly covered with rubble where the sequence has a gentle dip. In the Toomba Range the beds crop out well where the dip is steep, although structural complexities caused by cross-faults and suspected strike faults make it difficult to determine the stratigraphy in the sandstone sequence.

In some localities northwest from Toomba Bore, the Cravens Peak Beds rest on sandstone of the upper part of the Mithaka Formation, and the boundary is difficult to place accurately, particularly when both sandstones are brown. Some of the sandstone of the Mithaka Beds contains large pelecypods, by means of which the boundary may be delineated approximately. Southeast of Toomba Bore the Mithaka Formation crops out poorly, if at all, and the base of the Cravens Peak Beds is placed at the base of the oldest sandstone bed on the eastern side of the valleys which separate the ridges of Carlo Sandstone and Cravens Peak Beds.

The age of the Cravens Peak Beds was for some time in doubt; but Tomlinson (1968), in an exhaustive study of the provenance of Devonian fish in central Australia, indicated a hiatus between the lower and upper parts of the Beds, corresponding to a change from a 'transitional' (oscillating marine and non-marine) to a continental environment. Tomlinson's figure 6, which demonstrates the relationship, is here reproduced as Figure 33.

Devonian

Dulcie Sandstone

Derivation of Name: From Dulcie Range, which is capped by prominent outcrops of sandstone. Named by Smith (1964a).

Distribution: Huckitta and Barrow Creek Sheet areas (Sheet 3). Broad belt from southeast tip of Dulcie Range northwestwards for about 210 km; outcrops restricted to Dulcie Syncline.

Lithology: Cream, white, and brown, medium to coarse-grained, medium to thick-bedded, cross-bedded, clean to silty quartz sandstone with sporadic beds of pebble conglomerate, calcareous silty sandstone, and white siltstone. Type section at latitude 22°35′S, longitude 135°41′E, about 13 km southeast of old Huckitta homestead (see Appendix, Table 32).

Thickness: 622 m in type section; 520 m northwest of Picton Spring; 450+ m northeast of Grg 1; 450+ m in southern part of Barrow Creek Sheet area; about 100 m in northwest end of Dulcie Syncline; usually less than 40 m along most of northeast limb of Dulcie Syncline.

Contacts: Unconformable on Middle and Lower Ordovician and Upper Cambrian sequences, and overlain unconformably by Cainozoic sediments; base commonly concealed by Cainozoic sand.

Fossils: Fish remains (see Tomlinson, 1968).

Age: Lower part Lower Devonian; upper part Upper Devonian (see Fig. 33).

Description and Comment

The Dulcie Sandstone is an easily recognized lithological unit, but the boundary with the sandstone of the underlying Tomahawk Beds is difficult to map in places, particularly on the northeastern side of the Dulcie Syncline, where dips are usually low. At many other places in the scarp of the Dulcie Range, scree conceals the contact with the underlying Nora Forma-

tion and Tomahawk Beds. The contact can be located by observing the scour-and-fill structures in the older rocks. There is no apparent angular unconformity between the beds, but regional structure indicates a disconformity.

The best and thickest outcrops of the sandstone are on the southwestern limb of the Dulcie Syncline. Good exposures occur also on the northeastern side between locality HX93 and the southeastern extremity of the Dulcie Range. In these localities dips are steep in the lower beds, but flatten out rapidly to less than 5° across the remainder of the outcrop belt. The thickest sequence on the air-photographs is in the type area, and light-coloured beds below the *Bothriolepis* horizon can be traced around several outcrops northwestwards to the headwaters of Mistake Creek. Farther northwest, most of the sequence is probably below the horizon where *Bothriolepis* sp. has been found, although measurement is difficult in cross-bedded and poorly outcropping sediments when the dip flattens out a short distance from the base. A thickness of 450 m has been measured in section BX8 in the southeastern part of the Barrow Creek Sheet area.

Along most of the northeastern edge of the Dulcie Syncline the measurable thickness is less than 30 m in low scarps. At the northwestern end of the syncline, the Dulcie Sandstone is less than 90 m thick, and the fossil fish have been found in the sandstone.

The Dulcie Sandstone may be present under the soil-covered plains to the north of its outcrop area on the Elkedra and Barrow Creek Sheet areas. If so, it fills hollows in the Tomahawk Beds. There is some evidence for this in core hole Grg 2, where the sequence consists of 85 m (280 ft) of Quaternary sand overlying soft white clean quartz sandstone, silty quartz sandstone, and some pebbly sandy siltstone and white siltstone. On lithological grounds this sequence is regarded as part of the Dulcie Sandstone, but there is no supporting palaeontological evidence. Core recovery was poor, and the hole was abandoned at 108 m (354 ft) (Milligan, 1963, unpubl.).

The northwesterly extent of the Dulcie Sandstone is unknown; it was not recorded in core hole Grg 18, which recovered Upper Cambrian sediments at 94 m (310 ft) but farther northwest, on the Lander River Sheet area, Milligan, Smith, Nichols, & Doutch (1966, unpubl.) have mapped an apparently unfossiliferous sandstone, lithologically similar to the Dulcie Sandstone, unconformably overlying fossiliferous Middle Ordovician sediments.

The age of the Dulcie Sandstone has been discussed by Tomlinson (1968), who places it in correlation with the Cravens Peak Beds: in both the lower part is of uppermost Silurian to Lower Devonian age and is separated from the Upper Devonian upper part by a hiatus (Fig. 33).

PERMIAN(?)

Reynolds & Pritchard (1964, unpubl.) regard some small outcrops beneath Mesozoic(?) rocks, 18 km west of Roxborough Downs homestead, as probably Permian in age. Reynolds (1968) also regarded similar but larger outcrops in the Mount Whelan Sheet area as probably Permian. The sequences are unnamed.

The outcrops west of Roxborough Downs homestead consist of a few metres of unconsolidated bouldery gravel which has weathered from the slopes of small rounded hills capped by weathered Mesozoic sediments. One small outcrop of green-brown laminated siliceous shale appears to be associated with the gravel. The gravel consists mainly of silicified sandstone resembling that in the Ordovician sequences in the Toko Range; some of the blocks are fossiliferous, and Tomlinson (1959, unpubl.) has identified boulders of the Kelly Creek and Nora Formations. Some cobbles and pebbles have flat-iron shapes, some have impact structures, and a few are striated; on this account, Reynolds & Pritchard (1964, unpubl.) regard the gravels as probable glacial deposits of Permian age.

Reynolds (1968) described the unconsolidated pebble deposits in the Mount Whelan Sheet. They are widely distributed in hollows in the Toomba Range and over its eastern slopes, and also over the low hills in the western trough of the Toko Syncline and between Sun Hill and Pollys Lookout. The pebbles are mainly silicified quartz sandstone and appear to have been derived locally from older Palaeozoic rocks of the Toomba Range. Leslie (FBH, 1959, unpubl.) found some pebbles in unconsolidated boulder clay.

The pebble deposits are similar to those in the Glenormiston Sheet area and Reynolds also regarded them as probable Permian glacials.

According to their description, the sediments are similar to the Tarlton Formation of Condon & Smith (1959, unpubl.).

The type section is at latitude 22°48'S, longitude 136°48'E, south of Tarlton Downs homestead (Sheet 4), and is exposed in a scour on the southwestern scarp of a mesa. The sequence consists of 1 m claystone with faceted, polished, and striated boulders and cobbles overlain by 20.5 m of silty sandstone and siltstone (see Appendix, Table 33).

Many of the boulders in this and other sequences in the same area exhibited features attributable to glaciation, and consequently Condon & Smith considered that the formation was a Permian fluvioglacial deposit. Subsequently, the dating of plant fossils (White, 1961, unpubl.) showed that at least the upper part of the formation was of Triassic age, and now the whole of the sequence is placed in the Triassic.

The Tarlton Formation crops out extensively in mesas and small plateaux in the Tobermory and Hay River Sheet areas, and two small outcrops correlated with these occur in the Huckitta Sheet area. The base is seldom exposed, but the formation overlies Palaeozoic and Precambrian rocks. The maximum thickness observed is 43 m at Mount Ewing (lat. 22°59'S, long. 137°10'E; Sheet 4).

Jurassic and Cretaceous

Jurassic and Cretaceous sediments obscure the northwestern and southeastern margins of the Georgina Basin. Those in the northwest are a northern extension of the Mullaman Beds (Noakes, 1949; Skwarko, 1966).

The Mullaman Beds are not shown on Sheet 1, because the mapping of Helen Springs and Beetaloo Sheet areas had not been completed when it was compiled, and because only small outcrops of Mesozoic are known in the southern part of the Walhallow Sheet area, where Plumb & Rhodes (1965) reported Mesozoic sediments in gullies and small scarps.

Randal & Brown (1970) state that outcrop of Mesozoic sediments is thin, usually less than 3 m in the Helen Springs Sheet area.

The Mullaman Beds are horizontal and consist of quartz sandstone, pebble conglomerate, siltstone, and claystone. The thickest known sequence is 16 km east of Beetaloo homestead, where a water bore penetrated 87 m of Mullaman Beds without reaching the base of the sequence. The sediments in the bore contain Radiolaria and plant impressions.

The Mullaman Beds contain a fairly rich flora of Lower Cretaceous or possibly Jurassic age (Brunnschweiler, 1950, unpubl.; White *in* Randal & Nichols, 1963, unpubl.).

To the southeast the Georgina Basin plunges below the Jurassic-Cretaceous Eromanga Basin. The stratigraphic nomenclature for the Eromanga Basin has been developing steadily in recent years and the changes applicable to the western part are summarized in Figure 34. The nomenclature used in the geological map was taken from several maps and reports available at the time of compilation.

Figure 34 also summarizes the stratigraphy of the western part of the Eromanga Basin. Briefly, a basal sandy sequence (*Longsight Sandstone*) containing a lower freshwater part and an upper marine part identifies a widespread marine transgression. This is overlain and overstepped by a thick marine mudstone (*Wilgunya Formation*), interrupted by a thin limestone (*Toolebuc Member*). The Toolebuc is characterized by anomalously high radioactivity owing to small concentrates of uranium (Casey & others, 1960), which enables clear identification on gamma-ray logs of water bores. The Wilgunya Formation is overlain by a paralic mixed sandstone-mudstone sequence (*Mackunda Formation*) which marks a major regression.

Much of this sequence continues below the Quaternary sand of the Simpson Desert. Lower Cretaceous forams have been obtained at a depth of 57 m in a water bore on the Plenty River, and Smith & Vine (1960, unpubl.) have described 15 m of sandstone and siltstone, of probable Lower Cretaceous age, from Lake Caroline and near the Hay River. Both occurrences are in the Hay River Sheet area.

Thin or isolated Mesozoic outcrops over the rest of the Georgina Basin cannot be positively related to the Eromanga Basin sequence, and these are shown on the geological map as 'undifferentiated Mesozoic'. Most are sandy sediments which may be either locally derived or local facies. Those in the Sandover River Sheet area resemble the Tarlton Formation. The *Polland Waterhole Shale* is a marine formation which crops out extensively in the Mount Isa and Camooweal areas. It is lithologically similar to the Wilgunya Formation, and of comparable age.

Cainozoic

Thin Tertiary sediments crop out discontinuously but extensively on the Barkly Tableland, in the valleys of the Georgina River, Pituri Creek, and the Burke River, and at several other

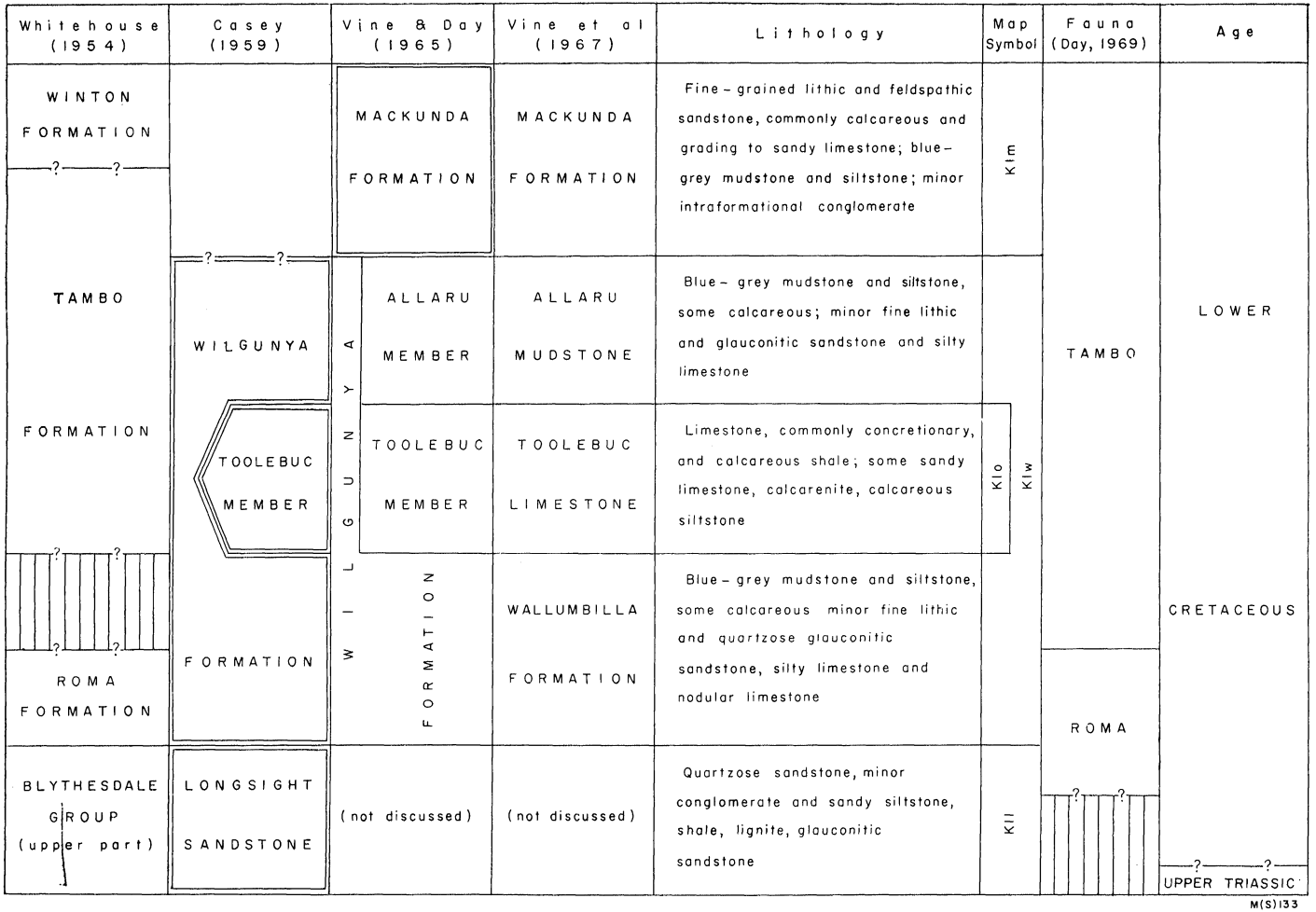


Figure 34. Stratigraphy of the Mesozoic sediments in the southeastern part of the basin.

localities within the Georgina Basin. Evidence from water bores and core holes indicates that Tertiary sediments may be widespread subsurface. On Sheets 1, 2, 3, and 4, the Tertiary sediments are not differentiated, because they are of no great concern to the geology of the Georgina Basin. However, various formations have been named and are described briefly below.

The *Arltunga Beds* (Madigan, 1932, re-defined by Smith, 1964a) crop out on the Huckitta Sheet area. They consist mainly of vuggy chalcedony, with relict patches of silicified limestone; the chalcedony grades downwards into limestone, with layers, nodules, and veins of chalcedony, and into grey or white limestone. In some localities, beds of sandstone and siltstone occur in the sequence. The outcropping thickness ranges from 11 to 27 m; in BMR core hole Grg 1, 26 m (86 ft) was recorded (Milligan, 1963, unpubl.).

The only fossils found in the Arltunga Beds are the freshwater gastropods reported by Madigan (1932, p. 98), which are regarded as Pliocene or Pleistocene in age.

The *Austral Downs Limestone,* named by Noakes & Traves (1954), crops out in the valley of the Georgina River and its tributaries and rests unconformably on many older units. It is a silicified limestone and chalcedonic limestone with some calcilutite and siltstone interbeds which crops out in mesas and also as pavements; the surface is commonly strewn with loose boulders of chalcedonic limestone. The thickness ranges from 2 to 30 m. Ostracods and Foraminifera have been reported from outcrops in the Glenormiston Sheet area (Reynolds & Pritchard, 1964, unpubl.) and Lloyd (1968) reports gastropods from many localities.

The *Marion Formation,* named by Casey (1959), consists of silicified sandy quartz siltstone which rests unconformably on lateritized Wilgunya Formation. The reference section is 8 km northwest of Strathelbiss homestead (28 km north of Boulia) at latitude 22°44′S, longitude 139°47′E. The formation is considered to be of freshwater and aeolian origin, deposited in a large Tertiary lake.

Reynolds (1965b, 1968) has reported the presence of the formation in the Springvale and Mount Whelan Sheet areas.

The *Noranside Limestone,* named by Casey (1959), consists of limestone and chalcedonic limestone resting unconformably on Palaeozoic and Cretaceous sediments in the Boulia Sheet area.

The limestone usually occurs as numerous flat plates and scattered outcrops on brown or black-soil plains. The basal 3 m contains ferruginous material from a redistributed soil. An irregular zone of siliceous limestone caps the sequence.

Ostracods, diatoms and gastropods are common and Casey & others (1960, unpubl.) consider algae responsible for structures such as aggregation of lime pellets and laminated structure around nuclei.

The Noranside Limestone overlies the Marion Formation, at least in part, but the relationship between the two is not fully resolved. Both are lacustrine, perhaps deposited in the same lake, but no lithological gradation between the two units has been observed.

The Noranside Limestone formed in a lake extending south-southeast from Digby Peaks to the Hamilton River. Springs issuing from the unconformity between Palaeozoic and Mesozoic sediments, or from fractured limestone in the Burke River Structural Belt, probably supplied lime-rich water to the lake. Casey & others (1960, unpubl.), consider that very slight southward tilting, combined with gentle meridional warping, drained the lake and destroyed the springs, probably in late Tertiary or early Quaternary time.

The *Mount Coley Sinter* (Reynolds, 1964, unpubl.) consists of 50 m of chalcedony, siliceous sinter, and fine-grained sandstone in the Mount Whelan Sheet area. It contains silicified wood.

The *Brunette Limestone,* named by Noakes & Traves (1954), covers a large area in the Ranken, Brunette Downs, Alroy, and Helen Springs Sheet areas. Good exposures are rare and the limestone occurs often as scattered blocks and boulders in black soil.

The rock consists of white to brown, fine to coarsely crystalline limestone and dolomite, which commonly contain chert and opaline nodules and smears. The sandstone and siltstone which are found as boulders on the surface probably occur in the sequence, and some sandy limestone is known.

Fossils found in blocks of conglomeratic limestone (Randal & Nichols, 1963, unpubl.), not in situ, include freshwater gastropods similar to *Planorbina,* and some similar to the marine forms *Lanistes* and *Daistoma* (Lloyd, 1968). Lloyd also recorded numerous specimens

of the foraminiferan *Ammonia beccarii* (Linne) and one ostracod; he considers the age 'not older than middle Miocene and possibly not younger than Pliocene'. The fossils indicate a marine or brackish environment in addition to the freshwater lake environment which is usually postulated for the Brunette Limestone.

Quaternary sand, soil, alluvium, gravel, and kunkar are widespread within the Georgina Basin and along its margins. Within the northern half of the basin, pedocalcic grey soil is widespread on the Palaeozoic carbonate rocks. Much of this soil is admixed with sand and debris of chert and gravel from breakdown of Tertiary laterite. The thickness of the Quaternary sediments is generally less than 10 m, for example 8 m (25 ft) in the Frewena No. 1 well, 4.5 m (15 ft) in Brunette Downs No. 1, and 6 m (20 ft) in BMR 11 (Cattle Creek). Similar thicknesses are recorded in many water bores in the area.

The northern half of the Georgina Basin contains one desert area, east and northeast of the Davenport Range. It is unnamed and consists mainly of sand plain, with low fixed dunes trending northwest in places on the Elkedra and Frew River Sheet areas. The desert is uninhabited, and the thickness of the sand is unknown.

In the southern half of the basin, soils are mainly of the red-earth residual type, but there are patches, for instance on Tobermory station, of grey pedocalcic soils on Cambro-Ordovician carbonate rocks. The thickness of the pedocalcic soils usually does not exceed 6 m, but is 10 m (33 ft) thick in the Ammaroo No. 1 well; and considerable thicknesses of unconsolidated sand have been recorded in some of the BMR core holes—53 m (173 ft) in Grg 5 and 85 m (280 ft) in Grg 2 (Milligan, 1963, unpubl.). East of Barrow Creek settlement, active dunes trend northwest, and are 6 to 27 m high.

The most conspicuous sands are in the Simpson Desert, which borders the basin in the southwest and encroaches onto the southeastern extension. The desert consists of parallel active dunes, trending northwest and spaced from $\frac{1}{2}$ to 1 km apart. The dunes are asymmetrical, with the steeper side on the east, and they reach a height of 30 m in many places, although the average height is probably about 15 m. Madigan (1945), Carroll (1944), and Crocker (1946) have reported on various aspects of the desert, and the overall conclusion, stated by Madigan, is that it was formed by the action of southeasterly winds on unconsolidated fluviatile sands. The heavy mineral content (studied by Carroll) indicated that the dunes originated near the sources of the heavy minerals, and had not all grown northwestwards from the southern edge of the desert.

The only known fossils in the Simpson Desert are a reptilian tooth and diprotodon bones of upper Cainozoic age found by M. R. Larter (BMR) in gypsiferous deposits near Pulchera Waterhole.

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APPENDIX

TABLE 10. FIELD RIVER BEDS

Thickness (m)	
	Grant Bluff Formation conformably overlying
172	*Quartz greywacke,* grey and red, coarse-grained; *arkose,* brown, coarse-grained, cross-bedded, pebbly; *siltstone,* red, thin-bedded, dolomitic in part; *dolomite,* red, thin-bedded
223	*Dolomite,* yellow and grey, thin and medium-bedded; thin interbeds of *siltstone,* yellow, dolomitic
	Concealed interval
76	*Arkose,* brown, pebbly, medium to coarse-grained, micaceous
73	*Shale,* green; *arkose,* green, dolomitic; *dolomite,* yellow and brown, medium-bedded
	Concealed interval
541	*Siltstone,* green, with fragments of rock, and grains of feldspar and quartz; *boulder beds; siltstone,* green, hard, laminated, with lenses of *sandstone,* grey, purple, medium-grained
	Base not exposed
Total 1085	

TABLE 11. WONARAH BEDS NEAR BARRYS CAVES

Thickness (m)	
3.7	*Silcrete* ('billy'), brecciated
0.3	*Quartz-pebble conglomerate*
6.1	*Quartz sandstone,* ferruginous. red and white, fine-grained; *siltstone*
10.7	Rubble
	Base not exposed
Total 20.8	

TABLE 12. SEQUENCES IN BMR Grg 15 AND 15A
(after Milligan, 1963, unpubl.)

Grg 15 (m)	
0-15	Quaternary and Tertiary
15-40.5	*Siltstone,* shaly, with rich fauna of *Xystridura,* agnostids; thin beds of *calcarenite, sandstone,* calcareous, and *limestone,* silicified, bioclastic
40.5-92.7	No cuttings, no core (too soft)
92.7-94.5	*Dolomite,* brownish; lenses of *chert,* grey, fossiliferous
Grg 15A	
6-15	Quaternary and Tertiary
15-76	*Siltstone,* shaly, with rich fauna of *Xystridura;* thin beds of *calcarenite, sandstone,* calcareous, and *limestone,* silicified
76-82	*Limestone,* brownish, fossiliferous, crystalline; lenses of *chert,* grey

TABLE 13. SEQUENCE IN BMR Grg 16

Thickness (m)	
0-11.3	*Soil, gravel*
11.3-30	*Dolomite, dololutite*
30-60	*Calcilutite, calcarenite,* and *limestone,* crystalline, in approximately equal amounts
60-92	*Limestone* (coquinite), oolitic, bioclastic, silicified near bottom; interbedded with *calcilutite*

TABLE 14. ARTHUR CREEK BEDS, EASTERN BELT

Thickness (m)	
49	*Unit* 3. *Sandstone,* buff, white, and brown, with *Asthenopsis* sp.; lensing into *dolomite,* brown, and *limestone,* blue; minor *siltstone*
75 (est.)	*Unit* 2. *Limestone,* blue, black, and grey, flaggy; trilobites and brachiopods
180 (est.)	*Unit* 1. *Shale* and *siltstone,* white and buff, with numerous trilobites; thin beds of *coquinite,* blue, and *sandstone,* pebbly, medium-grained, at base in places

TABLE 15. ARTHUR CREEK BEDS IN SECTION HX33

Thickness (m)	
	Top of mesa
21.3	*Sandstone,* buff and yellow, calcareous, medium-bedded, medium-grained
0.3	*Limestone,* grey, dense; brachiopods and trilobites
2.4	*Sandstone,* calcareous, buff and yellow, medium-bedded, fine-grained. *Asthenopsis* is present in unit 3 about 320 m north of section line
5.2	*Calcilutite,* grey and pink, laminated to thin-bedded; *limestone,* grey, medium-bedded
6.1	*Limestone,* dark grey, thin-bedded, cross-bedded, sandy; brachiopods
13.1	*Sandstone,* calcareous, yellow, soft, thin-bedded, micaceous
	Base not exposed (underlain by limestone of unit 2)
Total 48.4	

TABLE 16. REFERENCE SECTION OF THE MARQUA BEDS

Thickness (m)	
	Top of mesa
9	*Unit* 3. *Sandstone,* calcareous, brown and buff, medium-grained; flaggy; fragments of trilobites
162	*Unit* 2. *Limestone,* blue, fine-grained, crops out poorly, medium and thin-bedded, trilobite fragments; some *limestone,* sandy, grey, medium-grained, thin-bedded, crops out well.
32	*Unit* 1. *Shale,* buff and white, hard, silicified, thin-bedded, abundant trilobites—including *Xystridura* sp. (A. A. Öpik, pers. comm.); some *chert,* white
3	*Chert,* blue, fragments of trilobites, forms prominent band
	Unconformably overlying dolomite of Field River Beds
Total 206	

TABLE 17. MUNGEREBAR LIMESTONE NEAR McCABES KNOB

Thickness (m)	
3	*Calcilutite,* two-coloured grey, blue-grey, thin to medium-bedded; poorly exposed
1.2	*Limestone-breccia,* intraformational; altering to calcilutite, two-coloured, partly dolomitic, fossils near base
0.3	*Calcilutite,* grey; irregular burrows(?) filled with crystalline calcite
1.8	*Calcarenite,* coarse-grained, oolitic; intraformational *limestone-breccia,* very sandy, cross-bedded; lenses of *sandstone,* fine-grained, calcareous, oolitic
3.7	*Calcilutite,* grey, laminated, friable, mostly soft, sandy in part; poorly exposed; fossils 2 m above base
Total 10	

TABLE 18. TYPE SECTION OF THE CHATSWORTH LIMESTONE

Thickness (m)	
10.7	*Calcarenite,* sandy, laminated; brachiopods; (4½ m concealed)
3	*Sandstone,* calcareous
6	*Calcarenite,* sandy, thin and medium-bedded; agnostids at 145 m
4.6	*Calcarenite,* coarse-grained, some sandy; brachiopods at 136 m and trilobites at 135 m
1.5	*Calcarenite,* fine-grained, laminated; *calcilutite,* laminated
1.5	*Sandstone,* calcareous, cross-bedded, slumped
39.6	*Calcarenite,* sandy, fine-grained; trilobites, brachiopods, gastropods, and blastoids in coquinite at 113 m; trilobites at 105 m; (about 12 m concealed)
16.8	*Calcarenite,* laminated, thin-bedded; *calcilutite,* medium and thin-bedded; trilobites, blastoids, and brachiopods at 85 m
10.7	*Calcarenite,* thin-bedded, some sandy and some two-tone; trilobites
64	*Calcarenite,* coarse-grained; *calcilutite,* laminated; trilobites and shells at 33½ m
	Base not exposed
Total 158.4	

TABLE 19. CHATSWORTH LIMESTONE AT BLACK MOUNTAIN

Thickness (m)	
	Dolomite beds at base of Ninmaroo Formation overlying
135	*Calcarenite,* fine-grained, medium to thick-bedded, laminated in part; some sandy laminae, pyritic in part; brachiopods and trilobites
180	*Calcarenite,* fine-grained, some coarse-grained; some *sandstone,* friable, and *calcilutite.* Grey to blue-grey, thin-bedded, laminated; bituminous smell when struck; agnostid trilobites
	Base not exposed
Total 315	

TABLE 20. REFERENCE SECTION OF THE TOMAHAWK BEDS

Thickness (m)	
	Green siltstone of the Nora Formation overlying
7.9	*Sandstone,* grey, medium-grained, soft, porous, calcareous, glauconitic, fossiliferous
4	Concealed
4.6	*Quartz sandstone,* coarse-grained, friable, cross-folded; grades laterally into *dolarenite,* light-brown
2.4	*Sandstone,* brown and grey; poorly exposed; pelecypods
0.3	*Dolomite,* dark brown, coarsely crystalline
4.6	*Quartz sandstone,* grey, medium-grained, thin to medium-bedded, cross-bedded; worm trails
0.3	*Dolomite,* grey-brown, coarsely crystalline
1.5	*Sandstone,* medium-grained, friable, well sorted, thin to medium-bedded, cross-bedded
5.2	*Quartz sandstone,* medium-grained, thin to medium-bedded, cross-bedded; mud pellets, ripple marks; worm trails, abundant 'pipe-rock'
16.8	*Sandstone,* white and grey, medium-grained, friable, thin-bedded, poorly sorted
3	*Dolomite,* grey, medium-bedded to massive, cross-bedded in part
0.6	*Sandstone,* medium-bedded, cross-bedded, dolomitic
9.4	*Sandstone,* white, medium-grained, friable, well sorted
3	*Dolomite,* brown, coarsely crystalline, medium-bedded to massive
1.2	*Dolomite,* dark brown, medium-bedded, coarsely crystalline
0.3	*Sandstone,* fine-grained, laminated, glauconitic, micaceous
0.3	*Dolomite,* brown, sandy, coarsely crystalline
0.3	*Sandstone,* white, fine-grained, laminated, poorly exposed
0.3	*Dolomite,* grey-brown, thin-bedded, cross-laminated, sandy
0.6	*Dolomite-breccia,* medium-bedded, sandy
0.9	*Sandstone,* medium-grained, friable, poorly exposed
0.3	*Dolomite-breccia,* sandy
0.9	*Sandstone,* calcareous, thin to medium-bedded, poorly exposed
1.8	*Dolomite,* dark brown, thick-bedded, coarsely crystalline
8.2	Concealed
0.3	*Siltstone,* soft, glauconitic, micaceous
2.7	*Dolomite,* dark brown, laminated, sandy, massive weathering
7.9	*Calcarenite,* grey, sideritic, poorly exposed
0.6	*Limestone,* grey, coarsely crystalline, fossiliferous
3.4	*Sandstone,* grey, medium-grained, thin-bedded, poorly exposed; thin bands of *siltstone,* laminated, green
0.3	*Limestone,* grey; abundant brachiopods
1.8	*Limestone,* grey, flaggy, cross-laminated
2.7	*Limestone,* grey, poorly exposed
1.2	*Calcarenite,* grey-brown, medium-grained, thin-bedded
1.2	*Limestone,* grey, coarsely crystalline; numerous brachiopods
4.6	*Calcarenite,* grey, poorly exposed
1.5	*Dolomite,* brown and grey, sandy, cross-laminated
8.5	*Calcarenite,* grey, medium-bedded, cross-laminated
0.9	*Limestone,* grey, sandy, cross-laminated; abundant brachiopods
6.4	*Sandstone,* grey, medium-grained, thin-bedded, poorly exposed
1.2	*Limestone,* grey-brown, hard, sandy; abundant brachiopods
11	*Sandstone,* grey, glauconitic, medium-grained, cross-laminated, fossiliferous
4.3	*Dolomite,* dark brown, thin-bedded, poorly exposed
0.9	*Dolomite,* brown, sandy, thin-bedded
25.3	*Sandstone,* grey, medium-grained, glauconitic, poorly exposed; thin interbeds of *limestone,* sandy, glauconitic
3.4	*Sandstone,* grey, soft, porous, medium-grained, glauconitic

TABLE 20. REFERENCE SECTION OF THE TOMAHAWK BEDS—*Continued*

Thickness (m)	
4	*Siltstone,* green micaceous, laminated; thin interbeds of *sandstone,* grey, medium-grained, glauconitic, fossiliferous
3.7	*Sandstone,* grey, firm, medium-grained, thin-bedded, glauconitic, fossiliferous; interbedded with *siltstone,* green, micaceous
4.3	*Siltstone,* green, laminated; interbeds of *sandstone,* grey, glauconitic, fossiliferous, thin-bedded, medium-grained
16.2	*Siltstone,* green, poorly exposed
	Tomahawk Beds disconformably(?) overlie dolomite of Arrinthrunga Formation
Total 197	

TABLE 21. NINMAROO FORMATION AT BLACK MOUNTAIN

Thickness (m)	
6	*Limestone,* white, massive, fine-grained; nautiloids and brachiopods
80	*Calcarenite,* coarse and medium-grained, medium-bedded, minor cross-bedding; subordinate *intraformational breccia;* chert biscuits and plates; many stylolites; ribeirioids, brachiopods, and echinoderm ossicles
90	*Intraformational breccia,* interbedded with calcarenite, two-tone, medium-grained, medium-bedded, minor cross-bedding, some sandy laminae
75	*Calcarenite,* two-tone, medium-grained, some fine-grained, thin to medium-bedded, slumped in part; minor *intraformational breccia;* nautiloids common
230	*Calcarenite,* fine-grained, two-tone; minor *intraformational breccia,* thin-bedded and laminated; minor sand; chert nodules and biscuits; nautiloids fairly common in top 110 m; ribeirioids and echinoderm fragments
75	*Calcarenite,* fine-grained; minor *calcilutite,* medium-bedded and laminated, minor cross-bedding
115	*Dolomite,* thick-bedded, minor cross-bedding
	Conformably overlying calcarenite of Chatsworth Limestone
Total 671	

TABLE 22. NINMAROO FORMATION AT MOUNT NINMAROO

Thickness (m)	
	Leached silicified carbonate rocks of Swift Formation unconformably overlying
24	*Calcarenite,* medium-grained, sandy; some chert biscuits and silica blebs; brachiopods, gastropods, echinoderm ossicles, and coprolites
6	*Limestone,* white, fine-grained, massive; nautiloids, crinoids, brachiopods, gastropods(?), and coral-like structures
75	*Calcarenite,* fine and coarse-grained, some medium-grained; minor cross-bedding; chert biscuits; brachiopods and echinoderm plates
105	*Intraformational breccia* interbedded with *calcarenite;* minor sand, some slumping, cross-bedding, and chert biscuits; nautiloids, brachiopods, and echinoderm plates
90	*Calcarenite,* fine-grained; *calcilutite* and *intraformational breccia,* silica blebs common; nautiloids, brachiopods, gastropods, trilobites, and algae
290	*Calcarenite,* fine-grained; minor *intraformational breccia,* thin and thick-bedded, laminated in part; some slumping and chert rolls; few nautiloids in upper 240 m

TABLE 22. NINMAROO FORMATION AT MOUNT NINMAROO.—*continued*

Thickness (m)	
2	*Dolomite* Conformably overlying 320 m of Chatsworth Limestone
Total 592	

TABLE 23. TYPE SECTION OF THE KELLY CREEK FORMATION

Thickness (m)	
	Coolibah Formation overlying disconformably(?)
3	*Dolarenite,* grey-brown, fine-grained, thin and medium-bedded
0.6	*Chert,* white, thin-bedded
0.6	*Dolarenite,* grey-brown, fine to medium-grained
5.2	Concealed
2.1	*Chert,* white, thin and medium-bedded, fossiliferous; one interbed of *dolarenite,* fine-grained, thin-bedded and laminated
18.3	Concealed
3	*Dolarenite,* grey-brown, fine-grained, thin-bedded and laminated; alternating hard and soft in thick sets
4	Concealed
6.1	*Dolarenite,* fine-grained, thin-bedded and laminated, alternating hard and soft in thick sets
2.1	Concealed
3	*Dolarenite* and alternating *calcarenite;* fawn, fine-grained, thin-bedded laminated
3.7	Concealed
0.9	*Calcarenite,* fawn, fine-grained, thin-bedded; sandy lenses
3.4	Concealed
3.4	*Calcarenite,* fawn, fine-grained, thin-bedded; sandy lenses
4.9	Concealed
1.5	*Calcarenite,* fawn, fine-grained, thin-bedded; sandy lenses
45.7	Concealed
7.9	*Quartz sandstone,* white, fine to very fine-grained, laminated, thin and medium-bedded; well rounded, well sorted; worm trails on bedding planes, brachiopod coquina towards top
4.3	Concealed
5.5	*Quartz sandstone,* white, fine to very fine-grained, thin to medium-bedded; well rounded, well sorted; worm trails on bedding planes
2.7	Concealed
2.1	*Quartz sandstone,* white, very fine-grained, thin-bedded; well rounded, well sorted
3.4	Concealed
1.2	*Quartz sandstone,* white, very fine-grained, thin-bedded; well rounded, well sorted
1.8	Concealed
2.1	*Quartz sandstone,* white, very fine-grained, laminated; well rounded, well sorted
9.4	Concealed
3	*Quartz sandstone,* white, very fine-grained, laminated, cross-laminated; well rounded, well sorted
1.8	Concealed
0.9	*Quartz sandstone,* white, very fine-grained, silicified, thin and medium-bedded; well rounded, well sorted
2.4	Concealed
7.3	*Quartz sandstone* rubble, white, silicified; obscures contact with underlying Ninmaroo Formation
Total 167.3	

TABLE 24. SWIFT FORMATION IN TYPE AREA

Thickness (m)	
3	Chert breccia, of unknown age, resting unconformably on
6.1	*Chert,* white and grey, thin-bedded and laminated; some *coquinite,* silicified
7.6	Concealed
3.7	*Sandstone,* red and white, laminated, fine-grained; *siltstone,* red and white, laminated
	Swift Formation overlies Ninmaroo Formation, but contact not exposed here
Total 20.4	

TABLE 25. NORA FORMATION IN THE NORTHEASTERN PART OF THE TOKO RANGE

Thickness (m)	
	Carlo Sandstone conformably overlying
9	*Quartz siltstone,* yellow-brown and purple; laminated and thin-bedded; blebs and stringers of siltstone containing very fine sand grains
6	Concealed
2	*Quartz sandstone,* purple, fine-grained, laminated and thin-bedded, micaceous; a few clay pellets; interbeds of *siltstone,* sandy in part
6	*Siltstone,* yellow-brown, white, and purple, sandy in part; tracks and trails
26	Concealed; few plates of brown *coquinite* 12 m from top
11	*Quartz sandstone,* brown, grey-brown, and tan, fine-grained, laminated, and thin-bedded, friable; well sorted, well rounded; thin interbeds of *coquinite,* grey-brown and tan
	Thickness of section to base of scarp; base not exposed
Total 60	

TABLE 26. NORA FORMATION IN THE NETTING FENCE NO. 1 WELL

Thickness (m)	
73 (410-650 ft)	*Sandstone,* grey, grey-green, fine-grained, very shaly in places; grading into *shale,* sandy, pyritic, glauconitic; *quartz sandstone,* yellow, hard, tight, very fine-grained, predominates in interval from 500 to 600 feet; *shale,* grey-green, grey-brown, chocolate, and grey, silty and sandy, micaceous (biotite and muscovite)
40.5(650-783 ft)	*Quartz sandstone,* grey, micaceous, glauconitic and calcareous in places, bituminous and shaly in places; interbedded with *shale,* blue-grey, grey, green, fissile, very micaceous (biotite and sericite), pyritic; and *coquinite*

TABLE 27. NORA FORMATION IN THE SOUTHERN PART OF THE TARLTON RANGE

Thickness (m)	
	Carlo Sandstone overlying
15	Concealed; scree of *siltstone* and *quartz sandstone*
8.5	*Quartz sandstone,* fine-grained, porous, friable, highly gypsiferous in part
7.6	Concealed
17	*Claystone* and *siltstone,* brown and green, gypsiferous in part; numerous thin interbeds of *coquinite,* brown, pelletal, and *sandstone,* pale brown, fine-grained, indurated
8.2	*Siltstone,* green, micaceous; thin interbeds of *coquinite,* ferruginous, pelletal, *quartz sandstone,* and *sandstone,* glauconitic
5.2	*Coquinite,* ferruginous, pelletal; *dolomite,* shelly; all poorly exposed
	Overlies Kelly Creek Formation
Total 61.5	

TABLE 28. NORA FORMATION IN THE DULCIE RANGE

Thickness (m)	
	Dulcie Sandstone unconformably overlying
56.4	Mainly concealed; debris of Dulcie Sandstone and conglomerate with fragments of fossiliferous Ordovician sandstone; 'sub-outcrop' of *siltstone,* red, and *quartz sandstone,* purple, 40 m above base
19.8	Concealed; debris of dark brown fossiliferous *dolomite,* green fossiliferous *mudstone,* and grey fossiliferous *sandstone*
0.2	*Sandstone,* dark red, ferruginous, coarse-grained; small lenses of *dolomite,* brown
14.9	Concealed
0.3	*Mudstone,* green, fossiliferous
0.6	*Ironstone,* dark red, oolitic, coarse-grained
6.1	*Mudstone,* poorly exposed, green; some lenses of *sandstone,* coarse-grained, fossiliferous
0.6	*Mudstone,* greenish brown; some lenses of *sandstone,* medium and coarse-grained
0.3	*Ironstone,* dark red, coarse-grained
1.4	*Siltstone,* green
0.9	*Sandstone,* dark red, ferruginous, coarse-grained (sample Ha248A)
0.8	*Mudstone,* green, fossiliferous
0.8	*Sandstone,* light-green; some lenses of *sandstone,* dark red, ferruginous
1.2	*Mudstone,* green; some 5-cm bands of *sandstone,* dark red, ferruginous
8.5	Mainly concealed; some poor outcrops of *siltstone,* green
	Conformably overlies Tomahawk Beds
Total 112.8	

TABLE 29. CARLO SANDSTONE IN THE NORTHEASTERN PART OF THE TOKO RANGE

Thickness (m)	
	Lateritized Carlo Sandstone overlying
6	*Quartz sandstone,* brown, laminated to thin and medium-bedded, medium-grained; well sorted, well rounded; irregularly distributed clay pellets; interbeds of *quartz siltstone,* medium-bedded; tracks and trails on bedding planes
3	*Quartz sandstone,* brown, laminated and thin-bedded, fine to very fine-grained; well sorted, well rounded; interbeds of *siltstone,* laminated; tracks and trails on bedding planes
1.5	*Quartz sandstone,* brown, thick-bedded, cross-bedded, medium-grained; well sorted, well rounded; clay pellets, clay breccia
9	*Quartz sandstone,* mottled white, yellow-brown, and purple, thin and medium-bedded, medium-grained; well sorted, well rounded; clay pellets; interbeds of *siltstone,* thin-bedded and laminated
	Rests conformably on Nora Formation
Total 19.5	

TABLE 30. CARLO SANDSTONE IN THE TARLTON RANGE

Thickness (m)	
	Mithaka Formation conformably overlying
0.2	*Quartz sandstone,* red and brown, fine to medium-grained, medium-bedded, cross-laminated; rounded, well sorted; flute casts, mud pellets, interference ripple marks
5	*Quartz sandstone,* red-brown and buff, fine to medium-grained friable, thin-bedded to laminated; rounded, well sorted; rubbly outcrop
1.5	*Quartz sandstone,* red-brown and buff, fine to medium-grained, strongly cross-bedded; rounded, well sorted
9.1	*Quartz sandstone,* red-brown and buff, fine to medium-grained, friable, laminated to thin-bedded; rounded, well sorted; rubbly outcrop
1.2	*Quartz sandstone,* red-brown and buff, fine to medium-grained, strongly cross-bedded; rounded, well sorted
3.7	*Quartz sandstone,* red-brown and buff, fine to medium-grained, friable, laminated to thin-bedded; rounded, well sorted; rubbly outcrop
0.6	*Quartz sandstone,* red-brown and buff, fine to medium-grained, strongly cross-bedded; rounded, well sorted
15.2	*Quartz sandstone,* red-brown and buff, fine to medium-grained, friable, laminated to thin-bedded; rounded, well sorted; flute casts, ripple marks, and cross-laminations on harder beds; rubbly outcrop
0.6	*Quartz sandstone,* red-brown and buff, fine to medium-grained, strongly cross-laminated; rounded, well sorted; mud pellets, interference ripple marks
	Overlying Nora Formation
Total 37.1	

TABLE 31. REFERENCE SECTION OF THE CRAVENS PEAK BEDS

Thickness (m)	
	Top of ridge
6	*Quartz sandstone,* red-brown, medium-grained, medium-bedded, cross-bedded, hard; numerous narrow silica veins
7.5	*Quartz sandstone,* red and brown, medium-grained, medium-bedded, hard; some narrow silica veins in upper 3 m
11	*Quartz sandstone,* red, medium-grained, hard; poorly exposed
13.5	*Quartz sandstone,* red, medium-grained, medium-bedded, cross-bedded; clean, friable
4.5	Concealed
13.5	*Quartz sandstone,* red, medium-grained; poorly exposed
11	*Quartz sandstone,* red, medium-grained, medium-bedded, cross-bedded; silty in part; some mud pellets
20	*Quartz sandstone,* red, medium-grained, thin to medium-bedded, cross-bedded
38	*Quartz sandstone,* red, medium-grained, medium-bedded, cross-bedded, friable; numerous large mud pellets
7.5	*Quartz sandstone,* red, coarse-grained, medium-bedded, cross-bedded, friable; thin interbeds of *quartz sandstone,* cream, medium-grained, silty
7.5	*Quartz sandstone,* red, medium to coarse-grained, thin-bedded and laminated; clean
	Base not exposed
Total 140	

TABLE 32. TYPE SECTION OF THE DULCIE SANDSTONE

Thickness (m)	
	Top of mesa
5.5	*Quartz sandstone,* white, medium-grained
1.5	*Pebble conglomerate,* poorly sorted; subangular to subrounded pebbles in matrix of mudstone, soft, white
5	Concealed
2	*Sandstone,* white, medium-grained; abundant kaolin
7	*Sandstone,* white, medium-grained, cross-bedded; abundant interstitial kaolin, sporadic pebbles
14	Concealed
6.5	*Sandstone,* white, medium-grained, strongly cross-bedded; abundant interstitial kaolin
34.5	Concealed
35	*Quartz sandstone,* poorly exposed, friable; sporadic pebbles
24.5	Concealed
28	*Sandstone,* white, medium-grained, strongly cross-bedded, kaolinitic; *Bothriolepis* sp. between 9 and 16½ m above base
3.5	*Siltstone,* white, micaceous; some *mudstone,* soft, compact, light grey
19	Concealed
7	*Sandstone,* medium-grained, kaolinitic
11.5	Concealed
9	*Pebble conglomerate,* poorly exposed, soft, kaolinitic
21	*Sandstone,* medium-grained, cross-bedded, very kaolinitic; stringers of *pebble conglomerate*
59.5	*Quartz sandstone,* white, medium-grained, friable, cross-bedded; subangular
7	*Sandstone,* light grey, medium-grained, kaolinitic
38.5	*Sandstone,* white, poorly exposed, medium-grained; abundant kaolin
3.5	*Quartz sandstone,* white, medium-grained, cross-bedded
54	Mainly concealed; a few small outcrops of *sandstone*
19	*Sandstone,* white, fine-grained, strongly cross-bedded; abundant kaolin
42.5	Mainly concealed: a few small outcrops of *conglomerate,* fine-grained
35	*Sandstone,* white, medium-grained, cross-bedded, subangular; interstitial kaolin; some stringers of *conglomerate,* fine-grained
12	*Quartz sandstone;* white, medium-grained, strongly cross-bedded; some thin stringers of coarse well rounded quartz grains
42	Concealed
10.5	*Sandstone,* white, medium-grained, strongly cross-bedded; abundant interstitial kaolin; some thin bands of *pebble conglomerate*
50	*Quartz sandstone,* white, friable, medium-grained, strongly cross-bedded
12	*Quartz sandstone,* white, well sorted, medium-grained, firm, porous, strongly cross-bedded
	Contact with underlying Nora Formation not exposed
Total 620	

TABLE 33. TYPE SECTION OF THE TARLTON FORMATION

Thickness (m)	
	Silcrete, 1 m, on top of mesa overlying
5.2	*Sandstone,* silty, coarse and medium-grained; *siltstone*
9.1	*Sandstone,* white, thin-bedded, silty, medium-grained; and *siltstone*
6.1	*Sandstone,* white, scour-and-fill, cross-laminated, very coarse, coarse, and medium-grained, silty; *conglomerate,* silty, small pebbles; and *siltstone,* thin laminated
0.9	*Claystone,* pale grey, pebbly, with a few boulders
	Overlying lateritized Ordovician siltstone
Total 21.3	

GEOLOGICAL MAP
GEORGINA BASIN
NORTHERN TERRITORY AND QUEENSLAND
AUSTRALIA

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS
1966
Compiled by K.G.Smith
Drawn by G.Matveev

Scale 1:500,000

10 0 10 20 30 MILES
10 0 10 20 30 40 50 KILOMETRES

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COMPOSITE REFERENCE
SHEETS 1–4
(Units not in strict order of super position)

CAINOZOIC	QUATERNARY	Undifferentiated	Q	*Sand, soil, alluvium, kunker, gravel*
	TERTIARY	Undifferentiated	T	*Limestone, chalcedony, sandstone, siltstone, conglomerate*
MESOZOIC	LOWER CRETACEOUS	Polland Waterhole Shale	Klp	*Shale*
		Mackunda Formation	Klm	*Arkose, siltstone*
		Wilgunya Formation	Klw	*Claystone, siltstone*
		Toolebuc Member	Klo	*Calcareous siltstone*
		Longsight Sandstone	Kll	*Sandstone*
	TRIASSIC	Tariton Formation	TrL	*Conglomerate, siltstone, sandstone*
	UNDIFFERENTIATED		M	*Sandstone, conglomerate, mudstone, siltstone*
PALAEOZOIC	PERMIAN ?	Undifferentiated	P	*Conglomerate, shale*
	UPPER DEVONIAN	Dulcie Sandstone	Dud	*Sandstone, conglomerate*
	SILURIAN – DEVONIAN ?	Cravens Peak Beds	S-Dc	*Sandstone*
	MIDDLE ORDOVICIAN	Mithaka Formation (Toko Group)	Omm	*Sandstone, siltstone*
		Carlo Sandstone (Toko Group)	Omc	*Sandstone*
		Nora Formation (Toko Group)	Omn	*Siltstone, sandstone, dolomite*
		Coolibah Formation (Toko Group)	Omc	*Limestone, dolomite, chert*
	LOWER ORDOVICIAN	Kelly Creek Formation	Olk	*Sandstone, dolomite, siltstone, coquinite*
		Swift Formation	Olw	*Siltstone, sandstone, chert, calcarenite*
	UPPER CAMBRIAN – LOWER ORDOVICIAN	Ninmaroo Formation	€-On	*Dolomite, limestone, siltstone, sandstone*
		Tomahawk Beds	€-Ot	*Sandstone, dolomite, siltstone, limestone, conglomerate*
	UPPER CAMBRIAN	Georgina Limestone	€ug	*Limestone*
		Chatsworth Limestone	€uc	*Limestone, dolomite*
		Gola Beds	€ug	*Limestone*
		O'Hara Shale	€uh	*Shale, chert, sandstone*
		Pomegranate Limestone	€up	*Limestone*
		Meeta Beds	€um	*Dolomite, chert, sandstone, limestone*
		Arrinthrunga Formation	€ua	*Dolomite, limestone, siltstone, sandstone*
		Eurowie Sandstone Member	€ue	*Sandstone*
	MIDDLE TO UPPER CAMBRIAN	Mungeretbar Limestone	€m-u	*Limestone*
	MIDDLE CAMBRIAN	Undifferentiated	€m	*Dolomite, chert, limestone*
		Selwyn Range Limestone, Devoncourt Limestone, Roaring Bore Siltstone, Steamboat Sandstone, Split Rock Sandstone	€mra	*Limestone, sandstone, shale, siltstone*
		Mail Change Limestone, V-Creek Limestone, Currant Bush Limestone, Quita Formation, Blazan Shale	€mm	*Limestone, shale, sandstone, conglomerate*
		Inca Creek Formation	€mi	*Shale, chert, limestone, siltstone*
		Age Creek Formation	€ma	*Calcarenite, dolarenite*
		Thorntonia Limestone	€mk	*Limestone, dolomitic limestone*
		Beetle Creek Formation, Border Waterhole Formation, Thorntonia Limestone	€mc	*Shale, chert, siltstone, sandstone, limestone, dolomite, conglomerate*
		Marqua Beds	€mf	*Limestone, siltstone, sandstone, shale*
		Arthur Creek Beds	€ma	*Shale, limestone, dolomite, sandstone*
		Sandover Beds	€ms	*Siltstone, shale, limestone, dolomite, sandstone, conglomerate*
		Ranken Limestone	€mk	*Limestone, chert*
		Peaker Piker Volcanics	€my	*Basalt, trachyte, sandstone*
		Burton Beds	€mr	*Siltstone, chert, limestone, coquinite, calcarenite*
		Anthony Lagoon Beds	€mn	*Dolomite, chert, limestone, sandstone, siltstone*
		Wonarah Beds	€mw	*Limestone, chert, dolomite, sandstone, shale, siltstone*
		Gum Ridge Formation	€mg	*Shale, limestone, chert*
		Camooweal Dolomite	€d	*Dolomite, chert*
	LOWER CAMBRIAN	Helen Springs Volcanics	€hv	*Basalt, sandstone*
		Bukalara Sandstone	€lk	*Sandstone, conglomerate*
		Mount Birnie Beds	€bi	*Arkose, sandstone, shale*
		Riversdale Formation	€br	*Conglomerate, sandstone, dolomite*
		Mount Baldwin Formation	€b	*Dolomite, sandstone, greywacke, shale, siltstone*
	ADELAIDEAN – LOWER CAMBRIAN	Grant Bluff Formation (Mopunga Group, Mount Baldwin Formation, Upper Formation)	Z-Cg	*Sandstone, shale, siltstone, dolomite*
		Makbat Formation (Mopunga Group, Mount Baldwin Formation, Upper Formation)	Z-Cm	*Sandstone, conglomerate*
PRECAMBRIAN	ADELAIDEAN	Elguah Formation	Zue	*Shale, siltstone, arkose*
		Mount Cornish Formation	Zuc	*Boulder beds, siltstone, arkose, dolomite*
		Central Mount Stuart Beds	Zus	*Greywacke, arkose, siltstone, sandstone*
		Sylvester Sandstone	Zuy	*Sandstone, siltstone*
		Sun Hill Arkose	Zuh	*Arkose, conglomerate, sandstone, siltstone, dolomite*
		Field River Beds	Zuf	*Boulder beds, siltstone, arkose, dolomite, quartz sandstone*
		Colles Volcanics	Zuv	*Basalt*
		Mitiebah Formation	Zui	*Sandstone*
		Mullera Formation	Zul	*Siltstone, shale, sandstone*
		Constance Sandstone	Zuk	*Sandstone, conglomerate, siltstone*
	ADELAIDEAN ?	Pilpah Sandstone	Zup	*Sandstone, conglomerate*
		Rising Sun Conglomerate	Zur	*Boulder conglomerate, sandstone*
	CARPENTARIAN	Sybella Granite	Zgs	*Granite*
		Eastern Creek Volcanics	Zve	*Metabasalt and metasediments; some schist and gneiss*
		Marraba Volcanics	Zv	*Metabasalt, tuff, metaquartzite, slate, schist, limestone*
	PROTEROZOIC		Zg	*Granite*
			Zd	*Dolerite, gabbro*
			Zp	*Porphyry*
		Kalkadoon Granite	pCk	*Granite*
		Undifferentiated	pC	*Migmatite, gneiss, schist, metaquartzite, rhyolite, dacite, basalt, quartz sandstone, conglomerate, limestone, dolomite, siltstone, shale, slate, calc-silicates, tuff, agglomerate*
	LOWER PROTEROZOIC ?	Tomkinson Creek Beds	Ptt	*Sandstone, greywacke, siltstone, shale, acid and basic lavas*
		Hatches Creek Group	Pth	*Sandstone, greywacke, siltstone, shale, acid lavas* / *Basic lavas*
		Warramunga Group	Ptw	*Siltstone, sandstone, greywacke, mudstone, shale*
	ARCHAEAN ?	Arunta Complex	Aa	*Gneiss, schist, amphibolite, metaquartzite*

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried, where concealed, boundaries and folds are dotted, faults are shown by short dashes

Geological boundary
Unconformity, section only
Anticline, showing plunge
Syncline
Monocline
Overturned syncline
Fault

Macrofossil locality
Microfossil locality
Dyke or vein

Dry oil exploration well (abandoned)
Dry oil exploration stratigraphic well (abandoned)
Well with show of gas
Well with show of oil any gas

Water bore
Abandoned water bore
Well
Windpump
Waterhole
Spring

Measured strike and dip of strata
Prevailing strike and dip of strata
Horizontal strata
Vertical strata
Overturned strata
Dip < 15°
Dip 15° to 45°
Dip > 45°
Trend line (air-photo interpretation)
Joint pattern
Dip slope
Strike and dip of foliation
Vertical foliation

Highway or road
Vehicle track
Railway
Homestead
Airport
Landing ground
Town
State boundary
Height in feet, instrument levelled

GEOLOGICAL MAP
GEORGINA BASIN
SHEET 1 — NORTH-WEST
NORTHERN TERRITORY

AUSTRALIA
1966

Scale 1:500,000

10 0 10 20 30 MILES

10 0 10 20 30 40 50 KILOMETRES

Reference

CAINOZOIC	QUATERNARY	Undifferentiated	Q — *Alluvium, gravel, soil, sand*
	TERTIARY	Undifferentiated	T — *Limestone,*
PALAEOZOIC	UPPER CAMBRIAN – LOWER ORDOVICIAN	Tomahawk Beds	€-Ot — *Sandstone, conglomerate*
	UPPER CAMBRIAN	Meeta Beds	€um — *Dolomite, chert*
	MIDDLE CAMBRIAN	Undifferentiated	€m — *Dolomite, chert, limestone*
		Anthony Lagoon Beds	€mm — *Dolomite, limestone, chert, sandstone, siltstone*
		Wonarah Beds	€mw — *Limestone, chert, dolomite, sandstone, shale*
		Gum Ridge Formation	€mg — *Shale, limestone, chert*
	LOWER CAMBRIAN	Helen Springs Volcanics	€hb — *Basalt, sandstone*
PRECAMBRIAN	ADELAIDEAN	Mittiebah Sandstone	Esl — *Sandstone*
	ADELAIDEAN ?	Rising Sun Conglomerate	Ers — *Boulder conglomerate, sandstone*
	PROTEROZOIC		Pg — *Granite*
			Pp — *Porphyry*
			Pd — *Gabbro, dolerite*
	LOWER PROTEROZOIC ?	Tomkinson Creek Beds	Etk — *Sandstone, greywacke, siltstone, shale, acid and basic lavas*
		Hatches Creek Group	Eth — *Sandstone, greywacke, siltstone, shale, acid lavas*
			Basic lavas
		Warramunga Group	Ew — *Siltstone, greywacke, shale, mudstone*

Geological boundary
Unconformity, section only
Anticline
Syncline
Fault
Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes
Measured strike and dip of strata
Prevailing strike and dip of strata
Dip > 45° (air-photo interpretation)
Trend line
Dip slope
Macrofossil locality
Dyke; q — quartz
Dry hole, abandoned; St — Stratigraphic hole
Water-bore
Abandoned water-bore
Windpump
Highway or road
Vehicle track
Town
"Kurundi" *Homestead*
Airport
Landing ground
"745' *Height in feet, instrument levelled*

Geology to 1965 by: Officers of the Bureau of Mineral Resources

Compiled 1965 by: K.G. Smith

Drawn by: G. Matveev

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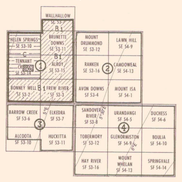

ANNUAL CHANGE 1°00'E

Geological Reliability

A Detailed mapping
B1 Numerous traverses and air-photo interpretation
C Air-photo interpretation and reconnaissance only

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Section

Quaternary omitted from section

Scale - $\frac{V}{H}$=2

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GEOLOGICAL MAP
GEORGINA BASIN
SHEET 2 — NORTH-EAST
QUEENSLAND
NORTHERN TERRITORY

AUSTRALIA
1966

Scale 1:500,000

10 0 10 20 30 MILES
10 0 10 20 30 40 50 KILOMETRES

Geology to 1965 by: Officers of the Bureau of Mineral Resources and Geological Survey of Queensland
Compiled 1965 by: K.G. Smith
Drawn by: G. Matveev

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled from 1:250,000 Series by the Division of National Mapping, Department of National Development and Royal Australian Survey Corps. Transverse Mercator Projection

Reference

CAINOZOIC	QUATERNARY	Undifferentiated	Q — *Sand, soil, alluvium, gravel*
	TERTIARY	Undifferentiated	T — *Chalcedonic limestone, dolomite, chert, siltstone.*
MESOZOIC	LOWER CRETACEOUS	Polland Waterhole Shale	Klp — *Shale*
	UNDIFFERENTIATED	Undifferentiated	M — *Sandstone, conglomerate, mudstone, siltstone*
PALAEOZOIC	UPPER CAMBRIAN	Meeta Beds	Cum — *Dolomite, chert, sandstone*
	MIDDLE CAMBRIAN	Undifferentiated	Cm — *Dolomite, chert*
		Ranken Limestone	Cmk — *Limestone, chert*
		Wonarah Beds	Cmw — *Limestone, shale, siltstone, chert*
		Peaker Piker Volcanics	Cmp — *Basalt, trachyte, sandstone*
		Burton Beds	Cmr — *Siltstone, chert, limestone, coquinite, calcarenite*
		Age Creek Formation	Cma — *Calcarenite, dolarenite*
		Thorntonia Limestone	Cmt — *Limestone, dolomitic limestone*
		Split Rock Sandstone	Cms — *Sandstone, siltstone, shale*
		Mail Change Limestone / V-Creek Limestone / Currant Bush Limestone	Cmm — *Limestone*
		Inca Creek Formation	Cmi — *Shale, chert, limestone*
		Border Waterhole Formation / Beetle Creek Formation	Cmc — *Shale, chert, conglomerate, limestone, siltstone*
		Camooweal Dolomite	Cd — *Dolomite, chert*
	LOWER CAMBRIAN	Bukalara Sandstone	Clk — *Sandstone, conglomerate*
PRECAMBRIAN	ADELAIDEAN	Colless Volcanics	*Basalt*
		Mittiebah Sandstone	Eul — *Sandstone*
		Mullera Formation	Eus — *Siltstone, shale, sandstone*
		Constance Sandstone	Euc — *Sandstone, conglomerate, siltstone*
	ADELAIDEAN ?	Pilpah Sandstone	Eul — *Sandstone, conglomerate*
	CARPENTARIAN	Sybella Granite	Epg — *Granite*
		Eastern Creek Volcanics	Epe — *Metabasalt*
	PROTEROZOIC	Undifferentiated	Eg — *Granite*
			pC — *Migmatite, gneiss, schist, metaquartzite, rhyolite, dacite, basalt, quartz sandstone, conglomerate, limestone, dolomite, shale, slate, calc-silicate, tuff and agglomerate*

- *Geological boundary*
- *Unconformity, section only*
- *Anticline showing plunge*
- *Syncline*
- *Fault*
  Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes
- *Measured strike and dip of strata*
- *Prevailing strike and dip of strata*
- *Horizontal strata*
- *Dip < 15°*
- *Trend lines* — *air-photo interpretation*
- *Joint pattern*
- *Macrofossil locality*
- *Vertebrate fossil locality*
- *Abandoned dry hole; St-stratigraphic hole*
- *Abandoned well with show of gas*
- *Water-bore*
- *Abandoned water-bore*
- *Windpump*
- *Waterhole*
- *Highway or road*
- *Vehicle track*
- *Railway*
- *Town*
- *Homestead* ("Ranken")
- *Airport*
- *Landing ground*
- *State boundary*
- *Height in feet, instrument levelled* (700')

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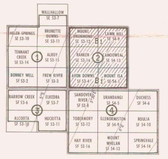
Showing Magnetic Declination



Geological Reliability

B1 Detailed reconnaissance - numerous traverses and air-photo interpretation

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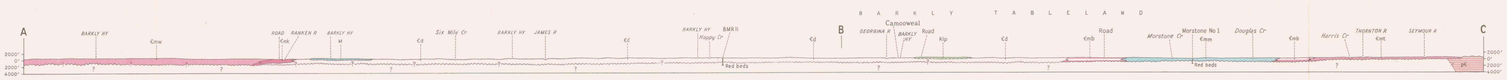
Section

Quaternary omitted from section
Scale: V/H = 2



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GEOLOGICAL MAP
GEORGINA BASIN
SHEET 3 — SOUTH-WEST
NORTHERN TERRITORY

AUSTRALIA
1966

Reference

MESOZOIC CAINOZOIC	QUATERNARY	Undifferentiated	Q	*Sand, soil, alluvium, gravel*
	TERTIARY	Undifferentiated	T	*Chalcedonic limestone, siltstone, sandstone*
	TRIASSIC	Tarlton Formation	Rt	*Conglomerate, sandstone*
PALAEOZOIC	UPPER DEVONIAN	Dulcie Sandstone	Dud	*Quartz sandstone, pebble conglomerate*
	MIDDLE ORDOVICIAN	Nora Formation	Onn	*Siltstone, sandstone*
	UPPER CAMBRIAN – LOWER ORDOVICIAN	Tomahawk Beds	€-Ot	*Sandstone, siltstone, limestone, dolomite*
	UPPER CAMBRIAN	Meeta Beds	Cum	*Dolomite, limestone, chert, sandstone*
		Arrinthrunga Formation	Cua	*Dolomite, limestone, siltstone, sandstone*
		Eurowie Sandstone Member	Cue	*Sandstone*
	MIDDLE CAMBRIAN	Arthur Creek Beds	Cma	*Shale, limestone, dolomite, quartz sandstone*
		Sandover Beds	Cmo	*Siltstone, shale, limestone, dolomite, sandstone, conglomerate*
	ADELAIDEAN – LOWER CAMBRIAN	Mopunga Group: Mount Baldwin Formation	€b	*Sandstone, greywacke, shale, siltstone, dolomite*
		Mopunga Group: Grant Bluff Formation	P-€g	*Sandstone, shale, siltstone, dolomite*
		Elguah Formation	Pue	*Shale, siltstone, arkose*
	ADELAIDEAN	Central Mount Stuart Beds	Pus	*Greywacke, arkose, siltstone, sandstone*
		Mount Conrigh Formation	Puc	*Boulder beds, siltstone, arkose, dolomite*
PRECAMBRIAN	PROTEROZOIC		Rg	*Granite*
			Rp	*Porphyry*
			Rd	*Gabbro, dolerite*
	LOWER PROTEROZOIC ?	Hatches Creek Group	Rth	*Sandstone, greywacke, siltstone, shale, acid lavas*
				Basic lavas
	ARCHAEAN ?	Arunta Complex	Aa	*Gneiss, schist, amphibolite, meta-quartzite*

Geological boundary
Unconformity, section only
Anticline, showing plunge
Syncline
Monocline
Overturned syncline
Fault
Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

Strike and dip of strata
Horizontal strata
Overturned strata
Dip < 15°
Dip 15°–45°
Dip > 45°
air-photo interpretation
Trend lines
Joint pattern
Strike and dip of foliation
Vertical foliation

Macrofossil locality
Dyke or vein

Dry well for oil
Stratigraphic well, dry — *abandoned*
Well with show of gas
Well with show of oil and gas

Water-bore
Windpump
Spring

Highway or road
Vehicle track
"Utopia" *Homestead*
Landing ground
3405' *Height in feet, instrument levelled*

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133°30′ 134°00′ 135°00′ 136°00′ 136°30′ 21°00′ 22°00′ 23°00′

25 M. Wauchope Hotel, 34 M
"Hatches Creek", 17 M
"Georgina", 108 M
"Argadargada", 12 M
Alice Springs, 120 M
Alice Springs, 110 M
Alice Springs, 140 M
Alice Springs, 150 M
234 M. Tarlton Downs, 23 M

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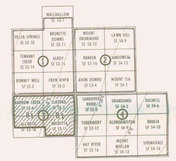
Showing Magnetic Declination



ANNUAL CHANGE 3'30"E

Geological Reliability

B1 Detailed reconnaissance – numerous traverses and air-photo interpretation

Scale 1:500,000

10 0 10 20 30 MILES
10 0 10 20 30 40 50 KILOMETRES

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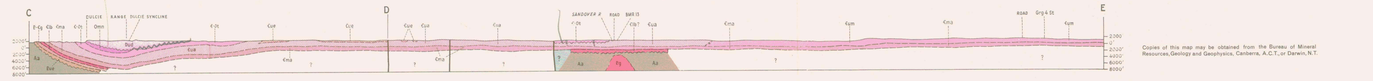
Compiled 1965 by: K.G. Smith
Drawn by: G. Matveev
Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled from 1:250,000 Series by the Division of National Mapping, Department of National Development. Transverse Mercator Projection

Sections

Cainozoic omitted from sections
Scale: $\frac{V}{H}$ = 2



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GEOLOGICAL MAP
GEORGINA BASIN
SHEET 4 – SOUTH-EAST

QUEENSLAND
NORTHERN TERRITORY

AUSTRALIA
1966

Scale 1:500,000

10 0 10 20 30 MILES
10 0 10 20 30 40 50 KILOMETRES

Geology, to 1965, by: Officers of the Bureau of Mineral Resources and Geological Survey of Queensland
Compiled, 1965, by: K.G. Smith
Drawn by: G. Matveev

Compiled and published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development. Base map compiled from 1:250,000 Series by the Division of National Mapping, Department of National Development and Royal Australian Survey Corps.
Transverse Mercator Projection

Reference

CAINOZOIC

QUATERNARY	Undifferentiated	Q	*Sand, soil, alluvium, konkar, gravel*
TERTIARY	Undifferentiated	T	*Limestone, chalcedony, sandstone, siltstone, conglomerate*

MESOZOIC

CRETACEOUS	Mackunda Formation	Kkm	*Arkose, siltstone*
	Wilgunya Formation	Klw	*Claystone, siltstone*
	Toolebuc Member	Klo	*Calcareous siltstone*
	Longsight Sandstone	Kll	*Sandstone*
TRIASSIC	Tariton Formation	Rt	*Conglomerate, siltstone, sandstone*
UNDIFFERENTIATED		M	*Sandstone*

PALAEOZOIC

PERMIAN ?	Undifferentiated		*Conglomerate, shale*
SILURIAN – DEVONIAN ?	Cravens Peak Beds	S-Dc	*Sandstone*
MIDDLE ORDOVICIAN	Mithaka Formation (Toko Group)	Omm	*Siltstone, sandstone*
	Carlo Sandstone	Omc	*Sandstone*
	Nora Formation	Omn	*Siltstone, sandstone*
	Coolibah Formation	Omo	*Limestone, dolomite, chert*
LOWER ORDOVICIAN	Kelly Creek Formation	Olk	*Sandstone, dolomite, siltstone, coquinite*
	Swift Formation	Olq	*Siltstone, sandstone, chert, calcarenite*
UPPER CAMBRIAN – LOWER ORDOVICIAN	Tomahawk Beds	€-Ot	*Sandstone, dolomite, limestone, siltstone*
	Nimmaroo Formation	€-On	*Dolomite, limestone, siltstone, sandstone*
UPPER CAMBRIAN	Georgina Limestone	€ug	*Limestone*
	Chatsworth Limestone	€uc	*Limestone, dolomite*
	Gola Beds	€ua	*Limestone*
	O'Hara Shale	€uh	*Shale, chert, sandstone*
	Pomegranate Limestone	€ug	*Limestone*
	Meeta Beds	€um	*Dolomite, chert, sandstone*
	Arrinthrunga Formation	€ua	*Dolomite, limestone, siltstone, sandstone*
MIDDLE – UPPER CAMBRIAN	Mungerebar Limestone	€m-u	*Limestone*
MIDDLE CAMBRIAN	Selwyn Range Limestone / Devoncourt Limestone / Roaring Bore Siltstone / Steamboat Sandstone / Quita Formation / Blazan Shale	€mg	*Limestone, sandstone, shale, siltstone*
		€ms	*Limestone, shale, sandstone, conglomerate*
	Inca Creek Formation	€mi	*Shale, chert, limestone, siltstone*
	Beetle Creek Formation / Thorntonia Limestone	€mc	*Shale, chert, siltstone, sandstone, limestone, dolomite*
	Marqua Beds	€mf	*Limestone, siltstone, calcareous sandstone, shale*
	Camooweal Dolomite	€d	*Dolomite with chert lenses*
LOWER CAMBRIAN	Mount Birnie Beds	€li	*Arkose, sandstone, shale*
	Riversdale Formation	€lr	*Conglomerate, sandstone, dolomite*
ADELAIDEAN – LOWER CAMBRIAN	Grant Bluff Formation	ℰ-Eg	*Quartz sandstone*
	Makbat Sandstone	ℰ-Em	*Quartz sandstone, conglomerate*
ADELAIDEAN	Sylvester Sandstone	Eslg	*Sandstone, siltstone*
	Sun Hill Arkose	Esh	*Arkose, conglomerate, sandstone, siltstone, dolomite*
	Field River Beds	Euf	*Boulder beds, siltstone, arkose, dolomite, quartz sandstone*

PRECAMBRIAN

CARPENTARIAN	Sybella Granite	Pgs	*Granite*
	Eastern Creek Volcanics	Pze	*Metabasalt and metasediments; some schist and gneiss*
	Marraba Volcanics	Pzu	*Metabasalt, tuff, metaquartzite, slate, schist, limestone*
PROTEROZOIC		Pg	*Granite*
	Kaikadoon Granite	pCk	*Granite*
	Undifferentiated	pC	*Migmatite, gneiss, schist, metaquartzite, rhyolite, dacite, basalt, quartz sandstone, conglomerate, limestone, dolomite, siltstone, shale, slate, calc-silicates, tuff, and agglomerate*
ARCHAEAN ?	Arunta Complex	An	*Gneiss, schist, metaquartzite*

- *Geological boundary*
- *Unconformity, section only*
- *Anticline showing the plunge*
- *Syncline*
- *Monocline*
- *Fault*
  Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes
- *Measured strike and dip of strata* (e.g. 20)
- *Prevailing strike and dip of strata*
- *Horizontal strata*
- *Vertical strata*
- *Dip < 15°*
- *Trend lines* (air-photo interpretation)
- *Joint pattern*

- *Dry oil exploration well* (abandoned)
- *Dry oil exploration stratigraphic well* (abandoned)
- *Water bore*
- *Abandoned water-bore*
- *Well*
- *Windpump*
- *Waterhole*
- *Spring*

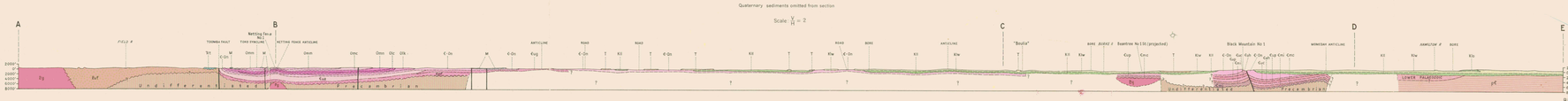
- *Highway or road*
- *Vehicle track*
- *Railway*
- *Homestead*
- *Landing ground*
- *State boundary*
- *Height in feet, instrument levelled* (e.g. 700')

- *Macrofossil locality*
- *Microfossil locality*

Sections

Quaternary sediments omitted from section

Scale: V/H = 2



INDEX TO ADJOINING SHEETS and 1:250,000 GEOLOGICAL SERIES

Showing Magnetic Declination

ANNUAL CHANGE 2' E

Geological Reliability

B1 Detailed reconnaissance - numerous traverses and air-photo interpretation

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. and Darwin, N.T. or the Geological Survey of Queensland, Brisbane

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