1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

JOANNA SPRING

WESTERN AUSTRALIA

SHEET SF/51-3 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

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Explanatory Notes on the Joanna Spring Geological Sheet

Compiled by R. R. Towner

The Joanna Spring 1:250 000 Sheet area lies in the north of Western Australia and is bounded by latitudes 20° and 21°S and longitudes 123° and 124°30′E. The Sheet area, which lies wholly within the Great Sandy Desert (Warburton, 1875), contains scattered outcrops of Mesozoic sedimentary rocks protruding through a widespread cover of Cainozoic superficial sediments. Geologically, it is part of the Canning Basin (Gentilli & Fairbridge, 1951).

There is no permanent settlement in the Sheet area though Aboriginals have lived there in the past. The nearest population centres are Port Hedland (470 km west), Broome (340 km north), Alice Springs (1000 km east), and Telfer (180 km south).

Access is by an unsealed road which connects Alice Springs in the east with Port Hedland in the west. The road is not maintained; it runs across the bottom southwestern corner of the Sheet area passing the site of WAPET Sahara No. 1 petroleum exploration well situated 11 km south of the Sheet area boundary. In the adjacent Anketell Sheet area, a branch road leading off this main access road winds its way in a northeasterly direction through the sand dunes to the site of Total Kemp Field No. 1 exploration well. Access within the area is confined to the seismic and gravity lines and access tracks to them, which were made in 1973 and 1967. These are mainly in the western half of the Sheet area. None of the geophysical tracks is maintained, and they were in poor condition in 1977 when fieldwork for this map and Notes was carried out.

Away from the tracks, travel is generally slow and tedious and is hampered by east-trending longitudinal sand ridges, patchy thick mulga, and rough spinifex-covered interdune areas.

A landing ground is located 22 km north of the Total Kemp Field No. 1 petroleum exploration well site but is not maintained. Geophysical parties constructed two small landing grounds in the south and centre of the Sheet area to facilitate aircraft and vehicle movement during gravity and seismic surveys.

The climate is arid and often windy. As there are no meteorological stations in the Sheet area, climatic data have to be inferred from peripheral stations. The annual rainfall is extremely variable and probably averages less than 200 mm; the heaviest falls occur between November and March (the cyclonic period). The annual evaporation rate is 3000-3300 mm. The average daily minimum and maximum temperatures are about 21°C and 40°C in January, and 7°C and 22°C in July (Commonwealth Statistician, 1973). The prevailing winds are from the east and southeast.

The area lies within the Canning Botanical District of Beard (1969), and the flora of that district have been described by him and by Beard & Webb (1974). The vegetation is sparse and consists mainly of small eucalypts, shrubs, and spinifex grass. The eucalypts are common along the upper flanks of the sand dunes, and along ancient drainage channels. Spinifex occurs throughout the area on all landforms except the crests of the sand ridges, where low shrubs predominate. An extensive area of ti-tree scrub (*Melaleuca* sp.) is present in the south near Mellinjerie Rock Hole and Carribuddy Springs. Growth periods occur after falls of heavy rain, but they are unpredictable and there is no assured growing season.

History of investigations

The earliest exploration of the Joanna Spring Sheet area was in 1873 by P. E. Warburton who travelled westwards across the northern part of the Sheet area on on his expedition from Alice Springs to the Oakover River (on the Yarrie Sheet area to the west). He named Joanna Spring (Warburton, 1875).

An exploration party in 1896 led by the surveyor L. A. Wells crossed the Sheet area from south to north and named Adverse Well in the south and Discovery Well in the north (Wells, 1902). In an attempt to locate the lost members of Well's Expedition, W. F. Rudall traversed part of the area in 1897, locating and naming the Carribuddy Springs and two other native wells in the south (Feeken & others, 1970).

Surface geology. In 1947, staff of the Zinc Corporation in conjunction with the Vacuum Oil Company Pty Ltd and the D'Arcy Exploration Company Ltd flew over the northeastern corner of the Sheet area during an aerial reconnaissance survey of the 'Desert Basin', the old name for the Canning Basin (Reeves, 1949).

As part of an extensive helicopter reconnaissance geological and gravity survey of the central Canning Basin in 1957, Veevers (1957) named the more prominent topographic features and made geological observations at Yarrana Heights, Battlement Rocks, Turkey Place Hill, and Traves Cliff, as well as at a number of unnamed mesas and hills in the Sheet area.

An account of the geology of the Canning Basin was published by Veevers & Wells (1961) and was accompanied by a map at a scale of 1 inch to 20 miles. Other reports which refer to rocks within this Sheet area include those by McWhae & others (1958) and Playford & others (1975).

Geological mapping of the whole of the Canning Basin at 1:250 000 scale was begun in 1972 as part of a joint project by BMR and the Geological Survey of Western Australia (GSWA) (Yeates & others, 1975; Towner & others, 1976). Sheet areas adjoining the Joanna Spring Sheet area, to the east, Dummer (Wyborn 1977), northeast, Crossland (Towner, 1977), south, Sahara (Yeates & Towner, 1978), and southeast, Percival (Yeates, 1978), were mapped between 1972 and 1975. In 1977 geologists from both organisations mapped the Joanna Spring Sheet area and the areas to the north (McLarty Hills) and west (Anketell and Munro) as part of a survey in the western Canning Basin involving the use of a helicopter and aerial photographs with some vehicle traverses (Towner & Gibson, 1980).

Magnetics. Only one magnetic survey, the South Canning Aeromagnetic Survey, conducted by Aero Services Ltd for WAPET in 1962-3, covers this Sheet area. This survey, carried out after the passing of the Commonwealth Petroleum Search Subsidy Act, delineated a broad basin ('the Joanna Spring Sub-basin') trending east-west, divergent from the general northwesterly trend of the Canning Basin. The maximum estimated depth of this sub-basin is over 6500 m below sea level (WAPET, 1966a).

Gravity. The gravity contours shown on the map are taken from the 1970 BMR 1:250 000 Bouguer Anomaly map, based on survey data by Wongela Geophysical Pty Ltd in 1968 processed by Darby & Fraser (1969). The contours outline parts of two gravity provinces: the South Canning Regional Low and the Munro Regional Gravity Shelf; the shelf is composed of three gravity units, one of which is the Joanna Gravity Ridge in the northern part of the Sheet area.

An earlier BMR gravity survey in 1952 had also mapped two gravity features (Flavelle & Goodspeed, 1962): the Joanna Spring Gravity Spur, similar in outline to the Joanna Gravity Ridge of Darby & Fraser, and the Dummer Gravity Platform, which was interpreted as a broad area bordering the northern part of a large gravity depression to the southeast of the Sheet area.

The Joanna Gravity Ridge of Darby & Fraser (1969) broadly correlates with the Joanna Spring Gravity High as outlined by WAPET's Joanna Spring Gravity Survey of 1963-64 (WAPET, 1963b; 1964a). The WAPET survey also indicated a broad gentle negative trend across the southwestern portion of this Sheet area and the adjacent Sahara Sheet area, corresponding to the South Canning Regional Gravity Low of Darby & Fraser (1969). At the border between the Sahara and Joanna Spring Sheet areas an east-west positive gravity feature, the Mellinjerie Swell (WAPET, 1964a), correlates roughly with some magnetic features.

A synthesis of all available pre-1962 gravity information in the Canning Basin, relating it to the known surface geology and the borehole stratigraphy, was published in 1974 (Flavelle, 1974).

Seismic. The Sahara seismic reconnaissance survey (WAPET, 1963c), in the northern part of the Sahara Sheet area and the southern part of the Joanna Spring Sheet area, mapped three seismic horizons and delineated several broad anticlinal structures. A sedimentary thickness in the order of 6000 m was interpreted. There was general correlation between the gravity anomalies and the structures delineated by this survey. WAPET Sahara No. 1 well drilled one of these gravity/seismic anomalies (WAPET, 1966b).

The seismic results from the McLarty seismic and gravity reconnaissance survey, whose main aim was to select drill sites in the central Canning Basin, delineated two geological structures (French Petroleum, 1968), one, an anticline, in the Joanna Spring Sheet area. The anticline coincides roughly with the Joanna Gravity Ridge which is believed to indicate a basement ridge or dense sediments in the core of the anticline (Darby & Fraser, 1969).

The only other survey involving the Joanna Spring Sheet area was the WAPET Sahara II Seismic Survey, (WAPET, 1973), a solitary seismic line 64 km long extending northwest from WAPET Sahara No. 1 well into the southwestern corner of this Sheet area. Its aim was to provide seismic control along the strike of a previously defined structural trend. The data from the three mapped seismic horizons revealed a number of closures along this anticlinal trend at Ordovician depths.

Drilling. Only one petroleum exploration well has been drilled—Total Kemp Field No. 1 (Total, 1968a).

Aerial photographs and maps. Aerial photographs covering the Sheet area are obtainable from the Division of National Mapping, Canberra, and the Department of Lands & Surveys, Perth; one set at 1:48 000 scale flown in 1953, and the other set at 1:120 000 flown in 1976.

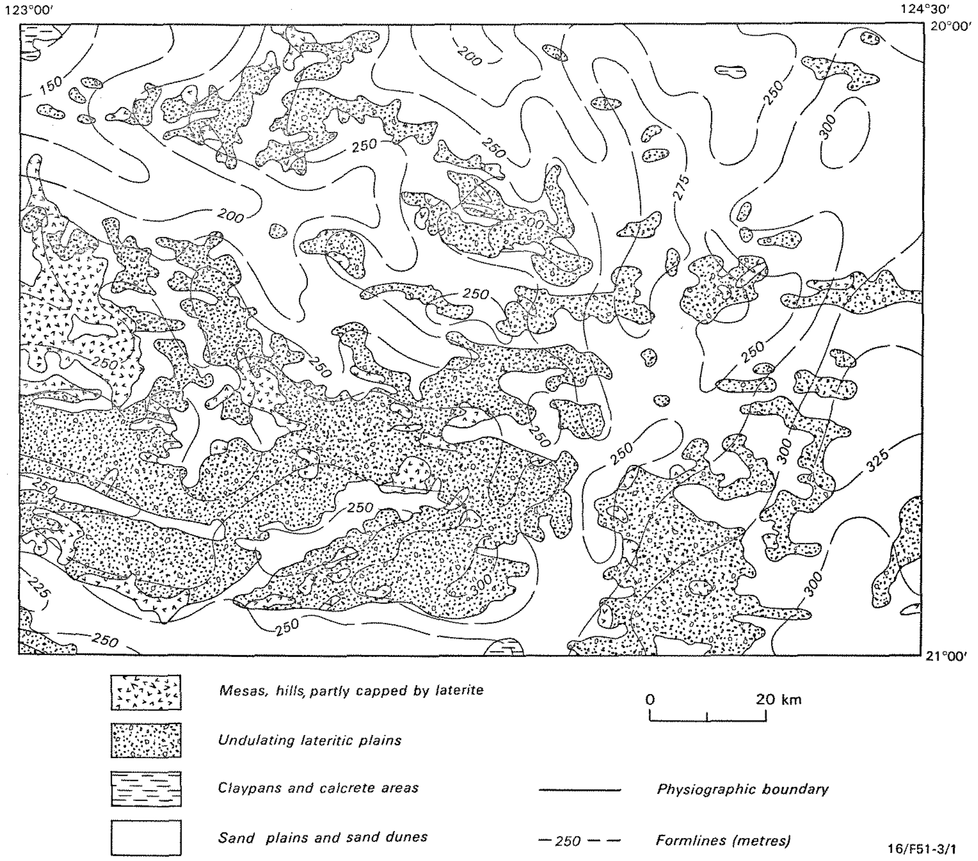

Fig. 1. Physiography.

A topographic base map at a scale of 1:250 000 (Joanna Spring SF/51-3, Edition 1, Series R502), complied in 1963 by the Royal Australian Survey Corps from 1953 aerial photography and 1960 photo-control strips and ground examination, is also available from the same sources.

PHYSIOGRAPHY

The Sheet area is situated entirely within the Great Sandy Desert. Landforms typical of a desert environment have been brought about by an earlier arid windy climate. Those landforms were in turn modified from an old, gently undulating plain that was lateritised during an earlier, wetter climate. Remnants of this plain are still present, but overall the landscape is dominated by sand dunes. The form lines shown on the physiographic map (Fig. 1) have been compiled from the widely spaced information from BMR gravity survey station heights. The ground rises to just above 300 m above sea level in the eastern sector of the Sheet area, and drops off gradually to the northwest to about 150 m above sea level. The main landform types are described below.

Undulating lateritic plains

An undulating lateritic surface dominates the landscape in the south but elsewhere is hidden under a cover of aeolian sand. It forms a low, gently undulating plain about 250 m above sea level, characterised by smooth, pisolite-strewn rises separated by sand-filled depressions. These depressions are remnants of valleys of a relict drainage system that has been recognised over much of arid Western Australia (van de Graaff & others, 1977). This drainage system, now dry, developed during a period of much higher rainfall. The surface of the lateritic plain is covered by pisoliths and, in places, by a thin blanket of red sand or by longitudinal sand dunes. Vertical sections exposed in low breakaways show that the plain is developed on the ferruginous pisolitic duricrust of a weathering profile.

Mesas and hills

Mesas and hills are developed where erosion has dissected the lateritic crust to expose the underlying deeply weathered rock. Since these rocks are far more susceptible to erosion than the protective capping, low cliffs are developed, below which wide, gently sloping scree-covered pediments grade into the surrounding sand plain or into lower parts of the laterite plain. Isolated hills up to 10 m high are present, especially in the north and northwest. Weathered outcrops not capped by laterite occur as scattered small rises between the sand dunes.

Claypans and calcrete areas

The flat, round claypans are composed of hard, sandy clay with minor gypsum. Grasses, ti-trees, and eucalypts are present on and around their margins. Calcrete forms low, rugged rises of nodular and vuggy, arenaceous limestone which, around the margins of some claypans, has been partly replaced by veins of chalcedony. The claypans and calcrete are confined to the northwestern corner and southern boundary of the Sheet area.

Sand dunes and plains

Sand dunes and plains together form the most extensive physiographic unit. The longitudinal dunes (seifs) trend predominantly west-northwest and range widely in length, separation, and complexity. Simple longitudinal dunes are the most common, though net-like and chain dunes occur in depressions (Crowe, 1975). The dunes overlie the lateritised bedrock (lateritic plains) at shallow depth and continue unbroken over most of the topographic rises. They were formed by prevailing winds which blew from the east and east-southeast.

The present-day drainage of the Joanna Spring Sheet area is poorly developed; there are no permanent watercourses, although the small claypans fill with water after heavy rain.

STRATIGRAPHY

The stratigraphy of the Sheet area is summarised in Table 1. Cainozoic terrestrial units up to about 30 m thick blanket much of the area. The pre-Cainozoic outcrops occur mainly in the west. Units older than the Jurassic to Lower Cretaceous Callawa Formation do not crop out. Information on them is based on outcrops in the adjacent Paterson Range Sheet area to the southwest, geophysical survey results, and data obtained from Total Kemp Field No. 1 (Total,

TABLE 1. STRATIGRAPHY OF JOANNA SPRING SHEET AREA

	Age	Rock unit and symbol	Estimated thickness (m)	Lithology	Stratigraphic relationship	Remarks
CAINOZOIC	Quaternary	Q1	5	Clay, silt, sand, minor gypsum	Superficial	Salt-lakes, claypans
		Qs	5	Sand, silt, minor gravel	Superficial	Alluvial and aeolian; in depressions
		Qz	25	Red quartz sand, fine to medium-grained; minor silt	Superficial	Aeolian sand in dunes and sand plains
		Czk	3	Calcrete, minor chalcedony	Superficial	Occurs along ancient drainage lines and lakes. Some pedogenic.
		Czs	2	Sand, silt, ferruginous pisoliths, minor gravel and clay	Superficial	Residual laterite capping plateaux
		Czl	3	Laterite, pisolitic or massive	Superficial	Upper part of lateritic weathering profile; pedogenic
	Cretaceous to Tertiary	Lake George Beds KTg	2	Sandstone, fine to coarse, poorly sorted, massive, silicified	Unconformable on Ka; capped by laterite	Interpreted as fluviatile and partly pedogenic
MESOZOIC	Early Cretaceous	Anketell Sandstone Ka	0–30	Fine sandstone and siltstone interbedded with lenticular coarse sandstone and granule conglomerate; poorly sorted; laminated to thin-bedded; bioturbated	Disconformable on Kf, Ja, JKc; top eroded	*Rhizocorallium* burrows, wood fragments; ?paralic
		Frezier Sandstone Kf	40+	Sandstone, fine to coarse, feldspathic, poorly sorted, poorly bedded; remnant crossbedding; minor conglomerate	Partly laterally equivalent to, and partly disconformable on JKc; disconformable on Ja; disconformable beneath Ka	Forms small dark hills on air-photos; fluviatile to deltaic, partly pedogenic
	Jurassic to Cretaceous	Undivided JK	7+	Sandstone, fine, massive, rich in heavy minerals	Possibly overlain by JKc	Outcrops along a fault line; ?marine
	Jurassic to Early Cretaceous	Callawa Formation JKc	50+	Sandstone, very fine to coarse; pebble conglomerate; crossbedded; minor siltstone; bioturbated	Unconformable on Pn; disconformable beneath Ka, partly laterally equivalent to and partly underlies Kf	Plant-bearing in Callawa Hills area in Yarrie Sheet area; fluviatile
	Late Jurassic	Alexander Formation Ja	40+	Sandstone, fine to medium; interbedded mudstone	Conformable on Wallal Sandstone; disconformably overlain by Kf	Subsurface only; intersected in Total Kemp Field No. 1; possibly restricted to northern part of Sheet area
	Early? to Late Jurassic	Wallal Sandstone Jl	100±	Sandstone, minor siltstone, conglomerate	Unconformable on Pn; conformable beneath Ja	Subsurface only; intersected in Total Kemp Field No. 1; Important artesian aquifer in south Canning Basin

TABLE 1. STRATIGRAPHY OF JOANNA SPRING SHEET AREA—(*continued*)

	Age	*Rock unit and symbol*	*Estimated thickness (m)*	*Lithology*	*Stratigraphic relationship*	*Remarks*
				UNCONFORMITY		
PALAEOZOIC	Early Permian	P	5+	Sandstone, very fine to fine, well-sorted, thin-bedded	Relationships unknown	Outcrops belong to either Pg, Pp, or Pn
		Noonkanbah Formation Pn	50–250	Mudstone, calcareous, micaceous; fine sandstone, limestone interbeds	Conformable on Pp; unconformable beneath Jl, JKc	Subsurface only; intersected in Total Kemp Field No. 1 well; shallow-marine
		Poole Sandstone Pp	14–50+	Sandstone, very fine to fine; interbedded mudstone; thin-bedded; clay-pellet lenses	Conformable beneath Pn and possibly disconformable on Pg	Subsurface only; intersected in Total Kemp Field No. 1; marine
		Grant Group Pg	350–500	Sandstone, fine to coarse; mudstone, minor conglomerate	Possibly disconformable beneath Pp; unconformable on Dm	Subsurface only; intersected in Total Kemp Field No. 1; marine to continental
				UNCONFORMITY		
PALAEOZOIC	Middle Devonian	Mellinjerie Limestone Dm	0–200	Dolomitic limestone, dolomite, shale, minor sandstone, anhydrite	Unconformable beneath Pg; conformable on Dt	Subsurface only; intersected in Total Kemp Field No. 1; marine
	Early Devonian	Tandalgoo Red Beds Dt	350–600	Red-brown, fine sandstone with minor interbeds of siltstone, shale, limestone	Conformable between Dm and Sc	Subsurface only; intersected in Total Kemp Field No. 1; mainly continental
	Late Ordovician? to Early Devonian	Carribuddy Formation Sc	1300±	Dolomite, dolomitic siltstone, shale, halite, anhydrite; minor sandstone	Conformable beneath Dt; disconformable on On	Subsurface only; intersected in Total Kemp Field No. 1; shallow marine
	Middle Ordovician	Nita Formation On	100+	Limestone, dolomite, interbedded shale	Conformable on Oo; disconformable beneath Sc	Subsurface only; inferred to be present from drilling N and SE of Sheet area; marine
		Goldwyer Formation Oo	400+	Shale, black, fossiliferous, calcareous, pyritic; interbedded limestone, dolomite; minor siltstone	Conformable between On and Ow	Subsurface only; inferred to be present from drilling N and SE of Sheet area; marine
	Early Ordovician	Willara Formation Ow	300+	Limestone, dolomitic, fossiliferous; interbedded shale and siltstone	Conformable between Ot and Oo	Subsurface only; inferred to be present from drilling N and SE of Sheet area; marine
		Nambeet Formation Ot	300+	Shale, grey to green; interbedded limestone and fine sandstone	Unconformable on pЄ; conformable beneath Ow	Subsurface only; inferred to be present from drilling N and SE of Sheet area; marine
				UNCONFORMITY		
PRECAMBRIAN		pЄ	unknown	*Igneous, metamorphic, and sedimentary*	*Basement rocks*	*Section only*

1968a) and from other petroleum exploration wells drilled in adjacent Sheet areas (including Total McLarty No. 1 (Total, 1968b) to the north, WAPET Munro No. 1 (WAPET, 1972) to the northwest, and WAPET Sahara No. 1 (WAPET, 1966b) to the south).

The geological cross-section has been compiled largely from depth-to-seismic-reflector information from French Petroleum Company (1968), in conjunction with information from Total Kemp Field No. 1 (Total, 1968a), and from petroleum exploration wells just outside the Sheet area (WAPET, 1966b; Total, 1968b).

PRECAMBRIAN

Precambrian rocks form basement to the Canning Basin succession in the area, but their nature is unknown. Outcrops in the adjacent Paterson Range Sheet area to the southwest are composed of metamorphic and igneous rocks of the Rudall Metamorphic Complex overlain by Paterson Province sedimentary rocks of Early to Middle Proterozoic age (Williams & others, 1976; Chin & others, 1981). Representatives of these rocks may be present in the Joanna Spring Sheet area. The top of the Precambrian is a very weak reflecting horizon which has only been sporadically recognised on some seismic sections.

PALAEOZOIC

Ordovician

Seismic surveys in the Sheet area and well sections outside it indicate the presence of at least 1100 m of Ordovician sedimentary rocks unconformably overlying Precambrian rocks. A complete Ordovician sequence was penetrated in WAPET Munro No. 1 (604.8 m thick) in the Munro Sheet area to the northwest; an incomplete section 960 m thick was intersected in Total McLarty No. 1 in the adjacent McLarty Hills Sheet area to the north. The basal Ordovician unit consists of shale with interbeds of limestone and fine sandstone (*Nambeet Formation*; Johnstone *in* WAPET, 1961) and is conformably overlain by grey dolomitic limestone with interbeds of shale and siltstone (*Willara Formation;* McTavish *in* Playford & others, 1975). These two Lower Ordovician formations are followed conformably by Middle Ordovician black shale with carbonate interbeds (*Goldwyer Formation;* Elliott, 1961) and a thin sequence of limestone and dolomite (*Nita Formation;* McTavish *in* Playford & others, 1975). Rocks of unquestionable Late Ordovician age are not known in the Sheet area.

Late Ordovician? to Early Devonian

The *Carribuddy Formation* (Koop, 1966a) was just penetrated in Total Kemp Field No. 1 between 1115.6 m and 1181.1 m, the total depth of the well. Its top is a prominent seismic reflector. Rocks in this sequence are commonly red and contain evaporites. In the Total McLarty No. 1 well to the north, the evaporite sequence consists of 700 m of massive halite with some intercalations of grey siltstone containing minor traces of anhydrite. The Carribuddy Formation may extend from Late Ordovician to Early Devonian in age; it is overlain conformably by the Tandalgoo Red Beds of Early Devonian age, and lies disconformably on the Middle Ordovician Nita Formation in wells outside the area (Total, 1968b).

Early Devonian

The *Tandalgoo Red Beds* (Koop, 1966a) overlie the Carribuddy Formation gradationally. The unit was intersected between 720.5 m and 1115.6 m in Total Kemp Field No. 1 (Total, 1968a). It is absent in Total McLarty No. 1 to the north, possibly owing to erosion. Its type section, in WAPET Sahara No. 1 immediately to the south of the Sheet area, is 599 m thick. The beds consist of red-brown, fine sandstone with minor siltstone, shale, and limestone. They were probably deposited in a continental environment. The sandstone contains well-rounded, well-sorted frosted grains indicating probable aeolian deposition. The formation has been dated as Early Devonian (Gross, 1971) on the basis of fish scales.

Middle Devonian

The *Mellinjerie Limestone* (Koop, 1966a) consists predominantly of carbonates and fine-grained clastics with some anhydrite, and gradationally and conformably overlies the Tandalgoo Red Beds. Its lowermost carbonate unit can be easily traced on seismic records. The unit is 157.5 m thick in Total Kemp Field No. 1 (Total, 1968a) and thins northwards and westwards from the well; it is absent in the McLarty Hills Sheet area to the north. Microflora and conodont fauna indicate a Middle Devonian age (WAPET, 1966b; Total, 1968a).

Permian

The *Grant Group* (Guppy & others, 1952; 1958; Crowe & Towner, 1976) lies with regional unconformity on the Devonian Mellinjerie Limestone and the Tandalgoo Red Beds. The unconformity is excellent seismic reflector. The group is 384 m thick in Total Kemp Field No. 1 where it comprises a lower sandstone unit, a middle mudstone unit, and an upper sandstone unit. At the base of the lower sandstone unit (termed the Betty Formation by Crowe & Towner, 1976), is a sequence composed of polymictic conglomerate containing striated pebbles, fine sandstone, and siltstone. This lithological unit (termed Braeside Tillite by WAPET, 1966b) can be tentatively equated with the Paterson Formation (Talbot, 1920; Traves & others, 1956). Palynomorphs recorded from cores and cuttings in the well section indicate an Early Permian (Sakmarian) age for the Grant Group.

The *Poole Sandstone* overlies the Grant Group possibly disconformably and was intersected from 157.9 m to 171.3 m in Total Kemp Field No. 1; it is present in Total McLarty No. 1 in McLarty Hills Sheet area and is 51 m thick in WAPET Sahara No. 1 (WAPET, 1966b). The sandstone is fine-grained and contains thin interbeds of micaceous siltstone. The microflora from the well sections of the unit indicates Stage 3 (Evans, 1969) and denotes an early Artinskian age.

The *Noonkanbah Formation,* encountered between 103.3 m and 157.9 m in Total Kemp Field No. 1, conformably overlies the Poole Sandstone. It crops out in the adjacent Paterson Range Sheet to the southwest, and is absent from McLarty No. 1, but thickens southwards to 227.6 m in WAPET Sahara No. 1 (WAPET, 1966b); it also thickens to the southeast. The Formation consists of medium-grey, calcareous mudstone with minor interbeds of fine sandstone and limestone. Pyrite occurs throughout as well as fossils. Fossil fragments and palynomorphs recovered from the cores and cutting in the well section indicate an Early Permian (Artinskian) age (WAPET, 1966b).

In the vicinity of latitude 20°21′15″S and longitude 124°13′45″E, very fine to fine-grained well-sorted sandstone crops out. The sandstone has well-developed thin bedding. Its relation to other outcrops is unknown. The sandstone is more compact and indurated than the Mesozoic rocks in the Joanna Spring and the adjoining Sheet areas. It has been mapped as *Permian undivided.*

MESOZOIC

Early to Late Jurassic

The *Wallal Sandstone* (McWhae *in* WAPET, 1961) is the base of the Jurassic section in the western Canning Basin. It was penetrated in Total Kemp Field No. 1 between 52.7 m and 103.3 m and is 102.1 m thick in Total McLarty No. 1 to the north, and 370 m in WAPET Munro No. 1 to the northwest. Its absence from wells to the south and southeast, together with seismic information, suggests that deposition of the Wallal Sandstone was mainly confined to the northwestern sector of the Sheet area. The unit consists largely of quartz sandstone with lenses of siltstone, conglomerate, and coal; it has been dated as Early to Late Jurassic (Toarcian to Oxfordian) from the abundant microflora and microfauna present (WAPET, 1961). The formation unconformably overlies the Permian Noonkanbah Formation; an angular discordance between the units is evident on the seismic sections. The top of the sandstone is conformable with the overlying Alexander Formation.

Late Jurassic

The *Alexander Formation* (Brunnschweiler, 1954) was intersected immediately below Holocene sands in Total Kemp Field No. 1, in which it is 35.9 m thick. It was penetrated in wells to the northwest and west, but not in those south or east of the Sheet area, suggesting that its deposition may also have been restricted to the northern and western parts of the Sheet area. The unit conformably overlies the Wallal Sandstone and is disconformably(?) overlain by the Frezier Sandstone and possibly by the Anketell Sandstone. The predominantly fine to medium-grained sandstone with mudstone interbeds has been dated as Late Jurassic (late Oxfordian to Kimmeridgian) from a rich macrofauna in exposures to the north in the Mount Anderson Sheet area, and from microflora.

Jurassic to Early Cretaceous

The oldest Mesozoic unit to crop out in the Sheet area is the *Callawa Formation,* which is exposed as small hills in the centre of the Sheet area. This high-energy fluvial sequence consists of cross-bedded, poorly sorted, fine to coarse sandstone, conglomerate, and minor siltstone. It may unconformably overlie the Permian Noonkanbah Formation and is laterally equivalent in part to, and partly underlies the Frezier Sandstone (Towner & Gibson, 1980). Only plant fossils have been found in the Callawa Formation, in the Callawa Hills (Yarrie Sheet area); Brunnschweiler (*in* Traves & others, 1956) identified several genera and assigned them a Late Triassic or Early Jurassic age. M. White (*in* Veevers & Wells, 1961) re-examined this collection and determined a Late Jurassic or Early Cretaceous age. Towner & others (1976) preferred a Jurassic to Early Cretaceous age for the formation, because of the absence of Triassic rocks elsewhere in the south of the Canning Basin. The Callawa Sandstone is at least 52 m thick in the Callawa Hills and is probably no more than that in this Sheet area.

At latitude 20°33′45″S, longitude 123°38′45″E, beside a small fault scarp, a sequence of massive, poorly-bedded, fine-grained sandstone with a substantial heavy-mineral content is exposed. It is capped by the Callawa Formation. The sequence may be equated with the Broome Sandstone but, due to the lack of precise dating and its distance from known Broome Sandstone exposures, it has been labelled *JK undivided* on the map.

Early Cretaceous

The *Frezier Sandstone* (Lindner & Drew *in* McWhae & others, 1958) is a unit of sandstone and minor conglomerate which rests on, and is laterally equivalent in part to, the Callawa Formation; it is considered to overlie, possibly disconformably, the Alexander Formation. The unit crops out as low, black, strongly ferruginised hills in the western half of the Sheet area. The age of the Frezier Sandstone is considered to be Early Cretaceous (possibly Aptian), based on rare fossils collected outside the Sheet area (Dickins *in* Veevers & Wells, 1961), and on its stratigraphic relation to other older units not present in the Sheet area (Towner & Gibson, 1980). It is probably a fluvial to deltaic deposit which in places has been subjected to pedogenic processes. Up to 40 m of Frezier Sandstone crops out at Battlement Rocks and Turkey Place Hill. At both localities the base is not exposed and the top is eroded.

The *Anketell Sandstone* (Traves & others, 1956) disconformably overlies the Frezier Sandstone and crops out in low breakaways and mesas; the best exposures occur at Traves Cliff and in a breakaway south of the Grabowsky Range. Fine to coarse sandstone, pebble conglomerate, and siltstone are the dominant rock types; the fine sandstone and siltstone are more prominent towards the top of the sequence. The sediments are laminated to thin-bedded and cyclically bedded, the cycles being made up of beds of poorly to moderately sorted coarse sandstone and conglomerate alternating with thin beds of siltstone and fine sandstone. Depositional features such as planar and small trough cross-bedding and ripple marks are present. Organic traces present are rare wood fragments, and *Rhizocorallium* worm burrows. The formation is laterally equivalent to the Samuel Formation which crops out on the Morris Sheet area to the southeast (Jackson & van de Graaff, 1981; Towner & others, 1976), and is therefore Early Cretaceous. The Anketell Sandstone was deposited in brackish water, probably in a nearshore environment (Towner & others, 1976). About 15 m of section is present at Traves Cliff where the base in not exposed (Veevers & Wells, 1961). Its top is everywhere eroded. The thickness of the formation probably ranges up to 30 m.

Cretaceous to Tertiary

The *Lake George Beds* (Crowe & Towner, 1976; Towner & Gibson, 1980), unconformably overlie the Anketell Sandstone and crop out in two small areas in the eastern part of the Sheet area. The beds consist of massive, fine to coarse, poorly sorted sandstone. No fossils are known from the unit. The beds are considered to be fluvial overbank deposits and in part pedogenic (Towner & others, 1976). In this Sheet area the beds have an eroded top and are no more than 2 m thick.

Cainozoic

Surficial rock and soil units, the produce of weathering in an arid climate, cover most of the Sheet area. The Cainozoic units depicted on the map commonly grade into one another and their recognition on airphotos is based on subtle differences in photo-tone arising from topographic position and expression, and vegetation cover; their mapped boundaries are approximate.

Ferruginous and siliceous duricrusts overlying deeply kaolinised zones are widespread; they were probably formed pedogenically during the early Cainozoic in a more humid climate than at present. Hard crusts of pisolitic and massive *laterite* (Czl), 1-3 m thick, are well developed on the fine-grained clastic rocks of the Anketell Sandstone, and on parts of the Frezier Sandstone.

Weathering of this lateritic crust has formed a smooth *undulating plain capped by residual soil* (Czs) which consist of sand, ferruginous pisoliths, and minor clay. Shallow depressions within this plain are part of a relict drainage system which has been mapped over much of the arid interior of Western Australia (van de Graaff & others, 1977). The system can have originated only during a period of much higher rainfall than is being experienced at present, probably during or before the Miocene (Lowry & others, 1972; van de Graaff & others, 1977). With a change to a drier climate and continued weathering and erosion, these depressions became filled with sediments composed of a mixture of *aeolian and alluvial sand, silt, and clay* (Qs) deposited by discharging distributaries.

Both pedogenic and fluvio-lacustrine forms of *calcrete* (Czk) are present, mainly in the western part of the Sheet area. They occur as low rises and rubble of pale grey limestone with minor, hard, vuggy chalcedony. Calcrete was and still is being formed by precipitation of carbonate from groundwater when the drainage depressions become filled with sediments.

Lake deposits (Ql) occur in the small claypans in the southern and northern parts of the Sheet area. Clay, silt, and sand were deposited in these during temporary filling with a few centimetres of water after heavy rain. Gypsum is precipitated on the sediments as a thin crust, and within them as an intergranular cement when the water evaporates.

Aeolian sand (Qz), the most widespread of the Quaternary units in the Canning Basin, forms extensive dune fields throughout the Sheet area. The dunes are topographically higher than the adjacent Quaternary units and consist of west-northwesterly and westerly trending longitudinal (seif) dunes composed of wind-blown red, well-sorted, fine to medium-grained quartzose sand. They are mainly 5-15 m high, stationary, and vary in length, density, and complexity. The slopes of the dunes support a light spinifex cover, indicating that very little sand movement now takes place. The crests, on the other hand, support very little vegetation and are loosely packed. Veevers & Wells (1961) and Crowe (1975) have described the sand dunes of the Great Sandy Desert.

STRUCTURE

The Joanna Spring Sheet area lies on the northern flank of the Kidson Sub-basin, a large, broad depression identified from aeromagnetic surveys (WAPET, 1966a; Koop, 1966b; Darby & Fraser, 1969; Playford & others, 1975). Seismic evidence (French Petroleum Company, 1967), and information from Total Kemp Field No. 1 and WAPET Sahara No. 1 indicate a thickening of the pre-Mesozoic sedimentary section in the southern portion of the Sheet area. The maximum estimated depth for this portion of the Kidson Sub-basin is over 6000 m in the southeastern corner.

The pre-Mesozoic sequence gradually thins to the north towards the Broome Arch on the McLarty Hills Sheet area, and to the northwest towards a structural high termed the Munro Arch located immediately northwest of the Sheet boundary. However, information from the surrounding Sheet areas indicates that the Jurassic to Cretaceous sequence thickens to the northwest from the centre of the Joanna Spring Sheet area.

A large anticlinal fold in the northwestern corner of the Sheet area coincides with the gravity ridge of Darby & Fraser (1969), who indicated that the gravity ridge could represent either a basement ridge or the presence of dense sediments in the core of the anticline, or both. No major faults appear to cut the Kidson Sub-basin sequence in this Sheet area.

GEOLOGICAL HISTORY

During the Precambrian, sedimentary strata were deposited and crystalline rocks were emplaced. They were deformed, probably also in the Precambrian. These rocks form the basement of the Canning Basin.

Information from outside the area suggests that, following a long period of erosion, silt, sand, and carbonates (Nambeet, Willara, Goldwyer, and Nita Formations) were deposited in a shallow sea that began to cover the area during the Early Ordovician. The sea retreated in Middle to Late Ordovician time and erosion followed. After this pause in deposition, a shallow restricted sea covered the area, and mud, carbonate, and halite (Carribuddy Formation) were deposited during the Late Ordovician to Early Devonian.

In the Early Devonian, a desert environment prevailed over the whole Sheet area. Fine red sands were distributed by winds and rivers (Tandalgoo Red Beds) over an extensive plain. The sea transgressed the land during the Mid-Devonian, and carbonates, mud and some sand accumulated (Mellinjerie Limestone). During the Devonian, downwarping occurred in the south Canning Basin to form the Kidson Sub-basin. There is no evidence that sediments were laid down in the Late Devonian or Carboniferous in this Sheet area.

In the earliest Permian, the sea covered the Sheet area, and the climate was cold; the adjacent highlands to the south (Paterson Range Sheet area) were undergoing glaciation. Sand with striated pebbles was deposited first, followed by mud and very fine sand (possibly due to a relative rise in sea level), and then by sand again (Grant Group). After a short interval of folding, faulting, and erosion in the north Canning Basin (Fitzroy Trough), the climate warmed, and sand and silt (Poole Sandstone) were laid down in a shallow transgressive sea. This was followed by the deposition of mainly mud and carbonate (Nookanbah Formation). There is no evidence in this Sheet area on which to base the rest of Permian history, but nearby to the south (Towner & others, 1976), the fine sand and mud of the Permian Triwhite Sandstone was deposited as the sea retreated from the South Canning Basin. This would seem to have been followed by erosion until the Jurassic.

Sedimentation resumed in the Jurassic, when continental and marginal marine sediments were laid down on relatively flat terrain (Wallal Sandstone). The sea then rose and moved southeastward across these sediments, particularly in the northern and western portions of the Sheet area, depositing sand and mud in very shallow water (Alexander Formation). Commencing at the same time and continuing into the Early Cretaceous, meandering rivers spread gravel, coarse sand, and silt (Callawa Formation) mainly across the southern part of the Sheet area.

With the regression of the sea from the Joanna Spring Sheet area in the Early Cretaceous, fine sand (Frezier Sandstone) was laid down by rivers which spread over the river-plain deposits of the Callawa Sandstone and the shallow-water deposits of the Alexander Formation. Later in the Early Cretaceous, following the transgression of the sea northwards from the Officer Basin region to the south (Jackson & van de Graaff, 1981; Towner & others, 1976) paralic conditions prevailed in the eastern and southern parts of the Sheet area, where fine sand and silt (Anketell Sandstone) were deposited in brackish water.

From Late Cretaceous time onwards, deep chemical weathering affected the entire Sheet area and the terrain was mainly of low relief. A widespread drainage system which is still partly preserved may have started developing at about this time (van de Graaff & others, 1977). The Lake George Beds may represent the earliest deposits of this drainage system. As the climate became hotter and more humid, extensive lateritic profiles developed, preserving this drainage pattern. Laterite may have formed periodically throughout the Cainozoic until the climate eventually became arid.

Erosion of the lateritic profile sculptured mesas and hills. As the climate dried, the streams became choked with alluvium, and playa lakes developed. Calcrete and minor evaporites formed around the lakes and in the drainage channels, and may still be forming. Continued weathering of the lateritic surface produced unconsolidated material which became increasingly susceptible to wind modification. Large dune fields developed during the more arid phases of the Pleistocene.

ECONOMIC RESOURCES

Little exploration has been carried out in the Sheet area but available information suggests that the economic potential is small. In addition, the distance between the area and the nearest centres of population makes exploration expensive, and these two factors therefore make it relatively unattractive.

Petroleum

Geophyisical surveys have revealed the presence of broad subsurface structures in the area, and units considered to have petroleum source rock potential elsewhere in the Canning Basin are present in Total Kemp Field No. 1.

As a result of a study of the geothermal constraints on the hydrocarbon potential of the Canning Basin, Burne & Kantsler (1977) concluded that the rock types which are considered to represent the most suitable source rocks occur in the Ordovician and Middle Devonian to Lower Carboniferous sequences. Although maturation and organic-content determinations indicate that the Ordovician sequences have source potential, the Ordovician strata have a low permeability and are also devoid of suitable reservoir lithologies.

The Middle Devonian Mellinjerie Limestone has low porosity and permeability in wells drilled to the southeast of the Sheet area, (WAPET, 1966c; AAP, 1969) and could act as a cap. Below it, both the Devonian Carribuddy Formation and the Tandalgoo Red Beds were deposited in mainly oxidising conditions and have very limited source potential, although the Tandalgoo Red Beds are one of the best potential reservoir units in the whole of the Canning Basin (Burne & Kantsler, 1977).

Of the remainder of the Palaeozoic sequence, the shale units in the Grant Group and Noonkanbah Formation may have some source rock potential, and the sandstone unit in the Grant Group has reservoir potential. However, most of the upper Palaeozoic units may not have been buried deeply enough and heated sufficiently to generate hydrocarbons. The area also appears to lack suitable faults, traps, and structural closures. In addition, the potential reservoirs in the Permian, Devonian, and also in the Jurassic are flushed with fresh water. The thin Mesozoic rocks in the Sheet area have no petroleum potential.

Water

Surface water is scarce owing to the low rainfall and high evaporation rate. Limited potable water exists in small rock holes after rain. Some rain water may also persist for a short time in the claypans between dunes but is generally unsuitable for human consumption.

Groundwater has not been systematically investigated and information on its occurrence, quality, and yield is meagre. Aquifers in the Grant Group, Callawa Formation, and Wallal Sandstone have yielded fresh water in the petroleum exploration wells drilled in the Joanna Spring and Sahara Sheet areas (Total, 1968a; WAPET, 1964b; 1966b).

Evaporites

A thick sequence of evaporites (halite with minor gypsum and anhydrite) was intersected at depth in the Carribuddy Formation in Total McLarty No. 1 to the north (Total, 1968b; Glover, 1973; Wells, 1980), These may also be present in the Joanna Spring Sheet area.

Construction materials

Abundant supplies of pisolitic laterite, suitable for road construction, are available in the Sheet area.

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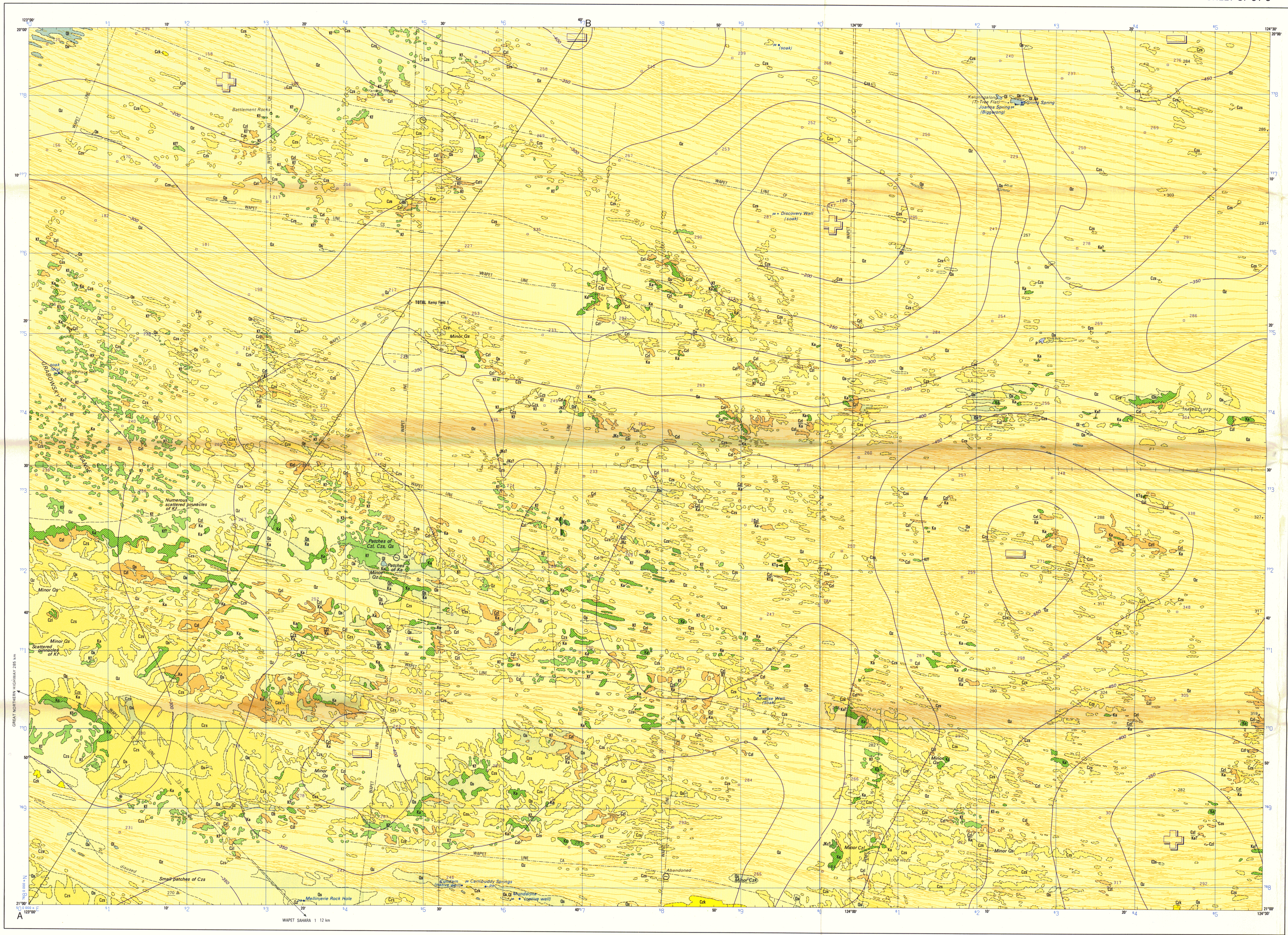
SHEET SF 51-3



CAINOZOIC	QUATERNARY	
	Ql	Clay, silt, sand; minor gypsum: lacustrine
	Qs	Sand, silt; minor gravel: mixed alluvial and aeolian
	Qz	Red sand, fine to medium; minor silt: aeolian
	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	CRETACEOUS TO TERTIARY — Lake George Beds	KTg — Sandstone, fine to coarse; poorly sorted, massive: fluvial and pedogenic
	EARLY CRETACEOUS — Anketell Sandstone	Ka — Fine sandstone, siltstone, interbedded with coarse sandstone and granule conglomerate; laminated to thin-bedded; bioturbated: probably paralic
	EARLY CRETACEOUS — Frezier Sandstone	Kf — Sandstone, fine to coarse, poorly sorted, feldspathic, poorly bedded, some relict cross-bedding: fluvial to deltaic, partly pedogenic
		JK — Sandstone, fine, massive: marine
	JURASSIC TO EARLY CRETACEOUS — Callawa Formation	JKc — Sandstone, very fine to coarse; conglomerate; cross-bedded; minor siltstone; plant fossils: fluvial
	LATE JURASSIC — Alexander Formation	Ja — Sandstone, fine to medium; interbedded mudstone, bioturbated, fossiliferous: shallow water marine (Section only)
	EARLY ? TO LATE JURASSIC — Wallal Sandstone	Jl — Sandstone; minor siltstone, conglomerate; palynomorphs: probably paralic (Section only)
PALAEOZOIC	PERMIAN	P — Sandstone, very fine to fine, well sorted, thin-bedded
	EARLY PERMIAN — Noonkanbah Formation	Pn — Mudstone, calcareous, micaceous; fine sandstone, limestone interbeds; fossiliferous: marine (Section only)
	EARLY PERMIAN — Poole Sandstone	Pp — Sandstone, very fine to fine; interbedded siltstone; thick-bedded; clay pellet lenses: shallow water marine (Section only)
	EARLY PERMIAN — Grant Group	Pg — Sandstone, fine to coarse; mudstone; minor conglomerate (Section only)
	MIDDLE DEVONIAN — Mellinjerie Limestone	Dm — Dolomitic limestone, dolomite, shale; minor sandstone, anhydrite (Section only)
	EARLY DEVONIAN — Tandalgoo Red Beds	Dt — Fine sandstone, reddish brown; minor siltstone, shale, limestone (Section only)
	LATE ORDOVICIAN ? TO EARLY DEVONIAN — Carribuddy Formation	Sc — Dolomite, dolmitic siltstone, shale, halite, anhydrite; minor sandstone (Section only)
	MIDDLE ORDOVICIAN — Nita Formation	On — Limestone, dolomite, interbedded shale (Section only)
	MIDDLE ORDOVICIAN — Goldwyer Formation	Oo — Shale, black, fossiliferous, calcareous, pyritic; interbedded limestone, dolomite; minor siltstone lenses (Section only)
	EARLY ORDOVICIAN — Willara Formation	Ow — Limestone, dolomitic, fossiliferous; interbedded shale and siltstone (Section only)
	EARLY ORDOVICIAN — Nambeet Formation	Ot — Shale, grey to green; interbedded limestone and fine sandstone (Section only)
PRECAMBRIAN		p€ — Igneous, metamorphic, and sedimentary rocks (Section only)

Geological boundary

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

Dip 5°-15°, Trend-line, Joint pattern — airphoto interpretation

Macrofossil location

Petroleum exploration well, dry, abandoned

Well

Spring

Soak, native well

pa Position approximate

Sand dunes

Vehicle track

Seismic line

Landing ground

270 Trigonometrical station with elevation in metres accurate

281 Elevation in metres approximate

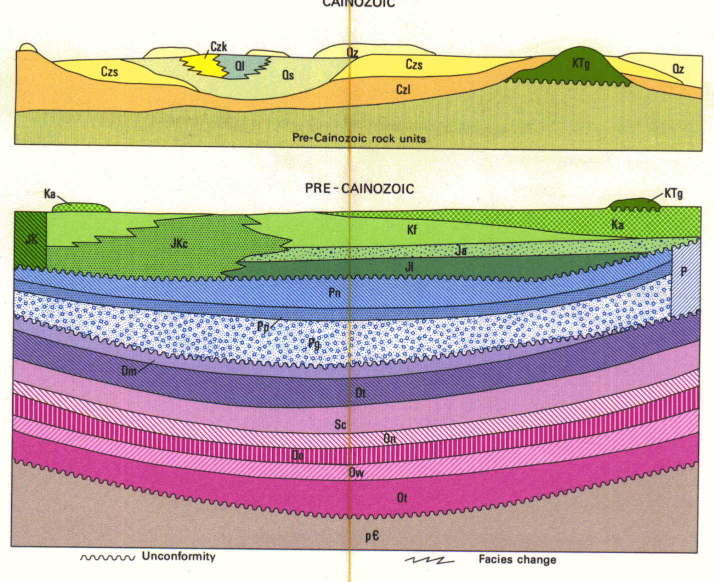
182 Selected gravity station with elevation in metres

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

Gravity anomaly — relative high

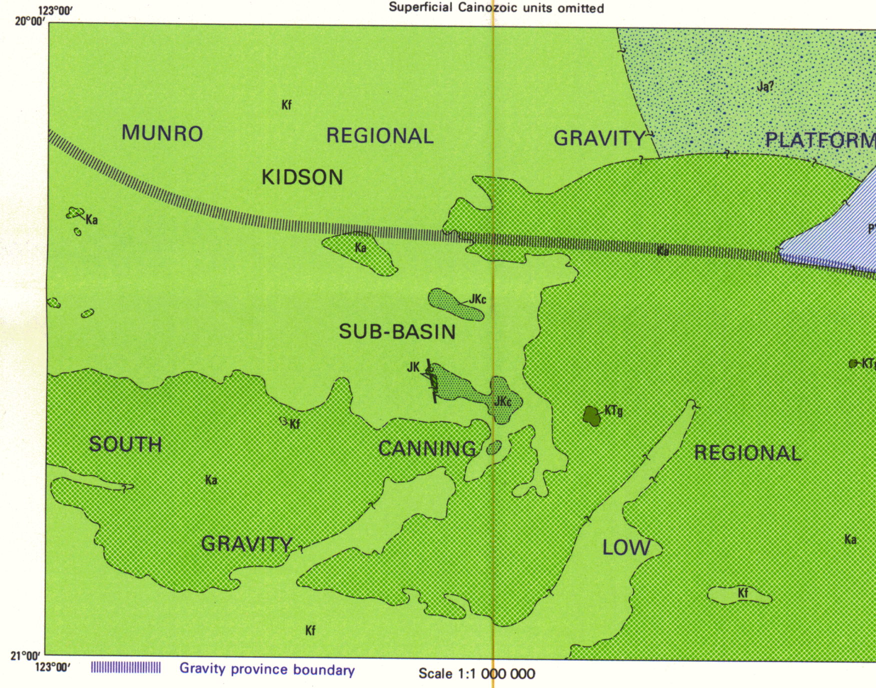
Gravity anomaly — relative low

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



SIMPLIFIED GEOLOGY AND STRUCTURE

Superficial Cainozoic units omitted



Gravity province boundary — Scale 1:1 000 000

Published by the Bureau of Mineral Resources, Geology and Geophysics Department of National Development and Energy, in conjunction with the Geological Survey of Western Australia. Issued under the joint authority of the Minister for National Development and Energy and the Minister for Mines, Western Australia. Base map compiled by the Division of National Mapping from aerial photography at 1:50 000 scale.

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INDEX TO ADJOINING SHEETS

Showing magnetic declination 1975

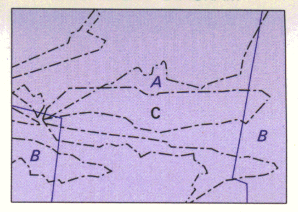
INDIAN OCEAN	LA GRANGE SE 51-10	MOUNT ANDERSON SE 51-11	NOONKANBAH SE 51-12	MOUNT RAMSAY SE 52-9
MANDORA SE 51-13	MUNRO SE 51-14	McLARTY HILLS SE 51-15	CROSSLAND SE 51-16	MOUNT BANNERMAN SE 52-13
YARRIE SF 51-1	ANKETELL SF 51-2	JOANNA SPRING SF 51-3	DUMMER SF 51-4	CORNISH SF 52-1
NULLAGINE SF 51-5	PATERSON RANGE SF 51-6	SAHARA SF 51-7	PERCIVAL SF 51-8	HELENA SF 52-5
BALFOUR DOWNS SF 51-9	RUDALL SF 51-10	TABLETOP SF 51-11	URAL SF 51-12	WILSON SF 52-9

SCALE 1:250000

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



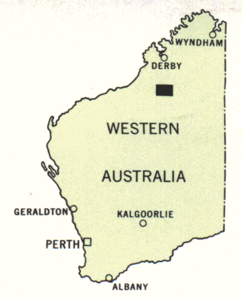
Geology C General reconnaissance: few traverses mainly airphoto interpretation

Helicopter traverse

Gravity A Detailed survey

B Reconnaissance

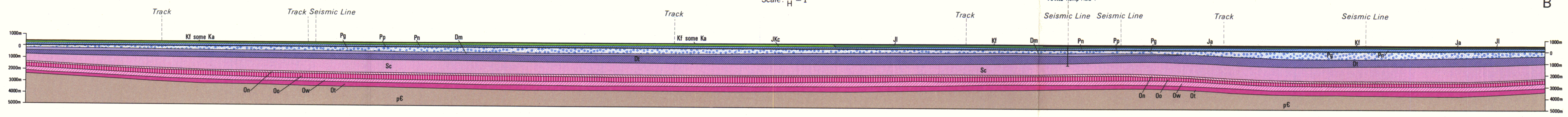
Geology 1957 by J.J. Veevers BMR
1977 by R.R. Towner, D.L. Gibson BMR
R.W.A. Crowe GSWA
Compiled 1978 by R.R. Towner, L. Murray
Gravimetry 1960-68 by BMR and private companies
Design by Cartography Section BMR
Drawn by Cangraphics Pty Ltd
Printed by Mercury Walch, Hobart, Australia



SCHEMATIC SECTION

Cainozoic sediments omitted

Scale: $\frac{V}{H} = 1$



FIRST EDITION 1980

JOANNA SPRING

SHEET SF 51-3

Copies of this map may be obtained from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A C T , or the Geological Survey of Western Australia, Perth