1:250,000 GEOLOGICAL SERIES—EXPLANATORY NOTES

HALE RIVER

NORTHERN TERRITORY

SHEET SG/53-3 INTERNATIONAL INDEX

COMMONWEALTH OF AUSTRALIA

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Compiled by R. D. Shaw

Issued under the authority of the Hon. David Fairbairn, Minister for National Development

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT
MINISTER: THE HON. DAVID FAIRBAIRN, D.F.C., M.P.
SECRETARY: R. W. BOSWELL, O.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
DIRECTOR: J. M. RAYNER, O.B.E.

THESE NOTES WERE PREPARED IN THE GEOLOGICAL BRANCH
ASSISTANT DIRECTOR: N. H. FISHER

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Explanatory Notes on the Hale River Geological Sheet

The Hale River Sheet area is situated in the Northern Territory east-south-east of Alice Springs, on the north-western margin of the Simpson Desert, and is bounded by longitudes 135° E and 136°30′ E and latitudes 24° S and 25° S. The area includes the north-eastern margin of the Amadeus Basin and the western margin of the Great Artesian Basin.

There are no settlements in the Sheet area. The nearest homesteads are Ringwood, 16 miles to the north-west, Limbla and Numery to the north, and Andado 38 miles to the south. There is one formed road in the north-west corner, and two tracks across the area from north to south. Several more tracks lead to watering points in the grazing areas. Cattle raising is the main industry, and is restricted to the western part.

The climate is semi-arid and is characterized by large diurnal and annual fluctuations in temperature (Slatyer, 1962). There is a difference of 30° F between the mean monthly maximum and minimum. Summer temperatures commonly exceed 100° F, and some frosts occur during the winter months.

The area lies in the 5 to 8-inch rainfall belt; most of the rain falls during sporadic storms. Water is available from bores, and in good seasons surface water is present in dams around the tablelands in the south. Further information on climate, soil, vegetation, and land use is given in Perry et al. (1962).

Maps and air-photographs covering the Hale River Sheet area include a photo-mosaic map (4 miles to 1 inch); a 1 : 250,000 topographical map (SG/53-3); dyeline maps at a scale of about 1 : 46,500, controlled by slotted-templet assembly, prepared by the Division of National Mapping, Department of National Development; and air-photographs at a scale of about 1 : 46,500 taken by the Royal Australian Air Force in 1950.

Previous Investigations

In 1904 Barclay (1916) travelled around the western margin of the Simpson Desert and skirted the western boundary of the Hale River Sheet area. In 1916, an expedition led by Day (1916) mapped the Hale and Todd Rivers. Madigan (1929) passed over the southern and north-eastern parts of the area during an aerial reconnaissance of the Simpson Desert.

The first detailed subdivision of the sedimentary succession was made by Mawson & Madigan (1930), who defined formations at Ellery Creek in the Hermannsburg Sheet area. Madigan (1932b) divided the rocks of the eastern MacDonnell Ranges into Archaean (Arunta Complex), Upper Proterozoic (Pertaknurra and Pertatataka Series), Cambrian (Pertaoorrta Series), and Ordovician (Larapintine Series).

The Amadeus Basin was mapped by the Bureau of Mineral Resources at a scale of 1:250,000 between 1956 and 1964. Prichard & Quinlan (1962) worked in the Hermannsburg Sheet area and redefined a number of Madigan's rock units. The north-eastern part of the Amadeus Basin, including the Hale River Sheet area, was mapped in 1964 (Wells et al., 1967; Forman, Milligan, & McCarthy, 1967). Balme (1959) and Evans (1964) have reported on the palynology of the Great Artesian Basin sequence in adjacent areas.

A land research study of the southern part of the Northern Territory by CSIRO was completed in 1958 (Perry et al., 1962). The study included a report on the geology by Quinlan & Ryan, an outline of the geomorphology by Mabbutt, and a report on the groundwater resources by Jones & Quinlan.

In 1956-60, Frome-Broken Hill Co. Pty Ltd made an appraisal of the petroleum prospects of the north-eastern part of the Amadeus Basin. Thomas (1956) reviewed previous geological work; McLeod (1959), Phillips (1959), and Wulff (1960) reported on the geology; and Taylor (1959a, 1959b) identified the fossils collected by the geologists. McNaughton (1962) and Ranneft (1963) assessed the potential of the entire Amadeus Basin, and Sprigg (1963) summarized information on the Great Artesian Basin in the Simpson Desert region and on the north-east Amadeus Basin. Michoud, Eyssautier, & Gates (1964) measured stratigraphic sections in the Hale River Sheet and adjacent areas, and Banks (1964) suggested an informal threefold subdivision of the Bitter Springs Formation while carrying out mineral reconnaissance for Magellan Petroleum Corporation in the north-eastern part of the Amadeus Basin.

Geophysical work has been undertaken for Flamingo Petroleum Pty Ltd and the Bureau of Mineral Resources. Burbury (1960) produced Bouguer anomaly maps of the old Oil Permits 34 and 42, which include the western half of the Hale River Sheet area. In 1960, the Bureau of Mineral Resources made a reconnaissance gravity survey in the Georgina Basin and neighbouring areas (Barlow, 1962). Langron (1962) made a regional gravity reconnaissance in the eastern Amadeus Basin, and this was continued into the western part of the basin by Lonsdale & Flavelle (1963).

A reflection seismic survey from the Rodinga Ranges to Malcolms Bore, along the track to Andado, was carried out by Denton (1961a). He estimated less than 4000 feet of section to be present near Malcolms Bore. A second seismic survey in 1963 by Bowman & Harkey indicated an east-plunging anticline which may represent the divide between the Amadeus and Great Artesian Basins. Seismic control was extended eastwards beyond the Hale River by Campbell (1965), who detected a shallow regional dip to the south-east.

An aeromagnetic survey of the Simpson Desert by the Bureau of Mineral Resources in 1962 included the Hale River Sheet area. The results were published as a total magnetic intensity map at a scale of 1:250,000 (Quilty & Milsom, 1964). Additional flight lines over most of the Sheet area were later flown by Aeroservice Ltd, and depths to basement were reinterpreted by Hartman (1964). The depths estimated by Hartman are in approximate agreement with recent estimates in the Rodinga Sheet area (Young & Shelley, 1966).

PHYSIOGRAPHY (Fig. 1)

The region lies within the Lake Eyre Drainage Basin of Mabbutt (1962), and three-quarters of the Sheet area lies within the Simpson Desert as defined by Madigan (1938). The elevation ranges from about 1000 feet above sea level in the north-west to less than 600 feet in the south-east. The three major streams, the Todd and Hale Rivers and Illogwa Creek, flow south-south-east across the area. The Todd River and Illogwa Creek both terminate on outwash plains in the Sheet area and the Hale River floods out in the McDills Sheet area to the south.

The land forms and geomorphological history have been outlined by Mabbutt (1962). After the sea retreated in Upper Cretaceous time there was a long period of erosion during a humid climate cycle. A deeply weathered peneplain formed, and is still partly preserved as a low tableland in the southern part of the area. During the subsidence of the Lake Eyre Drainage Basin the tableland was tilted to the south-east, and as a result of the tilting the weathered land surface and the ranges in the north-west corner of the Sheet area were dissected. When the climate became more arid, the outgoing drainage (to Lake Eyre) was substantially reduced, and the present internal drainage system established. The sandy alluvium was resorted by winds to form sand dunes and sand plains on lower ground. Earlier alluvial deposits were incised in late Quaternary time.

In the *Simpson Desert* the sand dunes are 100 to 1200 yards apart and are commonly about 40 feet high, with a maximum of 70 feet. The dunes are fixed by vegetation except along their crests, where some sand still moves. They trend north-north-west, and the eastern slopes are generally steeper than the western slopes. The flat interdune swales are filled with sand underlain by silt and clay. Spinifex is widespread throughout the desert, and eucalyptus and mulga grow along the drainage channels.

Sand plains border the Hale River and the leeward side of some of the ranges. The partly dissected *stony tablelands,* including the Allitra Tableland, have formed on the Rumbalara Shale and Etingambra Formation in the south. They rise 50 to 150 feet above the plain and slope south-eastwards, and are capped by Tertiary silcrete.

The *low mounds and banks* of loose material, which average 20 feet in height around Day Pinnacle, are the eroded remnants of the poorly consolidated conglomeratic sediments of the Pertnjara Group and the Crown Point Formation. Sand plain surrounds the mounds and banks.

The *strike ridges and alluvial plains* in the north-east occur in a region of folded and thrusted sandstone and carbonate rocks interbedded with recessive siltstone units. The ridges trend north-easterly and are up to 300 feet high. Small valleys contain alluvial plains, gravel terraces, and some sand dunes.

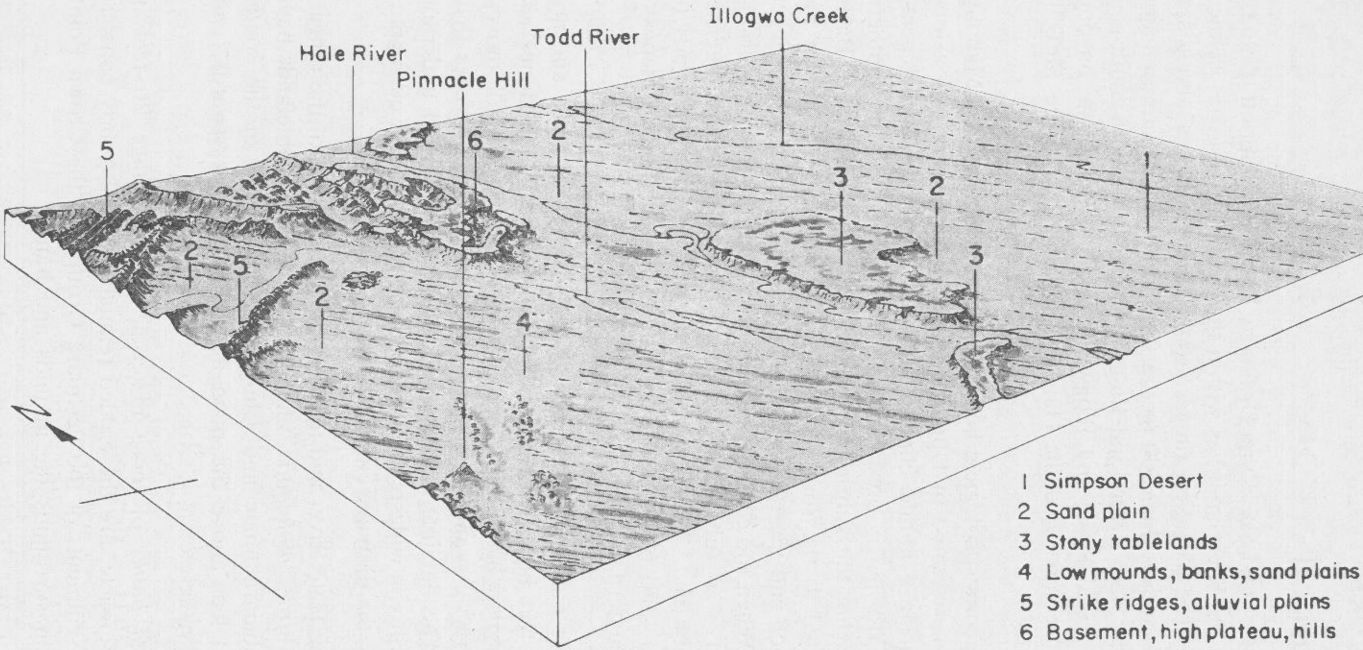

Fig. 1: Physiography of the Hale River Sheet

A *basement plateau* extends south-east from the north-west, where flat-lying Heavitree Quartzite forms a bold plateau with steep dissected escarpments up to 600 feet high. The underlying gneiss of the Arunta Complex forms plains and hills with a relief of up to 100 feet.

STRATIGRAPHY

The stratigraphy of the Hale River Sheet area is summarized in Tables 1, 2, and 3. The type localities and type sections of most of the rock units are in the Alice Springs Sheet area (Wells et al., in press) or the Hermannsburg Sheet area (Prichard and Quinlan, 1962).

PRECAMBRIAN (Table 1)

Metamorphic rocks of the ?Archaean *Arunta Complex* crop out in the plains and low hills south of Casey Bore.

Proterozoic

The *Heavitree Quartzite* lies unconformably on the Arunta Complex; it is probably a shallow-marine shelf deposit. The *Bitter Springs Formation,* which rests conformably on the Heavitree Quartzite, consists of two members. Part of the *Gillen Member* (lower) acted as a surface of slip for thrust-sheets in the extreme north-western part of the Sheet area. The lower part of the overlying *Loves Creek Member* contains abundant algae of the *Collenia* type; also in the Loves Creek Member are lenses of spilitic volcanics, and these have been mapped as a separate unit. A specimen of shale from Mount Charlotte No. 1 Well in the Rodinga Sheet area has been provisionally dated by the rubidium-strontium method at 1170 m.y. (V.M. Bofinger, BMR, pers. comm.).

The *Areyonga Formation* rests disconformably on the Bitter Springs Formation; elsewhere in the Amadeus Basin the relationship is unconformable. The formation was laid down during a period of widespread erosion and glaciation, though no indisputably glacigene sediments crop out within the Sheet area.

The succeeding *Pertatataka Formation* is thicker and more varied in the Hale River Sheet area than elsewhere in the basin. Five thin lenticular members of sandstone, carbonate, and conglomerate are interbedded with the siltstone and shale which make up the bulk of the formation. The members are well exposed in a syncline north of Hi Jinx Bore, and the type section of the three lower members is 5 miles south-east of Ringwood homestead. The Pertatataka Formation is largely marine. Two specimens of shale from the Rodinga Sheet area have been dated by the rubidium-strontium method; one gave an apparent age of 822 $\pm$ 8 m.y., and the other 760 $\pm$33 m.y. (V. M. Bofinger, BMR, pers. comm.).

PALAEOZOIC (Table 2)

Cambrian

The oldest unit of the *Pertaoorrta Group,* the *Arumbera Sandstone,* is a molasse-type sediment which was laid down in a shallow sea while the Petermann Ranges Orogeny was still active in the southern part of the

TABLE 1. STRATIGRAPHY OF PRECAMBRIAN UNITS

Age	*Rock unit*	*Thickness (feet)*	*Lithology*	*Fossils*	*Stratigraphic relationships*	*Topography*	*Hydrology*
PROTEROZOIC	Pertatataka Formation (Pup)	1000–6000	Siltstone and shale, with lenses of sandstone, dolomite, limestone, and conglomerate		Conformable on Areyonga Formation	Wide strike valleys prominent strike ridges	Poor prospects
	Julie Member (Puj)	300–500	Oolitic dolomite, limestone, sandstone, calcareous sandstone, lenticular in places	Some stromatolites	Conformable on siltstone of Pertatataka Formation	Prominent strike ridges	Porosity variable, prospects generally poor
	Waldo Pedlar Member (Pul)	200	Thin-bedded fine sandstone and siltstone		Conformable on siltstone of Pertatataka Formation	Low strike ridge	Poor prospects
	Olympic Member (Puf)	Up to 600	Siltstone, sandstone, and a distinctive pink dolomite at top; minor lenses of ?tillitic conglomerate		?Disconformable on Limbla Member	Strike valley	Poor prospects
	Limbla Member (Pum)	500	Sandstone with small cross-laminations, interbedded with brown siltstone. Underlain by oolitic and quartzose calcarenite and dolomite interbedded with intraformational conglomerate and siltstone		Conformable on siltstone of Pertatataka Formation	Low strike ridge	Porosity variable prospects poor
	Ringwood Member (Pur)	500	Limestone (calcarenite and structureless) and dolomite interbedded with siltstone	Some stromatolites in basal dolomite	Conformable on siltstone of Pertatataka Formation	Low strike ridges	Poor prospects
	Areyonga Formation (Pua)	Up to 600, very thin in places	Lithologically variable: (i) Aralka Well area; boulder and pebble conglomerate with fragments of chert and dolomite (ii) No. 6 Phillipson Bore area; siltstone, feldspathic sandstone, tilloid; some lenses of conglomerate with phenoclasts of quartzite, gneiss, amphibolite, phorphyry, chert, and dolomite (iii) SE of No. 6 Phillipson Bore; sandstone, dolomite; sandstone arkosic in places		Overlies Bitter Springs Formation with angular discordance in places in Alice Springs Sheet area. Probably disconformable in Hale River Sheet area	Strike ridge	Porosity variable, porous parts could give moderate supply

DISCONFORMITY

PROTEROZOIC	Bitter Springs Formation (Pub)	3000(?)	Dolomite, limestone, siltstone, sandstone, some basic volcanics	Stromatolites	Conformably overlies Heavitree Quartzite	Low ridges and hills	Good supply in some areas, but water generally saline
	Loves Creek Member (Pue)	800	Poorly bedded algal dolomite, overlain by interbedded algal limestone, red siltstone, dolomitic siltstone, and basic volcanics	*Collenia*-like algae in poorly bedded dolomite	Conformably overlies Gillen Member of Bitter Springs Formation		
	(Pue_1)		Basic volcanics; spilitic with ferruginous and cherty bands		Lenticular bodies in Loves Creek Member, typically at base		
	Gillen Member (Pug)	1500(?)	Interbedded siltstone, sandstone, and dolomite; one conspicuous bed of coarse-grained sandstone and granule conglomerate	Stromatolites			
	Heavitree Quartzite (Puh)	600–1000	Silicified coarse-grained sandstone, pebbly sandstone		Unconformably overlies Arunta Complex	A highly dissected plateau, some prominent ridges	Extremely poor prospects
PRE-CAMBRIAN	Arunta Complex (pCa)	Unknown	Gneiss, schistose gneiss, schist, quartzite			Low hills	Prospects generally poor

TABLE 2. STRATIGRAPHY OF PALAEOZOIC UNITS

Age	Rock unit	*Thickness (feet)*	*Lithology*	*Fossils*	*Stratigraphic relationships*	*Topography*	*Hydrology*
Permian	Crown Point Formation (Pc)	1200(?) in Malcolms Bore	White poorly sorted sandstone, pebbly sandstone, tilloid, conglomerate, siltstone	Spores from Malcolms Bore	Uncertain—possibly unconformable on Pertnjara Formation	Mesas and low mounds	Sandstone should yield water if not too clayey
Devonian to Carboniferous	Finke Group (Pzf)	Possibly up to 1800	Orange, red, and white, fine to coarse-grained sandstone, interbedded with and overlain by red and green siltstone and shale. Possible basal conglomerate	None	Correlated with Pertnjara Group	Subsurface (information from McDills No 1 Well, McDills Sheet Area)	Salt water from sandstones
Devonian to Carboniferous	Brewer Conglomerate (Pzb)	300–3000 (?)	Pebble to boulder conglomerate: (i) East of Bingie Bore, phenoclasts mainly of Pertaoorrta Group (ii) East of Day Pinnacle, phenoclasts mainly of Precambrian units		Unconformable on older sediments	Rounded hills, heaps of loose boulders, dendritic drainage in places	
Devonian to Carboniferous	Hermannsburg Sandstone (Pzt)	Unknown	Sandstone (micaceous in observed exposures)	None in Sheet area	?Disconformable on Mereenie Sandstone in subsurface in south	Low strike ridges	
					DISCONFORMITY OR UNCONFORMITY		
?Silurian to Devonian	Mereenie Sandstone (Pzm)	3000(?)–1500	Sandstone with thin cross-beds or cross-laminations in parts	None	Overlies older units with a low-angle regional unconformity	Prominent strike ridges	Good aquifer
					LOW-ANGLE REGIONAL UNCONFORMITY		
Cambrian — Pertaoorrta Group	(Cp)	2950 in Hi Jinx Bore area	Interbedded siltstone, shale, dolomite; some limestone				Poor prospects
Cambrian — Pertaoorrta Group	Shannon Formation (Cs)	800 in Hi Jinx Bore area	Interbedded siltstone and laminated dolomite; some limestone and chert	Stromatolites common	Conformable on Giles Creek dolomite	Strike valleys with low dolomite ridges	Porosity and permeability low
Cambrian — Pertaoorrta Group	Giles Creek Dolomite (Ck)	550 in Hi Jinx Bore area	Thick-bedded dolomite, minor limestone, some shale	None in Sheet area. Early Middle Cambrian fossils in Alice Springs Sheet area	Conformable on Todd River Dolomite	One or more strike ridges	Poor prospects

CAMBRIAN	PERTAOORRTA GROUP	Todd River Dolomite (Cr)	350 in Hi Jinx Bore area	Silty, glauconitic, poorly-bedded dolomite; shale, friable sandstone, local pebble conglomerate	Archaeocyathids and '*Micromitra*' *etheridgei*	Conformable on Arumbera Sandstone in Hi Jinx Bore area; disconformable on Arumbera Sandstone 6 miles south-east of Aralka Well	Low strike ridge	Poor prospects
		Arumbera Sandstone (Ca)	1250 in Hi Jinx Bore area	Red-brown silty sandstone, siltstone, and with clay pellets and slumps (i) South-east of Hi Jinx Bore, upper part is pebbly and is overlain by white cross-laminated sandstone (ii) East of Aralka Well, red sandstone is overlain by 200 ft of siltstone and some sandstone	None in Sheet area. *Rangea arborea* (Glaessner) near base in Rodinga Sheet area	Conformable on Pertatataka Formation	Prominent strike ridge	Porosity generally poor, prospects not good

Amadeus Basin. Impressions assigned to *Rangea arborea* have been found in the lower part of the unit in the Rodinga Sheet area, and Glaessner (*in* Taylor, 1959b) considers them to be of Upper Proterozoic age. However, arthropod tracks and *Diplocraterion* higher in the formation are Cambrian (Joyce Gilbert-Tomlinson, BMR, pers. comm.).

The *Todd River Dolomite* is generally conformable, but locally disconformable, on the Arumbera Sandstone; the formation contains Lower Cambrian brachiopods and archaeocyathids. The *Giles Creek Dolomite* conformably overlies the Todd River Dolomite, and contains early Middle Cambrian fossils (Ordian) near the base. The unit is laterally equivalent to the lower part of the Jay Creek Limestone farther to the west. The succeeding *Shannon Formation* contains lower Upper Cambrian fossils (Mindyallan) at the top, and so it appears that the whole of the Middle Cambrian is represented by these two conformable formations. The fossils in both formations have been found from outside the Hale River Sheet area.

?Silurian to Devonian

The *Mereenie Sandstone* was deposited in a mixed marine, deltaic, and aeolian environment. It appears to lie comformably on the Shannon Formation, but observations elsewhere in the Amadeus Basin show that the relation is actually a low-angled regional uncomformity. The exact age limits of the Mereenie Sandstone are unknown.

Devonian to Carboniferous

Sandstone and conglomerate of the Pertnjara Group have been correlated with the *Hermannsburg Sandstone* and *Brewer Conglomerate* respectively of Wells et al. (in prep.). The sandstone crops out 8 miles north-east of Day Pinnacle, and the conglomerate is extensively exposed farther to the north.

The base of the Pertnjara Group is dated as late Middle or early Upper Devonian by spores and fish remains in the central part of the Amadeus Basin. In the Hale River Sheet area, the lower sandstone is not well enough exposed to show its stratigraphical relations; the upper conglomerate is markedly unconformable on older formations, and thins rapidly to the south.

The subsurface existence of the *Finke Group* is inferred in the area south of Day Pinnacle; it may interfinger with the lithologically similar Pertnjara Group along a north-easterly zone of thin sediments in the Day Pinnacle area (cf. Stewart, 1967).

Permian

The *Crown Point Formation* is a unit whose glacigene origin can be seen at three localities near Day Pinnacle. Two of the outcrops are of white to red-brown massive sandy siltstone containing pebbles, cobbles, and boulders of quartzite, some of which are faceted. A conglomerate from the same area also contains polished, faceted, and striated phenoclasts. The formation has been dated as Lower Permian by spores in Malcolms Bore (Balme, 1959; also *in* Evans, 1964) and as Upper Carboniferous at the bottom and Lower Permian at the middle and top in the McDills No. 1 Well in the McDills Sheet area (Evans *in* Amerada Petroleum Corp., 1965).

MESOZOIC (Table 3)

?Jurassic

The *De Souza Sandstone* crops out as caps on low mesas and as low mounds in the south-west. It is tentatively assigned to the Jurassic partly because it is similar to a sandstone in the Mount Anna area of South Australia which contains Upper Jurassic to Lower Cretaceous plant remains (Wopfner & Heath, 1963), and partly because it is overlain unconformably by the Lower Cretaceous Rumbalara Shale in the Finke Sheet area. Sandstone, mudstone, and grit near Aralka Well and in the north-eastern corner of the Sheet area are also referred to the De Souza Sandstone.

Lower Cretaceous

The *Rumbalara Shale* is exposed in cliffs in the low tablelands (including the Allitra Tableland) in the centre of the Sheet area. It is deeply weathered, and chalcedony, iron oxides, and partly silicified yellow ochre are commonly present.

CAINOZOIC (Table 3)

Tertiary

The *Etingambra Formation* caps mesas in the central and southern parts of the Sheet area. It lies disconformably or unconformably on the Rumbalara Shale.

Unnamed Tertiary sediments include sandstone, siltstone, and conglomerate, capped by silcrete, 3 miles south of Hi Jinx Bore, and limestone, siltstone, and shale 2 miles south of Ringwood No. 6 Bore.

Silcrete caps the Etingambra Formation, and small patches also occur on ridges of Mereenie Sandstone in the Rodinga Ranges. It is thought to be the result of near-surface silicification during prolonged weathering in the Middle Tertiary (Langford-Smith & Dury, 1965).

Quaternary

Sand dunes and plains are widespread over the area. *Alluvium* is found only along banks and floodouts of the main drainage channels, bordering outcrops, and in some interdune swales. Together, sand and alluvium cover about three-quarters of the Sheet area.

Conglomerate and *scree* mantle some hill slopes, and thin *gravels* cap the river terraces near Aralka Bore and Casey Bore.

GEOLOGICAL HISTORY

The basement rocks of the Arunta Complex include metamorphosed and folded sediments and igenous rocks which were deformed during the Arunta Orogeny (Forman, Milligan, & McCarthy, 1967) before the Heavitree Quartzite was deposited.

In the Proterozoic, the deposition of the coarse-grained sands of the Heavitree Quartzite, possibly in a shallow sea, was succeeded by the accumulation of the carbonate, siltstone, and sandstone of the Bitter Springs Formation.

TABLE 3. STRATIGRAPHY OF CAINOZOIC AND MESOZOIC UNITS

Age	*Rock unit*	*Thickness (feet)*	*Lithology*	*Fossils*	*Stratigraphic relationships*	*Topography*	*Hydrology*
QUATERNARY	Alluvium (Qa)	Up to 40	Alluvial clay and silt, some river sand and gravel	None		Stream deposits, alluvial flats, scree slopes	Good potential for high-quality water in places
	Aeolian sand (Qs)	100	Fine to coarse-grained sand	None		Dunes, sand plains	Above water-table
	Conglomerate (Qc)	Unknown	Conglomerate, gravel, scree	None		Gibber plains, scree slopes	
TERTIARY	Silcrete (Tb)	5–10	Silcrete 'grey billy'	None	Capping on Etingambra Formation	Mesa cappings	Impermeable and above water-table
	Undifferentiated (Ts)	80–100	Sandstone, silty sandstone, siltstone conglomerate, claystone, chalcedony	None	Unconformable on older formations. Possibly equivalent to Egingambra Formation	Low mesas	Known deposits are above water-table
	Etingambra Formation (Te)	15	Coarse-grained unsorted sandstone, pebbly sandstone, lenses of granule conglomerate	None	Disconformable on Rumbalara Shale	Mesa cappings	Above water-table
					DISCONFORMITY		
LOWER CRETACEOUS	Rumbalara Shale (Klr)	450(?), 320+ in Malcolms Bore	Dark grey glauconitic mudstone, generally exposed as white to yellow-brown shale; yellow ochreous claystone, fine to coarse-grained kaolinitic sandstone; slightly micaceous, partly cross-bedded sandstone	None in Hale River Sheet area. Molluscs, sponges, microfossils, and tracks and trails at type locality in Finke Sheet area	Contact not exposed, probably disconformable	Mesa cappings	Poor aquifer, water saline
					DISCONFORMITY		
JURASSIC(?)	De Souza Sandstone (Md)	300+ in Malcolms Bore	Partly cross-bedded, partly kaolinitic, partly ferruginized, poorly sorted sandstone; pebbly sandstone, granule conglomerate, siltstone	None	Disconformable on Crown Point Formation	Mesas	Good aquifers with good water

During this time, evaporites were deposited and extensive algal carbonates formed. The deposition of red siltstone and the extrusion of a small amount of basic volcanics occurred during the closing stages of deposition of the Bitter Springs Formation.

After the deposition of the Bitter Springs Formation, epeirogenic movement and some slight folding were followed by erosion.

The Areyonga Formation, a thin unit with some clastics of glacial affinities, was deposited. An invasion of the sea took place, and was followed by the deposition of shale, sandstone, limestone, and tilloid of the Pertatataka Formation, in a continually subsiding basin.

In the lowermost Cambrian further subsidence occurred, and the margin of the basin possibly extended across the north-west corner of the Sheet area from about Middle Bore to south of the Rodinga Ranges. During the time of the Peterman Ranges Orogeny, far to the south-west, the basin was filled by the red-beds of the Arumbera Sandstone, which has some deltaic aspects. A widespread invasion of a shallow sea followed in the Lower Cambrian, with the deposition of the shallow-water Todd River Dolomite containing archaeocyathids.

A more extensive marine invasion took place in the Middle and Upper Cambrian period and possible also in the Ordovician. Rhythmic deposition of carbonate and siltstone of the upper part of the Pertaoorrta Group took place in the Upper Cambrian. Ordovician sediments of the Larapinta Group (Cook, *in* Wells et al., in prep.) may have been deposited in the Hale River Sheet area, but there is now no record of them. Some supratenuous folding may have begun in this period.

The Alice Springs Orogeny (Forman, Milligan, & McCarthy, 1967) took place in the period from Silurian to Carboniferous. The sediments were folded and uplifted, and some overthrusting and slip took place along décollement surfaces. The Mereenie Sandstone was laid down in a transitional marine and aeolian environment over most of the northern part of the area in the early stages of the orogeny.

Before this, all sediments of the Larapinta Group were removed from the area (assuming they had once been present). The thick molasse-type freshwater conglomerate of the Pertnjara Group was laid down during the main paroxysm of the orogeny, and the Finke Group was deposited farther south, probably at the same time. At the close of the Carboniferous and continuing into the Lower Permian, the Crown Point Formation was deposited, in a fluvioglacial environment.

No Upper Permian or Triassic sediments are preserved in the area. The freshwater De Souza Sandstone was laid down possibly in the Jurassic or early Cretaceous, and was followed by a marine transgression and the deposition of the Rumbalara Shale.

General uplift occurred after the Aptian and was followed by weathering and slight erosion of the upper surface of the Rumbalara Shale. In the Lower Tertiary, the fluvial gravels of the Etingambra Formation were laid down.

Weathering and erosion continued and a capping of silcrete formed on the early Tertiary sediments and Rumbalara Shale. Subsidence of the Lake Eyre Basin far to the south tilted the Tertiary surface to the south-east, and the resulting erosion reduced the Etingambra Formation and Rumbalara Shale to remnant mesas.

STRUCTURE

Figure 2 shows the structural framework of the Hale River Sheet area. The superficial Cainozoic cover rocks have been omitted to show the extent of the major rock units beneath.

Precambrian. The basement rocks of the Arunta Complex have been deformed and metamorphosed. The resulting moderate to high-grade metamorphic rocks have a marked foliation trending north-north-west.

Proterozoic and Cambrian. No major unconformities are evident in the Proterozoic and Cambrian sequences. The sediments were folded during the Alice Springs Orogeny, commencing in the Silurian (?) and reaching a climax in the Upper Devonian to Carboniferous. The folding caused the development of north-easterly folds and also two décollement surfaces, one in the lower part of the Bitter Springs Formation and the other near the base of the Pertaoorrta Group. Evaporites may be present at these levels (Wells et al., 1967).

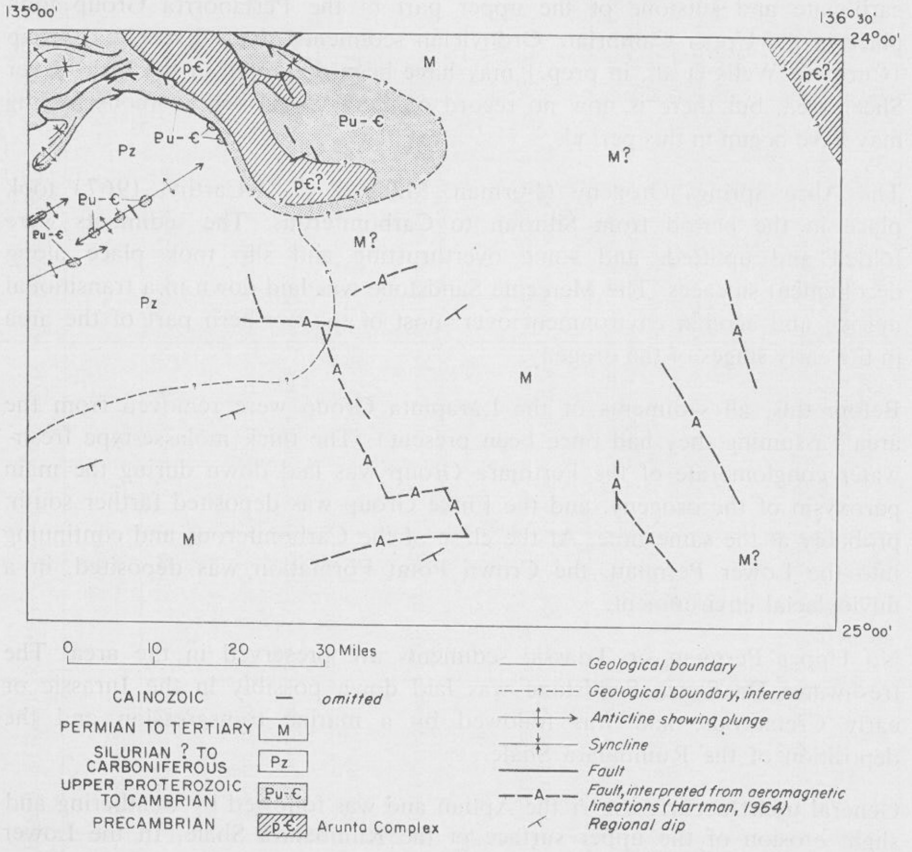

Fig. 2: Structural framework

In the Rodinga Ranges, Cambrian rocks form the cores of sharp narrow box-like anticlines separated by broad gently dipping synclines. The tightness of the anticlines indicates that they die out rapidly with depth; this is thought to be the result of a décollement developed either within the Bitter Springs Formation or at the base of the carbonate rocks in the Pertaoorrta Group. Between the fold belt in the Rodinga Ranges and the large nappes and recumbent folds to the north of the eastern MacDonnell Ranges (beyond the Sheet area to the north-west) is an intermediate zone of thrusts, folded thrusts, and complex anticlines and synclines.

In the Hi Jinx folded thrust in the western part of the intermediate zone, the Bitter Springs Formation is thrust over the Arumbera Sandstone. The thrust appears to be folded about an axis which plunges at 70° to 80° to the west. A second thrust of unknown dip lies between the Bitter Springs Formation and the top of the Pertatataka Formation in the central part of the zone. In the east, the incompetently folded Pertatataka Formation occupies the core of the structure, and the Heavitree Quartzite has been stripped off the Arunta Complex and doubled up farther along strike; on the southern limb, substantial movement has taken place along an exposed décollement near the base of the carbonate rocks of the Pertaoorrta Group. A number of interpretations of the Hi Jinx Folded Thrust have been outlined by Wells et al. (1967).

Silurian to Carboniferous. The Mereenie Sandstone overlies the Pertaoorrta Group with a low-angle regional unconformity. The unconformity represents an unstable period during which the Larapinta Group was removed by erosion. The period of instability foreshadowed the main climax of the Alice Springs Orogeny, when the synorogenic molasse-type conglomerate of the Pertnjara Group was deposited. The Mereenie Sandstone has been folded in conjunction with the Cambrian sequence, and the angular unconformity at the base of the overlying conglomerates of the Pertnjara Group is clearly visible.

Permian to Tertiary. The Permian, Mesozoic, and Tertiary sediments, including the sediments of the Great Artesian Basin, dip gently to the south-east. Minor unconformities are present at the base of the Crown Point Formation, the De Souza Sandstone, and the Etingambra Formation. These sediments have been slightly folded and block-faulted. A zone of north-north-westerly and east-west aeromagnetic lineaments, interpreted by Hartman (1964) as near-surface faults, suggest renewed movements along a zone of weakness in the basement which extend south-south-east across the Sheet area from the western margin of the basement inlier. The minor faults, folds, and unconformities represent a general adjustment to the uplift of the Arunta Block and the subsidence of the Lake Eyre Basin.

Subsurface Basement Configuration

An outline of basement features has been attempted from the interpretation of the total aeromagnetic intensity map (Hartman, 1964; Quilty & Milsom, 1964), with supporting evidence from the regional gravity data (Burbury, 1960; Barlow, 1962) and reflection seismic survey results (Bowman & Harkey, 1963; Campbell, 1965).

Generalized aeromagnetic basement zones are shown in Figure 3. Zone 1 represents areas where basement is less than 2000 feet below sea level. It includes three subzones (1a, 1b, 1c) which lie within the Hale River Gravity Platform, which Barlow (pers. comm.) believes is near-surface basement (cf. Barlow, 1962; Vale, 1965). Zone 1a represents exposed metamorphics of the Arunta Complex. Zone 1b, like zone 1a, is characterized by tight elongate anomalies trending north-north-west and is possibly a horst of shallow Archaean basement. Metamorphics of the Arunta Complex are exposed along the northern continuation of zone 1b, in the Illogwa Creek Sheet area. The steep magnetic gradient along part of the western margin may indicate a fault. Zone 1c contains a north-north-westerly linear series of very shallow anomalies of the type typically found over complex intrusives, such as granite offshoots, and is thought to represent shallow Archaean basement.

Zone 2, particularly the western part, is characterized by closures of smaller extent than those in zone 3 and may represent a different type of moderately shallow basement with depths generally less than 6000 feet below sea level. The East Rodinga Gravity Low is thought to coincide with a small basin of Palaeozoic sediments in the Amadeus Gravity Depression (Lonsdale & Flavelle, 1963). The boundary of the Amadeus Gravity Depression is defined by a marked gravity gradient and the boundary with the McDills Gravity Platform is considered to be a fundamental lineament marking the limit of Amadeus Basin sedimentation (Bowman & Harkey, 1963).

Zone 3 is a downfaulted block showing broad massive anomalies and broad and continuous gradients. Hartman (1964) interpreted it as a deep broad graben of sediments which possibly overlie a granitic mass. The depth to

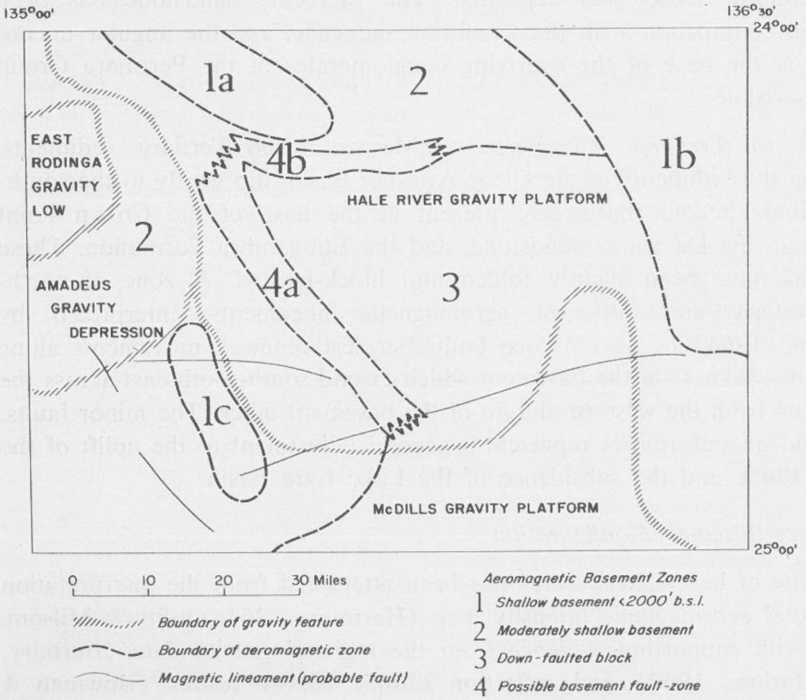

Fig. 3: Generalized aeromagnetic basement zones (after Hartman, 1964)

magnetic basement is over 6000 feet for most of the zone, with a maximum of about 10,000 to 15,000 feet below sea level in the south-east corner of the Sheet area.

Zone 4 includes two areas with marked magnetic gradients. Zone 4a is thought by Hartman to represent a pronounced basement fault. The zone is associated with near-surface magnetic anomalies which suggest faults in the stratigraphic sequence, and may also be complicated by the presence of acid or intermediate intrusions in the basement, particularly to the east of the fault zone. Zone 4b may also represent a basement fault or an abrupt steepening in the southerly dipping basement slope.

The east-north-easterly and north-north-westerly magnetic lineaments shown on Figure 3 may represent an old fault system in the Archean Basement.

ECONOMIC GEOLOGY

No minerals have been produced in the Hale River Sheet area.

Copper

Minor copper mineralization is known from near the base of the Areyonga Formation 2 miles south of Phillipson No. 6 Bore. Traces of malachite, azurite, and chalcocite are present along bedding planes in a 4-foot interval of green dolomitic siltstone. The mineralization has been traced along strike for more than 8 miles (Youles, 1965). Two holes have been drilled at the eastern end of the prospect (Youles, 1966).

In hole No. 1 semi-quantitative spectrographic analysis of sludge samples indicated copper in the interval 250 feet to 256 feet. Assays of 15 sludge samples from the interval 210 feet to T.D. at 360 feet averaged 280 ppm Cu and ranged from 40 to 2500 ppm.

In hole No. 2, fine disseminated sulphides, mainly pyrite, were found at a depth of 329 to 382½ feet. Core samples taken every foot from this interval averaged 190 ppm Cu. An average of 540 ppm was obtained for samples in the interval 367½ to 378½ feet, where values as high as 1200 ppm were recorded.

Phosphate

Thin beds of phosphorite are present in the basal part of the Areyonga Formation, 8 miles north of Ringwood homestead in the Alice Springs Sheet area. Here, a basal conglomerate about 4 feet thick contains 1 to 7 percent P_2O_5. Lenses of phosphorite up to 1 foot thick near or at the top of the conglomerate contain up to 27 percent P_2O_5. Similar phosphorite lenses may be present in the basal part of the Areyonga Formation in the Hale River Sheet area.

Limestone

Dolomite and limestone are common in the north-east of the Sheet area in the Bitter Springs Formation, the Pertatataka Formation, and the Pertaoorrta Group. They are impure, and individual beds are seldom more than a few feet thick.

Road Materials

Some of the weathered pebbly silty sandstone in the Crown Point Formation may be suitable for road gravel.

Petroleum Prospects

In the western part of the Sheet area the petroleum prospects are considered poor. The McDills No. 1 well was drilled in the central part of the adjacent McDills Sheet area and penetrated Lower Cretaceous, Jurassic(?), Permian, and Silurian(?) to Carboniferous rocks. The well was abandoned in Lower Cambrian carbonate at 10,515 feet. Possible source rocks include the carbonate rocks of the Pertaoorrta Group and of the Bitter Springs Formation. Cambrian carbonate rocks may have been exposed for a long period of erosion before and during the deposition of the Mereenie Sandstone; in the north-west corner of the Sheet area the Cambrian sequence appears to thin to the east and south. Although Permian rocks in the area are probably non-marine, they contain gas in Gidgealpa No. 2 well in South Australia (Harrison, 1964). The nature and the petroleum potential of the sequence in the south-east of the Sheet area, where up to 15,000 feet of sediments have been estimated, are unknown.

Groundwater

The regional water resources of the area have been discussed by Jones & Quinlan (1962). The water table is generally 50 to 100 feet below ground level.

The Mereenie Sandstone, the De Souza Sandstone, and the Cainozoic sediments are generally good aquifers and should provide good water if intersected below the water table. Potential bore sites are available in the Rodinga Ranges on the crests and shallow-dipping limbs of anticlines of Mereenie Sandstone. In the south-east part of the Sheet area, the De Souza Sandstone is an excellent and moderately shallow prospect over a wide area.

The gravels of the Hale River and Illogwa Creek should yield water in the northern part of the area, particularly following rain.

The Areyonga Formation and sandy parts of the Limbla Member of the Pertatataka Formation may be locally porous and form good aquifers, but surface exposures generally have low porosity. The Proterozoic carbonate rocks are expected to contain small supplies of highly saline water.

The available data on waterbores are listed in Table 4.

TABLE 4. WATERBORES

Name	Owner	Capacity (gal/hr)	Depth (ft)	Water Level (ft)	Formation Penetrated
Abandoned Bore	Numery	Small	420	86	Rumbalara Shale
Malcolms Bore	Andado	Dry	1840	..	Crown Point Formation
Aralka Well	Numery	Abandoned	40	40	Quaternary(?)
Abandoned Bore	Ringwood	Dry	70	..	Pertatataka Formation
Abandoned Bore	Ringwood	Dry; 400 initially	136	66	Pertatataka Formation
Abandoned Bore	Ringwood	20	128	89	Pertatataka Formation
Abandoned Bore	Phillipson S/R	Dry	36	..	Granite
No. 1 Try Bore	Ringwood	1000	195	Unknown	Mereenie Sandstone
Bennies Bore	W. Smith	Dry(?)	ca. 116	..	Unknown
Bennies Pump (Jack Bore)	W. Smith	Dry(?)	101	..	Unknown
Abandoned Bore	W. Smith	Salty(?)	Unknown	Unknown	Unknown
New Homestead Bore	W. Smith	1000	Unknown	Unknown	Unknown
No. 6 Phillipson Bore	Phillipson S/R	2800	84	52	Limbla Member, Pertatataka Formation
Casey Bore	Loves Creek	Good(?)	Unknown	Unknown	Unknown
Ringwood No. 6 Bore	Ringwood	Good(?)	Unknown	Unknown	Unknown
Taylors Bore	W. Smith	1500	200	150	Mereenie Sandstone
Bottom Bore	Numery	Unknown	..	..	Unknown
Bingie Bore	W. Smith	Unknown	..	..	Unknown
Hillside Bore	W. Smith	Unknown	..	..	Unknown
Safari Bore	Andado	1200; Salty	260	185	De Souza Sandstone
Highway Bore	Andado	1200	264	240	De Souza Sandstone
Survey Bore	Andado	1200	280	260	De Souza Sandstone
Bore	Ringwood	800	300	160	Mereenie Sandstone
Hi Jinx Bore	Ringwood	1000	102	Unknown	Areyonga Formation(?)
Old Camp Bore	Numery	Good	Unknown	Unknown	Unknown
Middle Bore	Numery	Good(?)	Unknown	Unknown	Unknown
New Homestead Bore	Numery	1200	40	16	Alluvium

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