1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

MUNRO
WESTERN AUSTRALIA

SHEET SE/51-14 INTERNATIONAL INDEX

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

DEPARTMENT OF MINES, WESTERN AUSTRALIA
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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COMPILED BY R. R. TOWNER

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA 1982

DEPARTMENT OF NATIONAL DEVELOPMENT & ENERGY

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

ISBN 0 644 01771 6

Printed by Graphic Services Pty Ltd., 516-518 Grand Junction Road, Northfield, S.A. 5085

Explanatory Notes on the Munro Geological Sheet

Compiled by R. R. Towner

The Munro 1:250 000 Sheet area lies between latitudes 19° and 20°S and longitudes 121°30′ and 123°E, in the north of Western Australia. The Sheet area covers part of the western edge of the Great Sandy Desert (Warburton, 1875). It contains scattered inliers of Mesozoic rocks in Cainozoic superficial sediments, and is part of the Phanerozoic Canning Basin.

Main access to the Sheet area is by the partly-sealed and maintained Great Northern Highway which connects Port Hedland in the south with Broome in the north. Access within the area is either by station tracks, which are confined to the northwestern part of the Sheet area, or minor company roads which connect the petroleum exploration wells drilled in the area with stations located either within the Sheet area or in the adjacent Mandora Sheet area to the west. None of these company roads is maintained. The station tracks and parts of the main road are at times impassable during the wet season.

The only permanently inhabited homestead in the area is Nita Downs; a research station at Talgarno is abandoned. Both have light-aircraft landing grounds.

The climate is semi-arid monsoonal, characterised by a warm, dry winter and a hot, wet summer. As there are no meteorological stations within the Sheet area, climatic data has to be inferred from peripheral stations. The annual rainfall is extremely variable and probably averages less than 300 mm, the heaviest falls occurring between November and March, the cyclonic period. The annual evaporation rate is approximately 2500 mm. The average daily minimum and maximum temperatures are about 24° and 35°C in January, and 15° and 26°C in July (Commonwealth Statistician, 1978). The prevailing winds are from the east and southeast.

The Sheet area falls within two distinct regions, each having a characteristic landscape and associated vegetation. The coastal strip is part of the Northern Botanical Province, and the remainder of the Sheet area lies within the Canning Botanical District (Beard, 1969). The floras of these two areas are described by Beard (1969) and Beard & Webb (1974). The sparse vegetation of the Canning Botanical District consists mainly of small eucalypts, desert Walnuts, Acacia shrubs, and spinifex grass. The flanks of dunes are normally thickly vegetated with spinifex hummocks and sparse shrubs, but the crests are commonly bare and subject to wind action.

The Northern Botanical Province is characterised by pindan and a thin strip of grass savanna. Pindan is essentially a grassland wooded by a sparse upper layer of trees and a dense thicket of phyllodal acacias forming a middle layer (Beard, 1969). The savanna occurs mainly on silty and clayey soil on the coastal plain between the coastal dunes and the pindan-covered higher ground. The grasses are perennial but strongly seasonal in their growth, flowering during the rainy season but becoming dry during the dry season. Small prostrate succulent plants or 'samphires', together with teatree scrub are generally present especially around claypans northwest of West Australian Petroleum Pty Ltd (WAPET) Munda 1 well, and along the southern part of the Sheet area.

A detailed study of the vegetation of the coastal fringe, particularly in the section along Eighty Mile Beach, has been made by Burbidge (1944).

History of Investigations

The earliest exploration of the Munro Sheet area was by Alexander Forest in 1879, who travelled along the coast in the northwestern corner of the Sheet area on his way from the De Grey River (Port Hedland Sheet area) to Darwin (Feeken & others, 1970).

Surface geology. In 1954, WAPET carried out a traverse from Anna Plains Homestead, in the Mandora Sheet area to the west, to McLarty Hills, in the McLarty Hills Sheet area to the east.

Review accounts of the geology of the entire Canning Basin, which includes the Munro Sheet area, have been made by Veevers & Wells (1961), McWhae & others (1958), and Playford & others (1975).

Magnetics. During 1954, BMR flew a reconnaissance aeromagnetic survey of the Canning Basin; one flight-traverse crossed the Sheet area (Quilty, 1960). In the same year, WAPET flew a semi-detailed aeromagnetic survey of the coastal Canning Basin, involving the Munro Sheet area (unpublished WAPET report, on microfilm at the Geological Survey of Western Australia (GSWA), Perth). The only other magnetic survey involving this Sheet area was the South Canning Aeromagnetic Survey, conducted by Aero Services Ltd for WAPET in 1962–3, which included the southeastern part; the results indicated that the depth-to-basement in this region is generally 1700 m to 3300 m below sea level (WAPET, 1963).

Gravity. Early gravity surveys in the Sheet area by BMR, and incorporating unpublished data from the 1954–55 WAPET gravity surveys along the coast, were synthesised by Flavelle & Goodspeed (1962), and Flavelle (1974). Later, more detailed gravity work carried out by WAPET in 1963–64 (WAPET, 1964a) and French Petroleum Company (Australia) Pty Ltd in 1967 (French Petroleum, 1967a, 1967b) involved the adjacent Sheet areas to the northeast, east, and southeast, and included a small portion along the eastern boundary of the Munro Sheet area. The results of these surveys were confined to the adjacent Sheet areas.

In 1967, the Munro Arch Gravity Survey was conducted for WAPET by Wongela Geophysical Pty Ltd. The survey objectives were to evaluate the stratigraphy and structure of the 'Munro Arch' area which separated the 'Joanna Spring Sub-basin' and the 'Parda Sub-basin' (features defined from areomagnetic data). Data from this survey, together with other available geological and geophysical information from adjacent areas, have resulted in sedimentary depressions, faults, and basement-high areas being interpreted. Seismic work and follow-up drilling was recommended to enable more information to be obtained for a better quantitative appraisal of these data (WAPET, 1967).

The gravity contours that are displayed on the accompanying map are based on survey data by Wongela in 1968 processed by Darby & Fraser (1969), and by Wongela in 1969 processed by Fraser (1974), together with revision of the earlier work of Flavelle & Goodspeed (1962) by Darby & Vale (1969). The nomenclature of the various gravity provinces used here and on the map is the revised version of Fraser (1976). The gravity contours outline parts of two gravity provinces; the Munro Regional Gravity Platform, and the Anketell Regional Gravity Ridge.

Seismic. In the period 1956–58, WAPET conducted some semi-detailed seismic surveys in the west of the Sheet area that helped to delineate the regional structural framework (unpublished WAPET data on microfilm at GSWA).

The Parda Seismic Reconnaissance Survey (WAPET, 1964b), the first survey in the area to be subsidised under the Petroleum Search Subsidy Act, was located east of Frazier Downs and Nita Downs Homesteads on southern La Grange and northern Munro Sheet areas. Its objectives were to investigate a possible sedimentary basin as interpreted from aeromagnetic data, to determine the significance of the Bouguer Gravity maximum trends, and finally, to indicate a drilling location to test the pre-Permian stratigraphy. The seismic data were considered generally reliable and the results showed the existence of a basin with at least 3000 m of sediments.

The reflection seismic survey of the Willara Hill Project was conducted by WAPET in March-April 1966 adjacent to the coast on southern La Grange and northern Munro Sheet areas. Its purpose was to ascertain the regional dip of the northwestern half of the 'Admiral Bay' fault, to investigate geophysical anomalies, and to locate a drill site on the Willara Hill Structure in the Admiral Bay fault zone, but further seismic work is required to define them accurately (WAPET, 1966a).

The objective of the Nita-Willara Seismic Survey (WAPET, 1966b) was to locate a shallow well site proposed on structure near Nita Downs Homestead, the drilling target being the Permian Grant Group. A possible drilling site was developed and two new structures were suggested for further seismic investigations.

The Munro Arch Seismic Survey (WAPET, 1969a), located on Munro and northern Anketell Sheet areas, was conducted by Geophysical Service International for WAPET in 1969. The first objective was to confirm that a structurally-high area exists between the Willara and Kidson Sub-basins as suggested by gravity and aeromagnetic data. The second objective was to define the trend of the faulted hinge-line ('Admiral Bay Hingeline') that forms the boundary between the Willara Sub-basin and the Broome Arch. Seven lines were shot, five east-west and two north-south. Three horizons were mapped: Horizon A, within the Permian upper Grant Group; Horizon B, within the Ordovician Goldwyer Formation; and Horizon C, within the Ordovician Thangoo Limestone. A structurally-high area trending north-south was mapped to the west of its predicted position. Since this high area is of less magnitude than that indicated by aeromagnetic data, it was considered that the seismic survey had failed to confirm the existence of the Munro Arch (but see below). The results also indicated that the Admiral Bay Fault is more likely to continue across the area in an easterly direction rather than swing to the south as suggested by earlier aeromagnetic and gravity interpretation.

The primary objective of the Munro R–1 Seismic Survey (WAPET, 1969b) was to more clearly outline the configuration of the Willara Sub-basin. The secondary objective was to investigate the manner in which the sedimentary section overlaps the Anketell Regional Gravity Ridge. Two lines were shot, with three horizons being identified: Horizon A, within the Permian Grant Group; Horizon B, within Ordovician Goldwyer Formation; and Horizon C, within the Ordovician Thangoo Limestone (Willara Formation equivalent). An isopach map of the interval between Horizons A and B was prepared. Four lines from the Munro Arch seismic survey were incorporated in the mapping. The results confirmed a basement ridge corresponding to the Anketell Regional Gravity Ridge but added little to the knowledge of the configuration of the Willara Sub-basin.

The Broome-Samphire Seismic Survey (WAPET, 1971a) provided regional reconnaissance control over an area extending from the Samphire Embayment in the south to the northern part of the Broome Arch. Two seismic horizons were mapped in the northern portion and four in the south. The results of the survey provided reliable data that could be carried across the Broome Arch and the Willara Sub-basin to the Anketell Ridge (now Anketell Shelf) where the stratigraphic section thinned markedly.

The Munro Detailed Seismic Survey (WAPET, 1971b) was carried out in early 1971 in the southeastern section of the Willara Sub-basin. The objectives were to delineate the Munro Structural Trend (Munro Arch), and the Munro Fault, and to site a well. The three horizons mapped were identified as near the top of the Cuncudgerie Sandstone (now the Grant Group), the Goldwyer Formation (Ordovician), and the Willara Formation (Ordovician). The best data were obtained from the Goldwyer Formation. The data from this survey were integrated with approximately 480 line-kilometres of data from earlier surveys in the area. The two structures under investigation were identified on the Ordovician horizons. The Munro Fault was defined as a northwesterly-trending normal fault, down-thrown to the southwest, and diminishing in magnitude to the northwest. Sediments younger than the Goldwyer Formation do not appear to be affected by the faulting which was apparently active throughout Ordovician times. The Munro Arch was proposed as an elongate northwest-trending anticline with a number of postulated separate culminations on the upthrown side of the fault.

The Munro D–2 Survey (WAPET, 1971c) was conducted in 1971 to confirm the closure on the Munro Arch, and to investigate a strong gravity-maxima trend situated to the east of it. Data quality of the three horizons mapped was generally fair. The survey supported an elongated northwest-southwest anticlinal structure along which four separate culminations were defined, two of which were recommended as well locations. The structure as a whole is closed to the northeast by the regional dip and to the southwest by the Munro Fault. WAPET Munda 1 was sited on one of these culminations.

During 1972 to 1977, the BMR Basin Studies Group, in the reinterpretation of the seismic data in the Canning Basin, recognised ten closed structures within the Sheet area (Gorter & others, 1979).

Drilling. Four petroleum exploration wells have been drilled in the Munro Sheet area: WAPET Willara 1 (WAPET, 1965b), WAPET Willara Hill 1 (WAPET, 1968), WAPET Munda 1 (WAPET, 1971d), and WAPET Munro 1 (WAPET, 1972) (see ECONOMIC GEOLOGY).

Aerial photographs and maps. Aerial photographs, one set at 1:48 000 scale flown in 1949, and the other at 1:80 000 flown in 1967, cover the Sheet area and are obtainable from the Division of National Mapping, Canberra, and the Department of Lands and Surveys, Perth.

A topographic base map at a scale of 1:250 000 (Munro SE/51-14, Edition 1, Series R502) compiled in 1957 by the Department of Lands and Surveys, Western Australia from 1949 aerial photography and with field revision in 1965, is also available from the same sources.

Latest investigations. In 1977 geologists from BMR and GSWA mapped the Munro Sheet area and the surrounding Sheet areas as part of a survey in the western Canning Basin which was carried out mainly by helicopter and vehicular traverses (Towner & Gibson, 1980).

PHYSIOGRAPHY

The Munro Sheet area is characterised by one dominant physiographic unit — sand plains and dunes (Fig. 1). Other minor physiographic units include scattered hills and mesas, laterite rises, claypans, and the coastal plain. The form lines shown on the physiographic map (Fig. 1) have been compiled using widely spaced elevation information from BMR gravity station heights. The elevation varies from about 192 m above sea level in the southeast to less than 25 m in the northwest.

There are no permanent watercourses in the Munro Sheet area, although the claypans retain water after heavy rain. Creeks drain into a large claypan in the southwestern corner of the Sheet area but these dry up during the hot, dry summers. Small ephemeral streams meander across the coastal plains.

Sand plains and sand dunes

Sand plains occur across the whole Sheet area, except in the far northwestern corner. Associated with them are elongate longitudinal dunes (seifs) with a predominant east-west trend and which have a wide range in length, separation, and

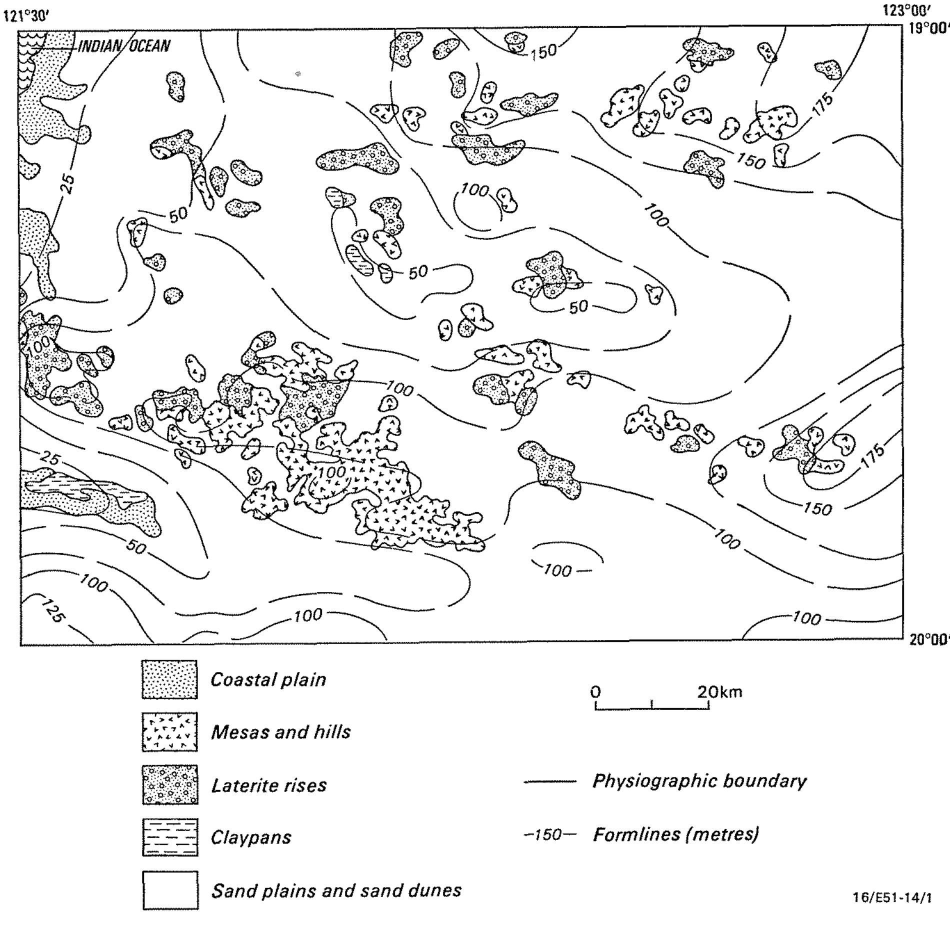

Fig. 1. Physiography.

complexity. The dunes continue unbroken over most of the low topographic rises. They were formed by prevailing easterly winds. Simple longitudinal dunes are the most common, though net-like and chain dunes occur in depressions (Crowe, 1975).

Laterite rises

Small remnants of a laterite-floored plain occur scattered over the Sheet area, and are characterised by smooth, pisolite-strewn rises (Czs) and in places by a thin blanket of red sand, or longitudinal sand dunes (Qz).

Mesas and hills

Isolated mesas and hills up to 10 m high are present throughout the area, but are dominant in the south and southwest of the Sheet area. Low breakaways have formed, mainly in the west and northwest, where erosion has cut through the laterite crust into the underlying deeply-weathered rock.

Weathered outcrops not capped by laterite occur as scattered small rises between the sand dunes.

Claypans

The claypans are flat areas underlain by hard sandy clay, and some contain gypsum. Saltbush, grasses, teatrees, and eucalypts are present along margins of the claypans. The claypans are confined to the centre and in the southwestern corner of the Sheet area.

Coastal plain

The coastal plain forms a continuous fringe 2 to 15 km wide. Small salt pans, clay flats (Qci), or thickly-grassed supratidal flats (Qcs) form swales between and behind the subparallel systems of beach and sand-ridges (Qpb). The beach ridges rise up to 5 m above the beach; inland they are covered with low, thick scrub, but those towards the coast support poorer vegetation, perhaps because they are younger. The present beach is sandy, but mud flats are exposed at low tide; tidal mega-ripples parallel the shore. The supratidal flats commonly support halophytic plants and rare patches of mangroves.

STRATIGRAPHY

The stratigraphy of the Sheet area is summarised in Table 1 and described briefly below. Cainozoic terrestrial units up to about 30 m thick blanket much of the area. Units older than the Late Jurassic to Early Cretaceous(?) Callawa Formation do not crop out, and information on them comes from the four petroleum exploration wells drilled in the Sheet area. The geological cross-sections have been compiled largely from information from these wells, together with depth-to-seismic-reflector information from some of the seismic surveys (WAPET, 1971b, 1971c).

PRECAMBRIAN

Precambrian basement rocks are shown in the cross-section. Their nature is unknown. WAPET Munro 1 bottomed in granite (WAPET, 1972) and WAPET Parda 1 (8 km north of the Sheet area) bottomed in gneiss and schist (WAPET, 1965a).

TABLE 1. STRATIGRAPHY OF MUNRO SHEET AREA

	Age	*Rock unit and symbol*	*Estimated thickness (m)*	*Lithology*	*Stratigraphic relationship*	*Remarks*
CAINOZOIC	Quaternary	Qa	3	Sand, silt, clay; minor gravel		Unconsolidated alluvial deposits
		Ql	5	Clay, silt, sand; minor gypsum		Claypans
		Qs	5	Sand, silt; minor gravel		Mixed alluvial and aeolian deposits
		Qz	10+	Red quartz sand, fine to medium-grained; minor silt		Aeolian sand in dunes and sand plains; occurs throughout the area
		Qcs	10±	Clay, silt, sand, minor salt	Superficial deposit	Supratidal mud flat deposits
		Bossut Formation Qpb	10±	Quartzose calcarenite, fine to coarse calcilutite; partly oolitic, cross-bedded	Unconformable on Kp, underlies and interfinger with Qcs, Qci	Shoreline beach ridge deposits; fossiliferous
		Qci	5±	Silty clay, black organic clay, minor salt	Superficial deposit	Tidal flat and mangrove swamp deposits
		Czk	3	Calcrete, minor chalcedony		Evaporitive, pedogenic
		Czs	2	Sand, silt, ferruginous gravel and pisoliths, clay		Gravel plains overlying Czl; pedogenic
		Czl	3	Laterite, pisolitic or massive		Upper part of lateritic weathering profile; pedogenic; well developed on Kp
MESOZOIC	Early Cretaceous	Frezier Sandstone Kf	0–20±	Sandstone, fine to coarse, feldspathic, poorly sorted; poorly bedded, remnant cross-bedding; minor conglomerate	Disconformable on Kp; disconformable on Kb; top eroded	Forms small dark hills on air-photographs; fluvial to deltaic, partly pedogenic
		Parda Formation Kp	0–10±	Mudstone, minor fine sandstone lenses, thin-bedded or massive	Disconformable on Kb, JKc; disconformable beneath Kf	Lagoonal(?)
		Broome Sandstone Kb	20–265±	Sandstone, fine to medium, well sorted; mudstone in part; minor conglomerate; ripple-marked, cross-bedded; minor bioturbation	Disconformable beneath Kp; conformable on JKr; possibly laterally equivalent to JKc	Outcrops in NE and SW Munro Sheet area; plant fossils; shallow marine

TABLE 1. STRATIGRAPHY OF MUNRO SHEET AREA *(continued)*

	Age	*Rock unit and symbol*	*Estimated thickness (m)*	*Lithology*	*Stratigraphic relationship*	*Remarks*
MESOZOIC	Late Jurassic to Early Cretaceous(?)	Callawa Formation JKc	0–20±	Sandstone, very fine to coarse; conglomerate; cross-bedded; minor siltstone	Disconformable or possibly unconformably on JKr; disconformable beneath Kp; possibly laterally equivalent to Kb	Outcrops in W. Munro; outcrops in adjacent Mandora and Anketell Sheet areas; possibly confined to SW Munro Sheet area; plant fossils; fluvial
		Jarlemai Siltstone JKr	20–200±	Mudstone, sand, glauconitic	Conformable between Ja and Kb; disconformable or possibly unconformable beneath JKc	Subsurface only; intersected in all petroleum exploration wells drilled in Munro Sheet area; fossiliferous; marine
	Late Jurassic	Alexander Formation Ja	15–60±	Sandstone, fine to medium; interbedded mudstone; bioturbated	Conformable between Jl and JKr	Subsurface only; intersected in all petroleum exploration wells drilled in Munro Sheet area; fossiliferous; shallow marine
	Early(?) to Late Jurassic	Wallal Sandstone Jl	50–500±	Sandstone; minor siltstone, conglomerate	Unconformable on Pn, Pp, Pg; conformable beneath Ja	Subsurface only; intersected in all petroleum exploration wells drilled in Munro Sheet area; palynomorphs; probably paralic
				UNCONFORMITY		
	Early Permian	Noonkanbah Formation Pn	110	Mudstone, calcareous, micaceous; fine sandstone and limestone interbeds	Conformable on Pp, unconformable beneath Jl	Subsurface only; intersected in WAPET Munro 1; fossiliferous; marine
		Poole Sandstone Pp	85	Sandstone, very fine to fine; interbedded mudstone; thin-bedded; clay pellet lenses	Disconformable on Pg; conformable beneath Pn; unconformable beneath Jl	Subsurface only; intersected in WAPET Munro 1; shallow marine
		Grant Group Pg	500–1000±	Sandstone, fine to coarse; mudstone; minor conglomerate	Unconformable on Sc, On, Oo, Ow, Ot; disconformable beneath Pp; unconformable beneath Jl	Subsurface only; intersected in all petroleum exploration explanation wells drilled in Munro Sheet area; glacial marine
				UNCONFORMITY		

TABLE 1. STRATIGRAPHY OF MUNRO SHEET AREA *(continued)*

	Age	*Rock unit and symbol*	*Estimated thickness (m)*	*Lithology*	*Stratigraphic relationship*	*Remarks*
PALAEOZOIC	Late Ordovician(?) to Early Devonian	Carribuddy Formation Sc	150–1000±	Dolomite, dolomitic siltstone, shale, halite, anhydrite; minor sandstone	Disconformable on On; unconformable beneath Pg	Subsurface only; intersected in all petroleum exploration wells drilled in Munro Sheet area; mainly non-marine
	Middle Ordovician	Nita Formation On	0–150±	Dolomite, limestone; minor interbedded shale	Conformable on Oo; disconformable beneath Sc; unconformable beneath Pg	Subsurface only; intersected in WAPET Willara 1 and WAPET Munro 1; marine
		Goldwyer Formation Oo	0–750±	Shale, black, fossiliferous, calcareous, pyritic; interbedded limestone, dolomite; minor siltstone lenses	Conformable between On and Ow; unconformable beneath Pg	Subsurface only; intersected in WAPET Willara 1 and WAPET Munro 1; marine
	Early Ordovician	Willara Formation Ow	0–750±	Limestone, dolomitic, fossiliferous; interbedded shale and siltstone	Conformable between Oo and Ot; unconformable beneath Pg	Subsurface only; intersected in WAPET Willara 1 and WAPET Munro 1; marine
		Nambeet Formation Ot	0–800±	Shale, grey to green, interbedded limestone, dolomite and fine sandstone	Unconformable on pЄ; conformable beneath Ow; unconformable beneath Pg	Subsurface only; intersected in WAPET Willara 1 and WAPET Munro 1; marine
				UNCONFORMITY		
	PRE-CAMBRIAN	pЄ	Unknown	Igneous, metamorphic, and sedimentary rocks	Basement rocks to Canning Basin	Section only (granite in WAPET Munro 1 well)

PALAEOZOIC

Ordovician

Ordovician rocks are present in WAPET Munro 1 and WAPET Willara 1. The following marine units are recognised (Gorter & others, 1979; Playford & others, 1975); they occur throughout much of the Canning Basin and extend across almost the whole of the Munro Sheet area.

The *Nambeet Formation* (Ot; Johnstone *in* WAPET, 1961a) is the oldest known unit in the Canning Basin. It contains an Early Ordovician or possibly Late Cambrian fauna in the Mandora Sheet area to the west (Gilbert-Tomlinson, *in* WAPET, 1961a) but is of Early Ordovician age in the Munro Sheet area, based on palynomorphs and conodonts (McTavish & Dolby *in* WAPET, 1972).

The overlying *Willara Formation* (Ow; McTavish *in* Playford & others, 1975) is probably also Early Ordovician, but may extend into the middle Ordovician.

The *Goldwyer Formation* (Oo; Elliot, *in* WAPET, 1961b) overlies the Willara Formation, and is of middle Ordovician age (McTavish & Dolby *in* WAPET, 1972).

The *Nita Formation* (On; McTavish *in* Playford & others, 1975) is probably of late middle Ordovician age (Balme *in* Total, 1968).

Late Ordovician(?) to Early Devonian

Disconformably overlying the Nita Formation is the mainly non-marine *Carribuddy Formation* (Sc; Koop, 1966a, 1966b). It is present in WAPET Munda 1 between 800.4 m and 1066.8 m (total depth of the well); it is 329 m thick in WAPET Munro 1 and 472 m thick in WAPET Willara 1. Massive halite is predominant in WAPET Munda 1. The age of the Carribuddy Formation is poorly known; information from outside the Sheet area suggests Early Devonian, but it may range down into the Late Ordovician (Total, 1968). Within the Sheet area, it is unconformably overlain by the Grant Group.

Permian

The subsurface, marine *Grant Group* (Pg; Guppy & others, 1952; 1958; Crowe & Towner, 1976) lies with regional unconformity on the Carribudy Formation and earlier rocks. This unconformity is an excellent seismic reflector. The group is 379.5 m thick in WAPET Munda 1, 772.0 m thick in WAPET Willara 1, 485.8 m in WAPET Munro 1 and was penetrated in WAPET Willara Hill 1. Crowe & Towner (1976) defined three formations within the Grant Group: the lower Betty Formation (fine to coarse sandstone with basal conglomerate); the middle Winifred Formation (mudstone); and the upper Carolyn Formation (sandstone). WAPET Willara 1 and WAPET Munro 1 intersected rocks that probably belong to the lower unit, the Betty Formation. The upper unit, the Carolyn Formation, is absent from WAPET Willara 1 and WAPET Munda 1, probably because of erosion.

The shallow-marine *Poole Sandstone* (Pp; Guppy & others, 1952) overlies the Grant Group disconformably, although the time gap between the two units is small. The Poole Sandstone is present only in WAPET Munro 1 where it is 85 m thick. It is present in Total Kemp Field 1 to the southeast but absent in Total McLarty 1 to the east, suggesting that the Poole Sandstone is mainly confined to south-eastern part of the Munro Sheet area. Palynomorphs recorded from cores and cuttings in wells indicate an Early Permian age for the Poole Sandstone.

The presence of the marine *Noonkanbah Formation* (Pn; Wade, 1938; Guppy & others, 1952) in WAPET Munro 1 only, where it is 110 m thick, as well as its presence in Total Kemp Field 1 and its absence in Total McLarty 1, suggest that this formation may also be restricted to the southeastern part of the Sheet area. Microflora from the unit in wells just outside the Sheet area indicate an Early Permian (Artinskian) age for the formation (Total, 1968).

MESOZOIC

Early(?) to Late Jurassic

The paralic to continental *Wallal Sandstone* (J1; McWhae *in* WAPET, 1961a), which does not crop out, is the basal unit of the Jurassic succession in the western Canning Basin. It is 370 m thick in WAPET Munro 1, 227.1 m thick in WAPET Willara 1, 151.8 m thick in WAPET Munda 1, and 237.1 m thick in WAPET Willara Hill 1. The unit has been dated as probably Early(?) to Late Jurassic (Toarcian to Oxfordian) from the abundant microflora and microfauna; it contains a little coal. The Wallal Sandstone unconformably overlies the Permian Noonkanbah Formation, Poole Sandstone and Grant Group. The top of the sandstone is conformable beneath the Alexander Formation.

The shallow-marine *Alexander Formation* (Ja; Brunnschweiler, 1954) does not crop out, but has been penetrated in all the petroleum exploration wells in the Sheet area. The formation conformably overlies the Wallal Sandstone and is conformably overlain by the Jarlemai Siltstone. The unit has been dated as Late Jurassic (late Oxfordian) by a rich macroflora in the exposures in the northeastern part of the Mount Anderson Sheet area, and by microflora in well cores and cuttings.

Late Jurassic to Early Cretaceous(?)

The shallow-marine *Jarlemai Siltstone* (JKr; Brunnschweiler, 1954) does not crop out but has been intersected in all the petroleum exploration wells within the Sheet area. It thickens northwestwards from 27 m in WAPET Munro 1 to 82 m in WAPET Willara Hill 1. The sand content of the siltstone increases upwards. Fossils in the unit indicate a Late Jurassic (late Oxfordian to Tithonian) age, but it may range into the Early Cretaceous (Towner & Gibson, 1980). It lies conformably between the Alexander Formation and the Broome Sandstone, and disconformably or possibly unconformably beneath the Callawa Formation.

The oldest Mesozoic unit to crop out in the Sheet area is the fluvial *Callawa Formation* (JKc; Traves & others, 1956) which is exposed in small hills in the west. It disconformably or possibly unconformably overlies the Jarlemai Siltstone, and is disconformably overlain by the Parda Formation; it possibly grades laterally into the Broome Sandstone. Plant fossils in the formation have been assigned Late Triassic or Early Jurassic (Brunnschweiler, *in* Traves & others, 1956) and Late Jurassic or Early Cretaceous (White *in* Veevers & Wells, 1961) ages; the Late Jurassic or Early Cretaceous age is the more likely as the underlying Jarlemai Siltstone is of Late Jurassic age. An incomplete section of less than 5 m is exposed.

Early Cretaceous

The shallow marine *Broome Sandstone* (Kb; Reeves, 1951; amended Brunnschweiler, 1957) crops out in small hills in the northeast, east, and south of the

Sheet area. It is the first consolidated rock unit in which all the exploration wells spudded. The formation thickens northwestwards from possibly less than 5 m in the vicinity of WAPET Munro 1 to 265.2 m in WAPET Willara Hill 1. The sandstone overlies the Jarlemai Siltstone conformably and is overlain disconformably by the Parda Formation. It possibly grades laterally into the Callawa Formation. The Broome Sandstone is possibly overlain by the Frezier Sandstone in the east (see diagrammatic relationship of rock units on the accompanying map), but poor outcrop renders this relationship hypothetical. Plant fossils, dinosaur footprints (Colbert & Merrilees, 1967), and microflora from the unit elsewhere in the Canning Basin indicate an Early Cretaceous (possibly Neocomian) age.

The lagoonal *Parda Formation* (Kb; McWhae & others, 1958) crops out beneath laterite in the northwestern half of the Sheet area. It is probably of Aptian age, since it occurs between rocks of probable Aptian age (Towner & Gibson, 1980). The formation lies disconformably on the Callawa Formation and the Broome Sandstone. At Karrobridill Hill, the Parda Formation interfingers with the overlying Frezier Sandstone, indicating possible rapid changes in the depositional environment in this area. The thickness of the Parda Formation in the Sheet area is unknown but up to 5 m crops out.

The continental *Frezier Sandstone* (Kf; Lindner & Drew *in* McWhae & others, 1958) rests disconformably on the Parda Formation and the Broome Sandstone. The unit crops out as low hills of black, strongly ferruginised rocks mainly in the southern half of the Sheet area. It has tentatively been dated as Aptian by Dickins (*in* Veevers & Wells, 1961) from rare bivalves collected outside the Sheet area. The Frezier Sandstone is probably a fluvial to deltaic deposit which in places has been subjected to pedogenic processes. The thickness of the unit is not known but up to 20 metres is exposed in some localities.

CAINOZOIC

Surficial rock and soil units, the products of weathering in arid and humid climates, cover most of the Sheet area. The coastal fringe of the area was intermittently submerged, and a variety of coastal sediments has accumulated. Many of the Cainozoic units depicted on the map commonly grade into one another. The boundaries between them are approximate as their recognition on the aerial photographs is based on subtle differences in photo tone arising from topographic position and expression, and vegetation cover.

Hard crusts of pisolitic or massive *laterite* (Czl), from 1 m to 3 m thick, or ferruginous duricrusts, are widespread, forming low rises and breakaways; laterite is often well developed over the Parda Formation. Weathering of the laterite crust has produced a smooth plain capped by *residual soil* (Czs) composed of ferruginous pisoliths, sand, and minor clay.

Calcrete (Czk) is exposed as low rises and rubble between sand dunes in some areas; it is thought to have resulted from water-table movements associated with the wet and dry seasons, and the resulting precipitation of calcium carbonate.

A small area of *intertidal sediments* (Qci) is present in the northwestern corner of the Sheet area.

The *Bossut Formation* (Qpb; Lindner *in* WAPET, 1961a) includes lithified dunes, beach, and offshore-bar deposits. It underlies and interfingers with the Holocene silt and sand of the tidal flats, and overlies the Parda Formation. It crops out discontinuously as beach ridges that parallel the coast. The beach ridges range in height from 2 to 5 m above sea level, and are well defined near the coast, and more subdued inland. The formation contains coral, foraminifera, and shell fragments.

The *supratidal flats* (Qcs) occupy an extensive area in the coastal part of the Sheet area. The flats are fringed landwards by low cliffs of aeolian sands, and are bounded seawards by the coastal dunes of the Bossut Formation. After heavy rains, particularly during the wet season, small claypans are formed on these supratidal flats. The flats are covered by grasses, samphires, and clumps of small wooded areas. The sediments are characteristically grey-mud, with minor amounts of coarse particles being present including quartz grains, pebbles, and laterite nodules.

The most widespread Quaternary unit is *aeolian sand* (Qz). This occurs as longitudinal seif dunes over much of the Sheet area, and as sand sheets, mainly in the northwest. The thickness of the sand dunes varies from 2 m to 5 m, and the sand beneath the adjacent plain may obtain a thickness of 5 m. Veevers & Wells (1961) and Crowe (1975) have described the sand dunes of the Great Sandy Desert.

Colluvial and alluvial deposits (Qs) are recognised by airphoto patterns, and occur between dunes in restricted areas in the southern half and in the northwest of the Sheet area. Some of the depressions in the south may be a remnant westward-drainage that formed before the sand dunes.

Lake deposits (Ql) occur in claypans present in the supratidal flat, in the centre of, and southwestern corner of, the Sheet area.

Small areas of *alluvium* (Qa) formed as small outwash fans within the interdune areas, and adjacent to claypans in the southwestern corner of the Sheet area.

STRUCTURE

The Phanerozoic rocks of the Munro Sheet area comprise a small part of the large intracratonic Canning Basin which trends north-westerly between the basement highs of the Precambrian Halls Creek Province to the northeast, and the Pilbara Block to the southwest. No basement rocks are exposed in the Sheet area; the thickness of basin sediment ranges from about 2000 m in the north and 500 m in the southwest to about 4000 m in the centre of the Sheet area. All the structures in the Sheet area are concealed beneath the undeformed Mesozoic rocks, and have to be deduced from geophysical data and from the stratigraphy in petroleum exploration wells.

Prior to the Devonian, the Canning Basin was essentially a shallow regional downwarp with little local basement relief (see Webby, 1978). However, in the Devonian, major faulting and downwarping initiated areas with different basement morphologies and depths. These basement features are preserved today and form the basis of the structural elements of the Canning Basin.

Three major tectonic elements of the Canning Basin are present in the Sheet area: the Broome Arch, Willara Sub-basin, and the Anketell Shelf (these features are shown on the simplified geology and structure sketch on the accompanying map). The boundaries between these three sub-divisions are gradational in many cases, and are based on depth-to-basement estimates.

(Note: The gradational boundary between the Anketell Shelf and the Willara Sub-basin is shown on the cross-section CD on the accompanying map to coincide with the Munro Fault. This is in error. The correct position of the boundary is as shown on the simplified geology and structure sketch map on the accompanying map. The Munro Fault is correctly shown).

A small portion of the *Broome Arch* (Broome Swell of Veevers & Wells, 1961; Broome Platform of Koop, 1966b) is present in the north. The basin sequence on the Arch is generally 2000 m to 3000 m thick. The Broome Arch is separated from the Willara Sub-basin by the *Admiral Bay Fault*, which is a combined fault and hinge line with a throw of about 1000 m.

The *Willara Sub-basin* occupies the central part of the Sheet area. Its recognition is based on an interpretation of the Bouguer gravity data, aeromagnetic basement-depth estimates, and scattered seismic control. The maximum estimated depth may be as much as 4000 m in the central Munro Sheet area.

The southwestern flank of the Willara Sub-basin is referred to as the *Anketell Shelf*. The shelf is a broad, poorly-defined area of flat-lying to gently-dipping shallow basement.

GEOLOGICAL HISTORY

It is presumed that sediments deposited during the Precambrian, intruded by igneous rocks, and subsequently deformed, metamorphosed, and partly eroded, constitute the basement of the Canning Basin.

Following a long period of erosion of the Precambrian rocks, carbonate, silt and sand were deposited in a shallow sea which transgressed the whole Sheet area during the Early Ordovician (Nambeet, Willara, Goldwyer, and Nita Formations). The sea retreated in Late(?) Ordovician time and erosion followed. After this pause in deposition, a shallow restricted sea probably covered the area possibly as early as the Late Ordovician and mud, carbonate, and evaporites (Carribuddy Formation) were deposited. The sea then withdrew from the Sheet area in the Early Devonian.

In the Early Devonian, desert conditions prevailed in the Sheet areas to the east and southeast where fine sands were distributed by winds and rivers over an extensive plain. The pre-Grant Group erosion, which is conspicuous elsewhere in the Canning Basin, probably removed such sediments from the Sheet area together with part of the Ordovician sequences. There is no evidence for sediments being laid down in Late Devonian to Late Carboniferous times within the Munro Sheet area.

In the earliest Permian, the sea probably covered the entire Sheet area, and the climate was probably cold; the highland area to the south (Yarrie Sheet area) was undergoing glaciation. Sand with pebbles were deposited first, followed by mud and very fine sand (possibly due to a relative rise in sea level), and then sand again (Grant Group). After a short erosional episode during which the climate became warmer, sand and silt (Poole Sandstone) followed by mud and carbonate (Noonkanbah Formation) accumulated in a shallow sea during the Early Permian (Sakmarian to Artinskian) times.

Regression and extensive erosion of the Permian deposits followed. Sedimentation recommenced in Early(?) Jurassic times with continental to shallow marine sand, minor silt, and gravel being deposited (Wallal Sandstone). In Late Jurassic (Oxfordian) times, sand and mud were deposited in a tidal environment (Alexander Formation). In late Oxfordian or Kimmeridgian times, mud and minor fine sand accumulated in a deeper marine environment (Jarlemai Siltstone). The sea began to retreat from the area in Late Jurassic times and alluvial sand and gravel (Callawa Formation) were deposited by meandering rivers flowing over the southwestern part of the area. As this regression continued into earliest Cretaceous times, continental deposition continued in the southwest, while shallow marine sand (Broome Sandstone) was laid down in the rest of the Sheet area.

The sea transgressed the whole Sheet area in Early Cretaceous (Aptian) time depositing mud and fine sand (Parda Formation). As it again regressed, fine clastic material (Frezier Sandstone) was laid down by rivers over the marine deposits of the Parda Formation and Broome Sandstone.

From Late Cretaceous time onwards, erosion over the entire Sheet area removed much of the Early Cretaceous sediments, and deep chemical weathering occurred. Laterite profiles developed during the more hot and humid periods until the climate became dominantly arid.

Erosion of the laterite profile produced mesas and hills. Alluvial deposition continued, and drainage channels became choked with detritus eroded from higher areas, resulting in the formation of shallow lakes. Sand and dunefields resulted from aeolian erosion of the weathered sediments; the strike directions of the dunes and the common orientation of their tuning fork junctions indicate that easterly to east-southeasterly winds prevailed. The dunes are stabilised by their cover of vegetation and are now mainly inactive. Mixed aeolian and alluvial sand, silt, and minor gravel were deposited in some interdune areas.

In the Quaternary, the sea transgressed the lateritised and alluviated coastal plains, inundating a narrow strip along Eighty Mile Beach. Deposits representing this transgression are the Bossut Formation, and also shallow marine muds which spread across the plains. As the sea retreated, laterally-equivalent sedimentary environments migrated seawards — intertidal flat, mangrove, and supratidal flat environments succeeded each other. Grass covered the supratidal flats as they became inactive. A series of parallel beach ridges developed along Eighty Mile Beach.

ECONOMIC GEOLOGY

Petroleum

The petroleum prospectivity of the area appears to be relatively poor. Four petroleum exploration wells have been drilled in the Sheet area; gas and oil traces occurred in WAPET Willara 1, and fluorescence and free oil in WAPET Munro 1. The other wells, WAPET Willara 1 and WAPET Munda 1, encountered no hydrocarbons.

Although Ordovician source rocks are present at depths likely to generate hydrocarbons (1500-3000 m), pre-Permian and early Mesozoic erosion and the lack of both suitable reservoirs and structural traps significantly downgrade the prospectivity of the area (Burne & Kantsler, 1977; Burne & others, 1979).

The Permian sediments are immature as source rocks, and the sandstone unit in the Grant Group with reservoir potential has probably been flushed with fresh water. The thin Mesozoic rocks in the Sheet area have no petroleum potential. Gorter & others (1979) recognised ten closed structures within the Sheet area, of which only two have been drilled.

Water

Surface water is scarce owing to the low rainfall and high evaporation rate, and ephemeral supplies are confined mainly to small rock holes. Some rain water may persist for a short time in the claypans between dunes but becomes generally undrinkable.

Groundwater has not yet been systematically investigated in the Sheet area and information on its occurrence, quality, and yield is meagre. Aquifers within the Grant Group, Callawa Formation, and Wallal Sandstone have yielded quantities of fresh water in the petroleum exploration wells drilled in the Sheet area (WAPET, 1972).

Small supplies of good quality water are present in the coastal dunes, but these are only sufficient to supply pastoral needs.

Construction materials

Pisolites within laterite, and reworked laterite, are present within the Sheet area and are suitable for, and have been used for, constructing roads.

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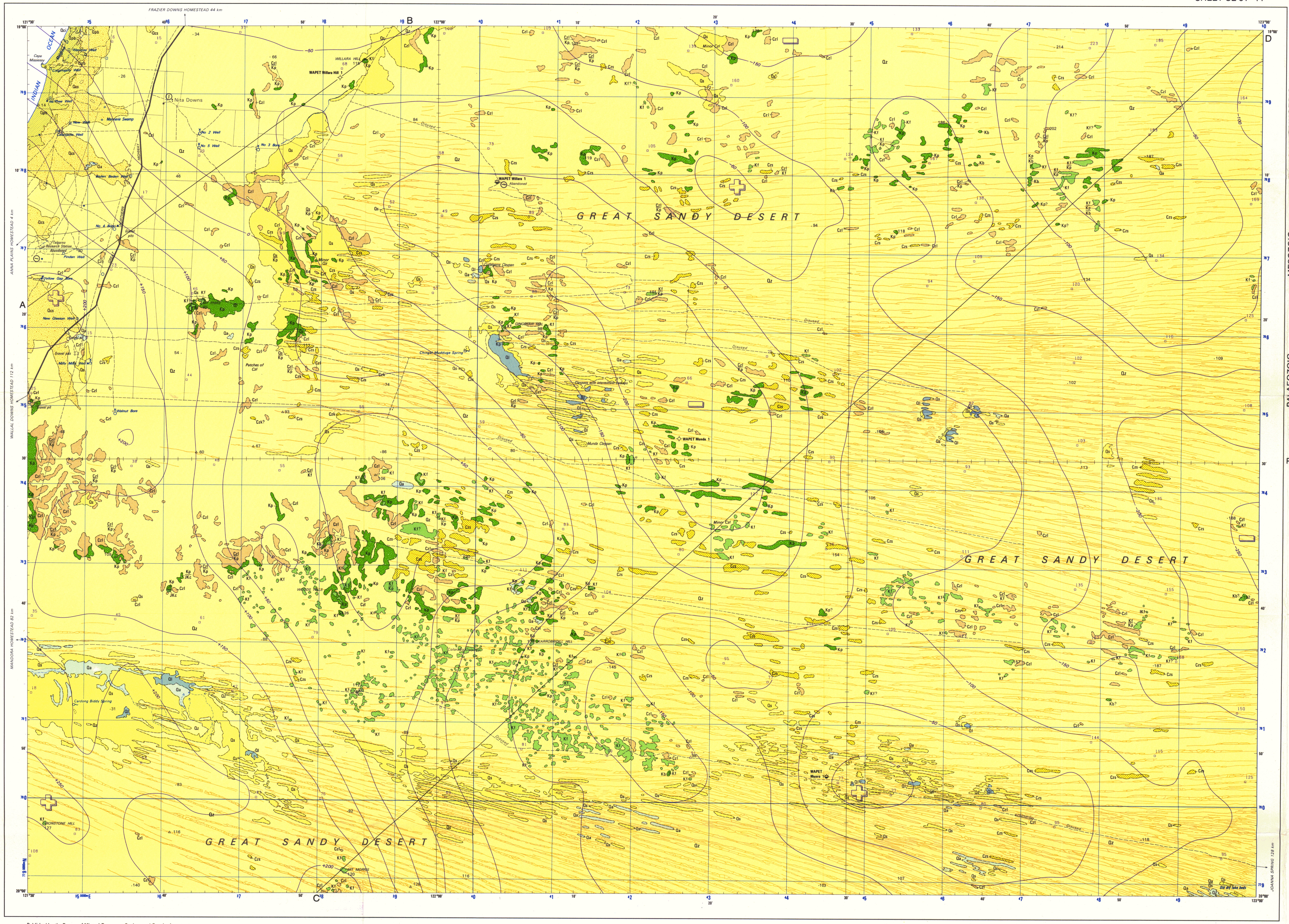
AUSTRALIA 1:250 000 GEOLOGICAL SERIES

MUNRO

WESTERN AUSTRALIA

SHEET SE 51-14



AUSTRALIA

CAINOZOIC	QUATERNARY		Qa	Sand, silt, clay; minor gravel: alluvial
			Ql	Clay, silt, sand; minor gypsum: lacustrine, claypans
			Qs	Sand, silt; minor gravel: mixed alluvial and aeolian
			Qz	Red sand, fine to medium; minor silt: aeolian
			Qcs	Clay, silt, sand; minor salt: supratidal mud flat deposits
		Bossut Formation	Qpb	Quartzose calcarenite, fine to coarse calcilutite; partly oolitic, cross-bedded; fossiliferous: shoreline beach-ridge
			Qci	Silty clay, black organic clay; minor salt: tidal flat and mangrove swamp
			Czk	Calcrete; minor chalcedony: evaporitic, pedogenic
			Czs	Sand, silt, ferruginous pisoliths; minor gravel, clay: pedogenic; gravel plains overlying Czl
			Czl	Laterite, pisolitic or massive: pedogenic
MESOZOIC	EARLY CRETACEOUS	Frezier Sandstone	Kf	Sandstone, fine to coarse, poorly sorted, feldspathic, poorly bedded, some relict cross-bedding; minor conglomerate: fluvial to deltaic, partly pedogenic
		Parda Formation	Kp	Mudstone; minor fine sandstone lenses; thin-bedded or massive: lagoonal?
		Broome Sandstone	Kb	Sandstone, fine to medium, well-sorted; mudstone in part; minor conglomerate; ripple-marked, cross-bedded; minor bioturbation; plant fossils: shallow water marine
	LATE JURASSIC TO EARLY CRETACEOUS ?	Callawa Formation	JKc	Sandstone, very fine to coarse; conglomerate; cross-bedded; minor siltstone; plant fossils: fluvial
		Jarlemai Siltstone	JKr	Mudstone, sandy, glauconitic, fossiliferous: marine
	LATE JURASSIC	Alexander Formation	Ja	Sandstone, fine to medium; interbedded mudstone, bioturbated, fossiliferous: marine
	EARLY? TO LATE JURASSIC	Wallal Sandstone	Jl	Sandstone; minor siltstone, conglomerate; palynomorphs: continental to shallow marine
PALAEOZOIC	EARLY PERMIAN	Noonkanbah Formation	Pn	Mudstone, calcareous, micaceous; fine sandstone, limestone interbeds; fossiliferous: marine
		Poole Sandstone	Pp	Sandstone, very fine to fine; interbedded mudstone; thin-bedded; clay pellet lenses: shallow water marine
		Grant Group	Pg	Sandstone, fine to coarse; mudstone; minor conglomerate: glacial marine
	LATE ORDOVICIAN? TO EARLY DEVONIAN	Carribuddy Formation	Sc	Dolomite, dolomitic siltstone, shale, halite, anhydrite; minor sandstone: mainly non-marine
	MIDDLE ORDOVICIAN	Nita Formation	On	Dolomite, limestone;minor shale: marine
		Goldwyer Formation	Oo	Shale, black, fossiliferous, calcareous, pyritic, interbedded limestone, dolomite; minor siltstone lenses: marine
	EARLY ORDOVICIAN	Willara Formation	Ow	Limestone, dolomitic, fossiliferous; interbedded shale and siltstone: marine
		Nambeet Formation	Ot	Shale, grey to green, interbedded limestone, dolomite and fine sandstone: marine
PRECAMBRIAN			p€	Igneous, metamorphic, and sedimentary rocks

JKr to p€: section and rock relationship diagram only

Geological boundary

Fault - (from seismic data)

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

Trend-line, airphoto interpretation

Macrofossil locality

Palynomorph locality

Petroleum exploration well, dry, abandoned

Petroleum exploration well with show of oil and gas

Bore, Well

Windpump

Water storage

Spring

Swamp

Ancient drainage

Intermittent drainage

Sand dunes

Cliff

Claypan

Highway

Vehicle track

Landing ground

Nita Downs Homestead

Building

Yard

Fence

Trigonometrical station

·46 Elevation in metres

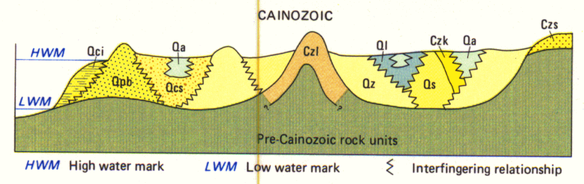
182 Selected gravity station with elevation in metres

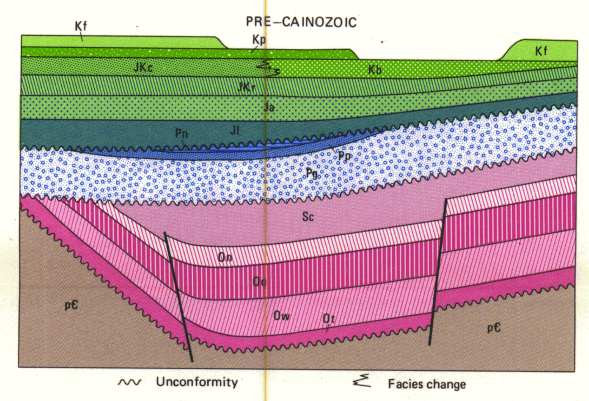
+200 Bouguer gravity anomaly (micrometres sec^{-2}), computer-plotter produced

Gravity anomaly — relative high

Gravity anomaly — relative low

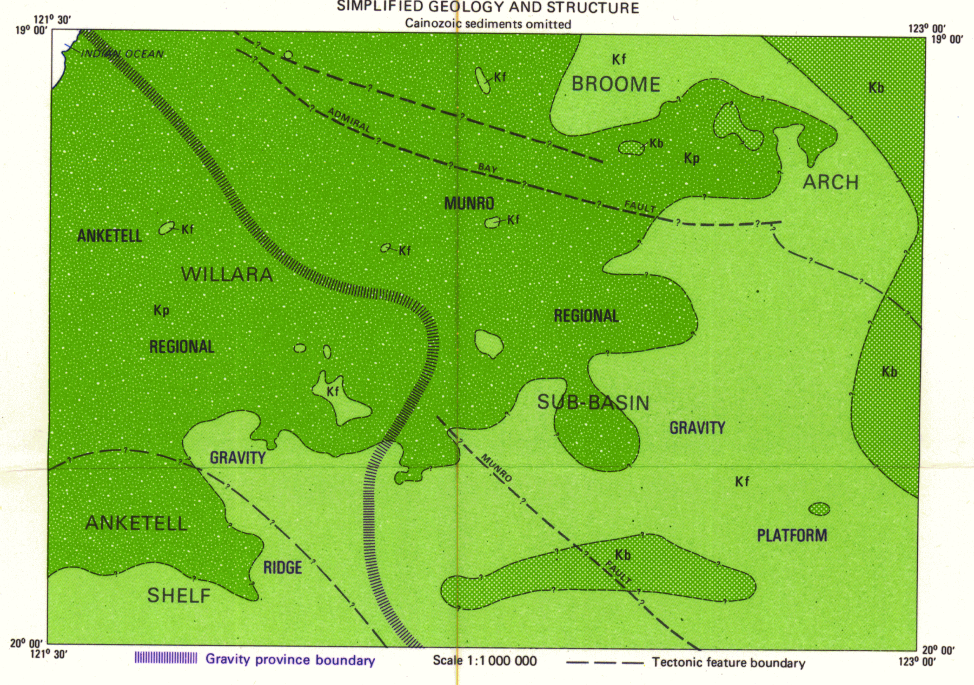
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS





SIMPLIFIED GEOLOGY AND STRUCTURE

Cainozoic sediments omitted



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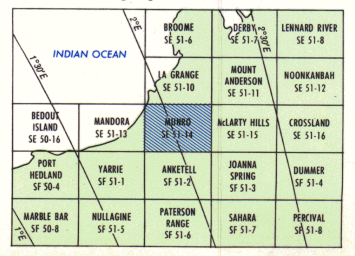
INDEX TO ADJOINING SHEETS

Showing magnetic declination 1975

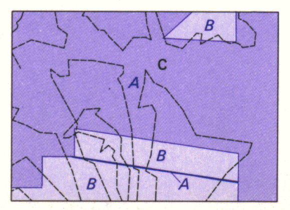


SCALE 1:250 000

5 0 5 10 15 20 25 Kilometres

BLUE NUMBERED LINES ARE 10 000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID, ZONE 51 TRANSVERSE MERCATOR PROJECTION

RELIABILITY DIAGRAM

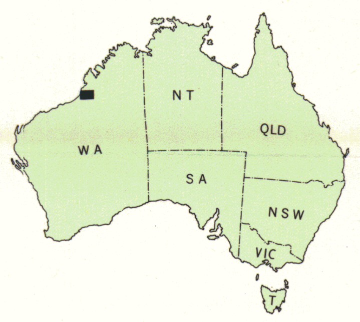


Geology C General reconnaissance: few traverses, mainly airphoto interpretation

Helicopter traverse

Gravity A Detailed survey

B Reconnaissance



Geology 1977 by R.R. Towner, D.L. Gibson BMR; R.W.A. Crowe GSWA

Compiled 1978 by R.R. Towner, D.G. Walton

Gravimetry 1955-67 by BMR and private companies

Design by Cartography Section BMR

Drawn by Mercury-Walch, Hobart, Australia

Printed by Valentine Graphics, Melbourne, Australia

UNIVERSAL GRID REFERENCE

GRID ZONE DESIGNATION: 51K

100,000 METRE SQUARE IDENTIFICATION

UU VU

UT VT

TO GIVE A STANDARD REFERENCE ON THIS SHEET TO NEAREST 1000 METRES

SAMPLE POINT: · MT MORRIS

1 Read letters identifying 100 000 metre square in which the point lies: UT

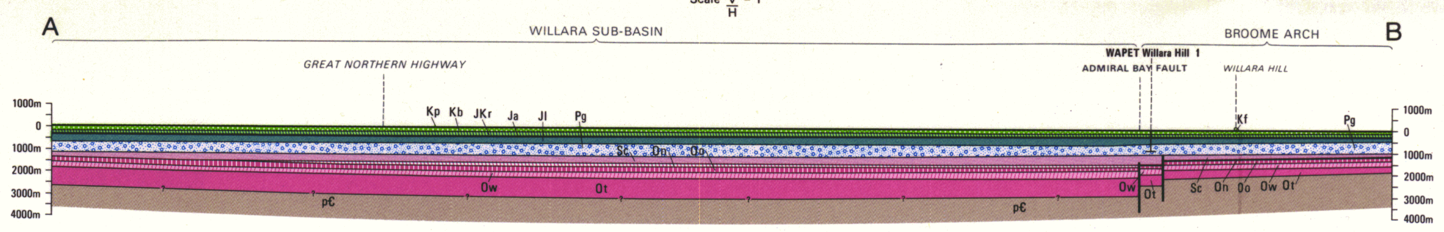
2 Locate first VERTICAL grid line to LEFT of point and read LARGE figure labelling the line either in the top or bottom margin, or on the line itself

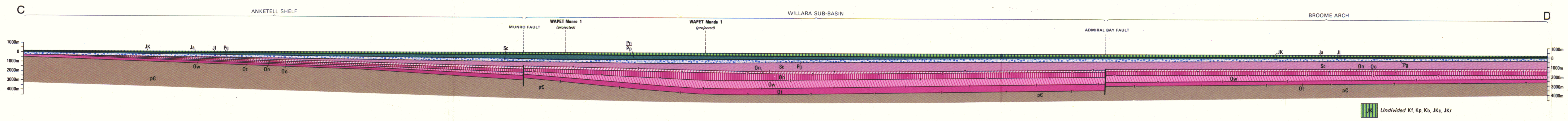
SAMPLE REFERENCE UT8491

If reporting beyond 18° in any direction, prefix Grid Zone Designation, as: 51KUT8491

SCHEMATIC SECTIONS

Cainozoic sediments omitted





Undivided Kf, Kp, Kb, JKc, JKr

MUNRO

SHEET SE 51-14

FIRST EDITION 1981