1 : 250,000
GEOLOGICAL SERIES

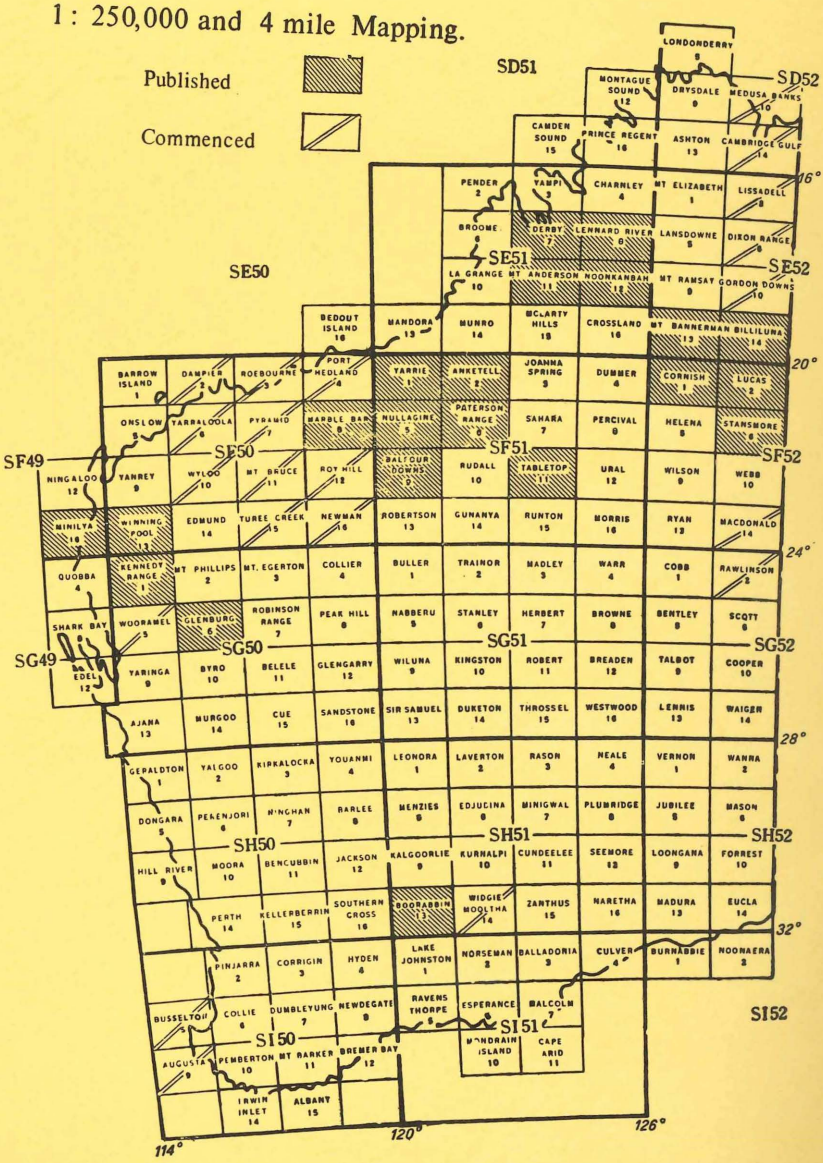
EXPLANATORY NOTES

BALFOUR DOWNS, W.A.

Sheet SF/51–9

C.6634/63.

1 : 250,000 and 4 mile Mapping.



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1 : 250,000 GEOLOGICAL SERIES

EXPLANATORY NOTES

BALFOUR DOWNS, W.A.

Sheet SF/51–9

Compiled by L. de la Hunty

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Director: J. H. LORD

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Explanatory Notes on the Balfour Downs Geological Sheet

Compiled by L. de la Hunty

INTRODUCTION

The Balfour Downs 1 : 250,000 Sheet, SF/51–9, is bounded by latitudes 22° and 23° S. and by longitudes 120° and 121° 30′ E. The Great Northern Highway from Meekatharra runs north along the western edge of the Sheet area. Nullagine, 10 miles north of the Sheet area, is the nearest township.

Fairly good roads connect the station homesteads to the highway and the many station tracks provide access to most parts of the area. Several roads have been made by mining companies, and the track along the Rabbit Proof Fence is well-defined.

Pastoral stations wholly or partly in the area are : Noreena Downs (sheep), Bonney Downs (sheep), Roy Hill (sheep and cattle), Riverdale (cattle), Ethel Creek (cattle), Balfour Downs (cattle), Talawana (cattle), and Billinnooka (sheep).

The easternmost limit of the grazing land is 10 miles west of the eastern edge of the Sheet area. The country to the east consists of desert, with long dunes and bold rock outcrop.

HISTORY OF INVESTIGATIONS

W. F. Rudall traversed the south-eastern corner of the area in 1897 and his traverses are plotted on Talbot's maps (1920). R. H. Downes explored the north-eastern part of the area in 1899. The survey work for the Sheet was done by C. Crossland within the period 1890 to 1905, during which time he mapped nearly all the creeks in the middle and north of the area.

Previous geological work in the area was done by H. W. B. Talbot (1920) in 1914, when he surveyed a large tract of country, including the area of the Sheet. Mineral claims for manganese were pegged in the area in 1956 and 1957. Some of these were inspected in 1956 (de la Hunty, 1958) and some in 1957 (O'Driscoll, 1958 ; de la Hunty, 1960a), and 1958 (de la Hunty, 1959a ; 1959b).

The most recent geological work was by de la Hunty (1960b ; 1961) in 1959 and 1960, assisted in 1959 by J. Sofoulis. The main purpose of the investigation was to determine the origin of the manganese deposits.

The more important investigations made of adjacent areas were those of Maitland (1908), Traves, Casey, & Wells (1956), and Noldart & Wyatt (1962).

PHYSIOGRAPHY

The three river systems in the area are the Oakover, the Fortescue, and the Nullagine Rivers. They are non-perennial and contain only a few pools and rockholes for most of the year. Relief is limited to about 400 feet, and is usually 200 feet or less.

The head of the Oakover River lies about 10 miles south of the area at longitude 121° 10′ E., and flows north through the area to join the Nullagine River about 95 miles to the north. The drainage system of the Oakover River, including the Davis River, covers 3,800 square miles of the Sheet area ; the Nullagine River drains only 250 square miles in the north-western corner of the area. The divide between the Oakover and the Fortescue Rivers extends from 8 miles north-west of Noreena Downs Homestead, south-east through Rat Hill to the south boundary of the area, 14 miles south of Balfour Downs Homestead. The country to the west of this divide, 1,500 square miles, is part of the drainage basin of the Fortescue River.

The remaining 450 square miles, in the south-eastern corner of the area, is desert.

The Nullagine River is youthful, but its tributaries, flowing over granite, are mature. The Oakover River is also mature, but there is evidence of rejuvenation since the deposition of the Oakover Formation in the Tertiary Period. Much of the Tertiary land-surface is still evident, especially between the Davis and Oakover Rivers, where there is a dissected plateau 800 square miles in area. Claypans occupy about 30 square miles immediately east of Talawana Homestead, near the headwaters of the Oakover River. The Fortescue River is mature, with braided channels and a broad flood-plain on which its tributaries follow ill-defined courses.

The desert features seif dunes with a west-north-west trend for the most part, but varying to west in places. Some chain dunes are also present. The dunes vary in length from a quarter-mile to more than 10 miles and have an average height of 30 to 40 feet, with a width of several chains at the base. They are fixed by vegetation and usually have lines of eucalypts along the crests. Dunes are concentrated south and south-west of Bocrabee Hill, opposite an air gap in the Woora Woora Hills : they probably occupy an old river valley which has been filled by wind-blown sand. There are a few dunes 2 miles west of Ethel Creek Homestead and also 12 miles north-east of the homestead.

Plains which are devoid of watercourses occur on Noreena Downs Station in the north-west, Roy Hill and Ethel Creek Stations in the south-west, and Talawana Station in the south-eastern part of the area.

TABLE 1—STRATIGRAPHY OF THE BALFOUR DOWNS SHEET

Era	Period	Stratigraphic Unit	Thickness (in feet)	Lithology
Cainozoic	Quaternary		70	Sand, river gravels, alluvium and outwash.
	Tertiary	Oakover Formation	20	Conglomerate.
			50	Outwash.
			100	Limestone with opaline silica.
			50	Laterite and supergene deposits.
			50	Chert breccia.
			?	Quartzite cap.
Palaeozoic	Permian	Bunmardie Beds	80	Cross-bedded sandstone with some faceted boulders.
		Braeside Tillite	100	Tillite with unsorted, faceted, striated boulders.
Proterozoic		Bocrabee Sandstone	300	Cross-bedded sandstone with intercalations of quartzite.
		Googhenama Conglomerate	300	Coarse boulders (bottom 50 ft) and pebble conglomerate.
		UNCONFORMITY		
		Manganese Group: Noreena Shale	100	Chocolate-coloured blocky shale-siltstone with pellets of braunite.
		Manganese Group: Balfour Shale	1500	Green micaceous shale varying to calcareous, sandy and cherty.
		Manganese Group: Bee Hill Sandstone	70	Banded cross-bedded reddish sandstone with pebble bands and white spots.
		Manganese Group: Coondoon Conglomerate	50	Conglomerate containing angular boulders and sandy, ferruginous and manganiferous shales.
		Pinjian Chert Breccia	50	Angular fragments of banded chert with silica cement—occasionally replaced by iron or manganese. Has glacial pavements.
		UNCONFORMITY		
		Carawine Dolomite	400	Impure siliceous red-grey crystalline dolomite with some chert bands and some *Collenia*.
		Lewin Shale	800	Shales, banded chert and jaspilite, mudstone, thin dolomite; iron and chert concretions.
		Little De Grey Lava	200	Green, amygdaloidal, basic to intermediate lava—several flows.
		Tumbiana Pisolite	150	Grey–blue–green pisolite, oolitic, sandy or cherty, with some *Collenia*.
		Beaton Creek Conglomerate	50	Boulders and bands of grit and sandstone.
		UNCONFORMITY		
Archaean		Warrawoona Series		Jaspilites, talc-chlorite and alumina-rich schists.

INTRUSIVES

Proterozoic

Davis Dolerite
Hornblende Porphyrite
Bamboo Creek Porphyry
Duffer Creek Porphyry
Gregory Range Granite

Archaean

Quartz veins and pegmatite dykes
Dolerite dykes
Granite

STRATIGRAPHY

There are three well-defined unconformities in the Precambrian succession in this area. A marked angular unconformity exists between the Archaean and the Proterozoic rocks, and there are two unconformities within the Proterozoic Era, one above and one below the Manganese Group.

Other breaks in the stratigraphy rarely show any angular discordance at the contacts. They occur between the Proterozoic and the Permian and between the Permian and the Cainozoic.

ARCHAEAN

The Archaean rocks of the Pilbara area have been described by several authors, the latest publication being that of Noldart & Wyatt (1962). They mapped and described the rocks of the area covered by the Marble Bar and Nullagine 4-mile Sheets. The Archaean rocks include the metamorphosed sedimentary and igneous rocks of the Warrawoona Series, the metamorphosed sediments of the Mosquito Creek Series, and the granite, quartz, pegmatite, and dolerite intrusives, and gneiss.

Excluding the granite and the minor intrusive rocks, all the Archaean rocks in the area of the Balfour Downs Sheet are here classed in the Warrawoona Series.

Warrawoona Series

Jaspilites of the Warrawoona Series crop out in the north-western corner of the area, where they have a north-easterly strike ; a further outcrop extends 8 miles south-east from Turkey Bore in the centre of the area. At Rat Hill, rocks of the Warrawoona Series are alumina-rich schists containing corundum and diaspore ; outcrop conditions are poor and most of the area is covered with quartz rubble derived from quartz veins intruding the schist and also from vesicles in the overlying Proterozoic basalt.

Granite and Gneiss

Granite, with a rim of gneiss, occurs in the north-western corner of the Sheet area. It is medium to coarse-grained, with quartz, feldspar, and biotite as the main constituent minerals. Its intrusive character is indicated by the presence of xenoliths of Warrawoona jaspilite in the gneiss. Foliation is rather weak in the granite but very marked in the gneiss, where it is parallel to the edges of the mass. The exposures of granite in the Archaean belt running south-east from Rat Hill to the southern edge of the area have no visible gneiss rims.

Minor Intrusive Rocks

Numerous dolerite dykes and quartz veins intrude the granite and there are many quartz veins in the schists at Rat Hill. A large dyke of coarse-grained dolerite intrudes the Warrawoona rocks in the north-western corner of the area. Ten miles to the east, in the vicinity of Five Mile Creek, there are pegmatite veins in the granite. Some tantalite and beryl have been won from eluvial deposits near the pegmatite bodies.

PROTEROZOIC

The low-dipping sedimentary and volcanic rocks of Proterozoic age have been termed the Nullagine Series in the Pilbara Goldfields (Maitland, 1908), and other parts of the North West Division. Several authors have described the Nullagine Series, but the significance of the Manganese Group has not hitherto been recognized. The group, which is best developed in the area of the Balfour Downs Sheet, consists of the Coondoon Conglomerate, Bee Hill Sandstone, Balfour Shale, and Noreena Shale. It overlies the Pinjian Chert Breccia, which follows an unconformity, and is itself unconformably overlain by the Googhenama Conglomerate and Bocrabee Sandstone.

Noldart & Wyatt (1962) recognized these two unconformities, but considered them major time breaks and ascribed a Cambrian age to the Pinjian Chert Breccia and the overlying Waltha Woora Beds. The Waltha Woora Beds can be correlated with the Manganese Group.

In the Manganese Province (de la Hunty, 1963) the first break in the sedimentation of the Proterozoic rocks followed the deposition of the Carawine Dolomite. In the country to the west of the Sheet area sedimentation was continuous to a much later time, and the Manganese Group as such was not deposited there : the Manganese Group consists of shallow-water sediments, whereas in the area to the west, deeper-water sediments overlie the dolomite.

The Gregory Range Granite (with its associated intrusives) is older than the Googhenama Conglomerate and younger than the Lewin Shale.

Sediments and Extrusives

Noldart & Wyatt (1962) named the *Beatons Creek Conglomerate* from its type locality at Beatons Creek, 1 mile west of Nullagine township. It crops out in two areas on the Sheet : at Sunday Hill in the north, and extending for 4 miles south-east from Tellurometer Station M48, 2 miles east of Turkey Bore, in the centre of the area. At M48 the conglomerate overlies jaspilite of the Warrawoona Series, with parallel strike. It is about 50 feet thick and contains many large boulders, as well as bands of grit and sandstone. The boulders, which are often angular and up to 3 feet across, include mineralized jaspilite, schist, quartzite, and quartz. Volcanic ash and fragmentary material at both localities, together with some vesicular lava which also underlies the conglomerate, are included with the Little De Grey Lava.

Noldart & Wyatt (1962) named the *Tumbiana Pisolite* from its outcrop at Tumbiana Pool in the Nullagine River, where they reported that it contained beds of mudstone, shale, dolomite, and oolitic and pisolitic limestone and that it ' appears to be interbedded in part with the lower beds of the Carawine Dolomite '. However, they placed it below the Little De Grey Lava in the stratigraphic column and that is its position in this area.

At Sunday Hill a thin bed of pisolitic rock underlies the lava and a bed 150 feet thick is interbedded with the lava. Outcrops of the pisolite have been traced at the base of the Proterozoic succession to the southern boundary of the Sheet, where it is more than 50 feet thick. The rock is generally grey-blue-green, and varies considerably in composition. The writer mapped pisolitic and oolitic carbonate beds, limestone with *Collenia* fossils, calcareous greenish sandstone, oolitic mudstone, and pale blue oolitic chert (with disseminated pyrites).

The stratigraphical position of the pisolite varies somewhat. At the most southerly outcrop in the Sheet area, it overlies vesicular basalt (Little De Grey Lava) and is capped with chert breccia.

The *Little De Grey Lava* was named by Noldart & Wyatt (1962) from its type locality at the Little De Grey River and is a basic to intermediate amygdaloidal lava more than 200 feet thick. Minor developments of columnar jointing have been seen in several places. The lava is usually deep green to apple-green in colour, and most amygdules are of quartz ; some are of calcite, sometimes with a silica lining. Where flows are thick the lava often appears rather massive and basaltic, but frothy flow-tops are composed mostly of silica and the larger amygdules contain quartz crystals up to 2 inches long, enveloped by chalcedonic silica. Some of the amygdules are as large as 12 inches long and 4 inches thick, with the silica envelope at least an inch thick.

Some interfingering of the lava with carbonate beds is evident. There are occasional bands of limestone and a thick band of pisolite between flows. Noldart & Wyatt (1962) state that dolomitic beds have been noted both above and below lava beds.

Pyroclastics and vesicular basalt, which underlie the Beatons Creek Conglomerate 2 miles east of Turkey Bore, have been included in the Little De Grey Lava. Tuff which crops out over an area of about 5 square miles, 8 miles north-west of Noreena Downs Homestead, is also part of this formation.

The *Lewin Shale* is named from Mount Lewin (approximate latitude 22° 37′ S., approximate longitude 120° 13′ E.), on the north side of the broad valley of the Fortescue River. It is a prominent hill with steep slopes, the summit rising more than 200 feet above the surrounding country. The rocks of the Lewin Shale are shale, chert, mudstone, and thin dolomite bands. The formation has a low southerly dip here and dips are generally low ; but 2 miles south-west of Sunday

Hill the formation is tightly folded, and the ferruginous cherts (jaspilites) bear a marked similarity to the jaspilites of the Warrawoona Series. In most outcrops the Lewin Shale is little more than 200 feet thick, but a thickness of 800 feet was observed in the Sunday Hill locality.

Lenticular black chert concretions, 2 inches in diameter and a half-inch thick, occur in some of the mudstone and thin dolomite beds of the Lewin Shale. Some porous limonite was also noticed in cavities of similar size in the thin dolomite bands. Black ferruginous pseudomorphs after pyrite are common in the shale. They are spherical, up to 2 inches in diameter, and cube and pyritohedron faces are present on the outside of the nodules. The crystal structure does not persist beneath the skin : fibres of limonite radiate from a central half-inch core of hematite. The chert bands contain flattened bi-convex geodes of chert with quartz crystals. These geodes are up to a foot in diameter and 6 inches thick, and many of them enclose small concretionary structures. The quartz crystals are about half an inch long.

Iron deposits lie on this formation immediately west of the Sheet area. They were formed by replacement and supergene enrichment of ferruginous rocks within the formation (Sofoulis, 1960).

The *Carawine Dolomite* extends south from the type locality at Carawine Gorge, 35 miles north of the Sheet area, to the southern boundary of the area. Dolomite exposed in the valley of the Fortescue River at Goodiadarrie Hills, 60 miles west of the Sheet, is also correlated with it. In the Goodiadarrie Hills, the dolomite overlies the Lewin Shale and lies below the ferruginous cherts of the Hamersley Range.

The Carawine Dolomite is grey to reddish and has a wide range of composition : silica ranges from 3 percent to 50 percent. The silica occurs as fine grains and as bands of chert within the dolomite, and quartz crystals have been observed on joint surfaces and among the weathering products. Some of the crystals are 2 inches long at a locality 9 miles north of Balfour Downs Homestead. The Carawine Dolomite varies in thickness, reaching a maximum of 400 feet in the centre of the Oakover Syncline, where it is blocky and rather massive. (The thin dolomitic bands underlying shale at the Great Northern Highway, near Mount McKay, are the lowest beds of the Lewin Shale in that area.)

The Carawine Dolomite is known to contain *Collenia* at Woodie Woodie, 25 miles north of the Sheet. Some concentric structures 2 feet in diameter were seen 14 miles north-east of Mount Hodgson and in several other localities.

Noldart & Wyatt (1962) nominated Pinjian Pool, 70 miles north of this Sheet in the Nullagine River, as the type locality for the *Pinjian Chert Breccia.* The Breccia has a wide distribution throughout the Nullagine Sheet area as well as

the Balfour Downs area. It invariably overlies sediments, usually dolomite. It crops out in a few places in the valley of the Fortescue River, but the formation is mostly confined to the drainage basin of the Oakover River.

The chert breccia consists of fragments of banded chert with a matrix of silica. The chert fragments are mostly about a half-inch in diameter, but boulders as large as 3 feet have been seen. In some places the matrix has been replaced by hematite or cryptomelane, with a consequent change in colour from white to red or black.

The Pinjian Chert Breccia is believed to be a terrestrial deposit which has derived its silica as well as its fragments from the Carawine Dolomite and the Lewin Shale. It forms a mantle on an old erosion surface and has filled old valleys and crevices in the underlying dolomite. It is difficult to distinguish from the chert breccia of the Tertiary Period (described below), but the Proterozoic age of the Pinjian Chert Breccia is indicated by the fact that it is underlain and overlain by Proterozoic rocks. The Pinjian Chert Breccia has been striated and grooved by Permian glaciers at Carawine Gorge, 35 miles north of the area boundary, at Woodie Woodie, 16 miles south-east of Carawine Gorge, and in the Ripon Hills, 27 miles north-west of Carawine Gorge.

The maximum thickness of chert breccia is 50 feet.

The *Coondoon Conglomerate* is named after its type locality, immediately north of the junction of Coondoon Creek with the Davis River. The formation overlies the Pinjian Chert Breccia and is the basal formation of the *Manganese Group*. It ranges in thickness from 6 inches to more than 50 feet and there are many rolls in the bedding. The formation includes beds with angular fragments (about 2 inches across), pebble beds, boulder beds, and interbedded sandy, ferruginous, and manganiferous shales.

It crops out underneath the Sunday Hill manganese deposits, as well as in two larger areas south of the type locality. It is exposed at Nooganoonga Rockhole, around the edges of a small basin 3 miles north of Saddleback Hill, and also a half-mile north of Coorapline Well. At Moseley Mill, 3 miles east of Ant Hill, the Davis Dolerite is shown as overlying the Little De Grey Lava, but there is a band of conglomerate, 6 inches thick, between them. Some other outcrops of Coondoon Conglomerate do not show on the map because of the shadowing effect of overlying rocks.

The *Bee Hill Sandstone* overlies the Coondoon Conglomerate and is somewhat difficult to distinguish from it in places. The maximum thickness observed for the formation is 70 feet. In the type locality 2 miles south-east of Bee Hill and extending south for 6 miles, it contains fine pebble bands, grit, sandstone and sandy shale, and a distinctive type of sandstone. This sandstone is cross-bedded and banded (red to purple and white), and has white spots (a quarter-inch to an inch in diameter) and shows some surface silicification. The banding is

spectacular and is caused by heavy mineral layers repeated every quarter to half an inch. A marked bedding cleavage is also noticeable : it is parallel to the general bedding planes but cuts through the cross-bedded sections. The distance separating the bottom-set and top-set beds is about 2 feet.

The *Balfour Shale* is widely distributed and distinctive. It is well exposed at Mount Trew in the southern part of the Sheet area, and has been mapped as far north as Bee Hill. In the type locality, immediately north-east of Mount Trew, the formation consists of thinly laminated green shales which are intruded by sills of dolerite (Davis Dolerite). Dips are generally low, although some steep dips were recorded at Googhenama Creek in the north-eastern part of the Sheet, where the formation is thickest (1,500 feet). Similar green shale underlies the manganese deposit 2 miles north-east of Balfour Downs Homestead.

Although the Balfour Shale is typically green, it varies in colour to grey-green and grey, and in composition from finely laminated to sandy and calcareous. Some chert beds are present, and Farquharson (in Talbot, 1920) identified glauconite in some of the sandy beds. The shale contains some manganese, and the areas of outcrop near Balfour Downs Homestead are covered with black manganiferous rubble. Two samples of the shale beneath the main manganese deposit assayed 13·6 percent Mn (de la Hunty, 1959b).

The type locality of the *Noreena Shale* is 8 miles east-south-east of Mount Cooke, on a bulldozed track.

The Noreena Shale is of limited distribution and conformably overlies the Balfour Shale. It crops out in the Ant Hill–Bee Hill–Turummunda Rockhole area and also at Enacheddong Creek and Googhenama Creek. The prevailing colour of the Noreena Shale is chocolate, but parts are purplish to red-brown, owing partly to the presence of oxides of iron and manganese. Its components range from blocky shale to siltstone, and many are micaceous. It is generally covered by outcrops of the Davis Dolerite between Mount Cooke and the Davis River. The formation has a thickness of 100 feet.

The most outstanding feature of the Noreena Shale is the presence of braunite pellets along its bedding planes. Surface staining and thin sheets of manganese dioxide could have resulted from the weathering of dispersed manganese-bearing minerals throughout the rock, but the pellets are a feature of deposition. (The oxide–silicate braunite is a ' primary ' mineral.) Two specimens of chocolate shale from the type locality assayed 10·3 percent and 4·0 percent Mn (de la Hunty, 1959b).

The braunite pellets range in diameter from about a tenth of an inch to an inch, with an average diameter of half an inch and an average thickness of less than a quarter-inch. Pellets collected from the surface 4 miles south-east of Mount Cooke assayed 42·9 percent Mn and the manganese mineral was

determined as braunite. Not every outcrop of the chocolate shale displays pellets, but they were noticed 3½ miles north-north-east of Saddleback Hill and 3 miles south-east of Saddleback Hill, as well as in the localities already mentioned.

The type locality for the *Googhenama Conglomerate* is south of Googhenama Rockhole in the upper reaches of Googhenama Creek, in the north-eastern part of the Sheet. The conglomerate is well developed in a band, about 30 feet thick, which strikes south from the north-eastern corner of the Sheet area, swinging west then north around the outcrop of Proterozoic granite.

The formation also crops out 11 and 13 miles north, 12 miles west, and 20 miles west-south-west of Balfour Downs Homestead.

The Googhenama Conglomerate contains large boulders up to 3 feet across at its base, but grades into a somewhat ferruginous rock with smaller pebbles 1 inch to 3 inches across, and then into a fine pebble conglomerate. The maximum thickness of the coarser material is 50 feet and the finer material has local thicknesses of 250 feet. Dips are low.

The *Bocrabee Sandstone* is named after its occurrence at Bocrabee Hill near the middle of the eastern edge of the Sheet.

The Bocrabee Sandstone is about 300 feet thick and consists of cross-bedded sandstone with intercalations of quartzite. Four miles north-east of Bocrabee Hill a bed of quartzite has resulted from 'case-hardening', and will give way to sandstone down dip, away from the surface. The formation of the Tertiary quartzite cap is discussed below.

INTRUSIVES

The main acid rock which intrudes the Proterozoic rocks in the Sheet area is the Gregory Range Granite. The Duffer Creek Porphyry, the Bamboo Creek Porphyry, and the hornblende porphyrite are probably consanguineous with this granite. As none of these acid rocks have been seen intruding rocks younger than the Lewin Shale, they may have been emplaced before the deposition of the Manganese Group. Noldart & Wyatt (1962) suggested that the Gregory Range Granite is older than the Pinjian Chert Breccia ; but it is possible that the folding of the Manganese Group was contemporaneous with the intrusion of the Gregory Range Granite, even though the granite did not intrude the Manganese Group.

The only basic intrusive recognized in Proterozoic rocks is the Davis Dolerite, which intrudes the Manganese Group as well as the older rocks. Although the Googhenama Conglomerate locally overlies the Davis Dolerite, the dolerite is considered intrusive and is therefore younger than any other Proterozoic rock in the area.

The *Gregory Range Granite* crops out over an area of 35 square miles in the north-eastern corner of the Sheet : this is the southern end of a belt of hornblende-biotite adamellite about 5 miles wide, which extends north through the Nullagine Sheet area. In the Balfour Downs Sheet area, the rock ranges from a medium-grained granite to an augen gneiss. Biotite outlines the feldspar phenocrysts. This granite, which contains rafts of Warrawoona schists with auriferous quartz reefs, also intrudes the Little De Grey Lava of the Gregory Range in the Nullagine Sheet area. The granite is unconformably overlain at its eastern edge by the Googhenama Conglomerate.

Small outcrops of purplish-grey porphyry with phenocrysts of clear and kaolinized feldspar overlie the Gregory Range Granite and underlie the Googhenama Conglomerate. The porphyry is similar to a very dark porphyry which Talbot (1920, p. 129) reported at Lookout Rocks, 8 miles to the north of the Sheet area. Noldart & Wyatt (1962) correlated this dark porphyry with the *Duffer Creek Porphyry*, which they considered to be a late phase of the Gregory Range Granite.

Minor outcrops of feldspar porphyry are correlated with a similar rock which Noldart & Wyatt (1962) called the *Bamboo Creek Porphyry*. It is a pink rock, rarely fresh, and contains pink feldspar crystals, ranging from a quarter-inch to more than 1 inch in length. The porphyry intrudes the Little De Grey Lava 2½ miles north of Rat Hill, and a half mile east of Turkey Bore ; and a small outcrop overlies banded chert 14 miles farther south. The exposures are rather small, but the rock is distinctive.

A dyke of *Hornblende Porphyrite* intrudes the axial plane of a tight fold in the Lewin Shale, 2 miles south-west of Sunday Hill. The rock is weathered, but laths of hornblende, up to a half-inch long, can be seen in the pink groundmass. It is similar in appearance to intrusive rocks at Bamboo Creek, 78 miles to the north-north-west, which Noldart & Wyatt (1962, p. 88) have correlated with the Mount Edgar Porphyrite. No other outcrops of this rock type are known in the Sheet area.

In the eastern half of the Sheet area extensive areas of flat-lying *Davis Dolerite* form plateaux. The dissected plateau at the Davis River, 4 miles east of Mount Cooke, is the type locality. It has a surface area of more than 20 square miles. Another dolerite plateau of similar size occurs just east of Saddleback Hill and Mount Divide.

The Davis Dolerite is generally fine-grained, but at Talawana in the south-eastern corner of the Sheet, the rock is coarse-grained and has a speckled green and white appearance. No volcanic characteristics, such as vesicles or flow structures, have been seen in the dolerite, and the presence of dykes connecting sills in some areas is proof of its intrusive nature. Some marginal chilling has been observed, mainly at the base of sills.

Dolerite has intruded the Carawine Dolomite at Carawine, and the cherts and shales in the Hamersley Range (Talbot, 1920). Dolerite also intrudes the Lewin Shale 3 miles west of Bee Hill in the northern part of the Sheet. These are all believed to be contemporaneous sills, although the Davis Dolerite usually overlies the Balfour Shale and the Noreena Shale in this Sheet area.

The upper contact of the dolerite is rarely exposed, but it has been observed with the Balfour Shale, the Noreena Shale, and the Googhenama Conglomerate. The dolerite has a distinctive photo-pattern due to the complete absence of trees. The underlying chocolate shale forms a dark fringe around many outcrops of Davis Dolerite.

Although no copper has been found in the dolerite, the proximity of copper ore, in this Sheet and in the vicinity of Bulloo Downs, Ilgararrie, and Kumarina, 150 miles south-west of the Sheet (Talbot, 1920), suggests some association.

PALAEOZOIC

PERMIAN

The only rocks in the area intermediate in age between the Proterozoic and Cainozoic Eras are the Braeside Tillite and the Bunmardie Beds of Permian age. There is no direct fossil evidence for the Permian age of the glacial deposits, but they are demonstrably post-Proterozoic and Traves et al. (1956) have established that they are pre-Jurassic. They are correlated with Permian glacial deposits known elsewhere in Western Australia.

The Permian rocks are confined to the north-eastern part of the Sheet area in a strip 2 miles wide and 13 miles long, between Enacheddong Creek and Googhenama Creek. This is the southern limit of the Permian rocks which are prominent along the Oakover River to the north.

The *Braeside Tillite* was named after its type locality 2 miles north-north-west of the old Braeside Homestead, west of the Oakover River and about 55 miles north of the Balfour Downs Sheet. The formation is about 100 feet thick in the Balfour Downs Sheet area. It consists of unsorted and unstratified boulders of quartz, granite, gneiss, vesicular basalt, and sandstone. The boulders range in diameter from 2 inches to more than 6 feet and many of them are faceted and striated.

Noldart & Wyatt (1962) proposed the name *Bunmardie Beds* for some arenaceous sediments overlying the Braeside Tillite. In the Balfour Downs Sheet area a cross-bedded sandstone overlies the tillite. It is 80 feet thick and outliers along the eastern edge of the tillite appear as white hills rising above a plain of boulders.

CAINOZOIC

TERTIARY

In the Balfour Downs Sheet area, as in many other parts of Western Australia, the Tertiary sediments are largely chemical deposits resulting from the mobilization of lime, magnesia, silica, iron, and manganese. Surface silicification of pre-existing rocks yielded chert breccia and quartzite, which are probably the oldest of the Tertiary rocks. The presence of ferruginous concretions at the base of the Oakover Formation indicates that laterite was formed before the beds were laid down, but most of the laterite in the area was probably formed at the same time as the Oakover Formation. The manganese deposits were also formed at that time.

Quartzite Cap : In the south-eastern part of the Sheet area outcrops of quartzite are associated with sandstone, sandy shale, and fine conglomerate. In many places the quartzite forms a cap on these rocks, but it has also been seen dipping into and under them. In all places the quartzite appears conformable with the rocks above and below. In exposures 4 miles north of Mount Frank and 8 miles east-north-east of Old Mia on Talawana Station, the quartzite contains many cavities up to a half-inch in diameter. Close inspection revealed that these holes had been caused by the removal of silica by solution from rounded chert pebbles. The silica was probably removed as the rock was being silicified. It seems evident therefore that the quartzite was formed by the surface silicification of favourable Proterozoic beds during Tertiary times, without the destruction of the original structural characteristics.

Chert Breccia : The Pinjian Chert Breccia has been recognized at a break within the Proterozoic succession, but another chert breccia, of Tertiary age, covers the 800-square-mile Oakover–Davis plateau at the junction of those two rivers. Dolomite and younger Proterozoic rocks have been seen underlying the chert breccia, which forms an almost continuous cover—streams have dissected it somewhat, and there are a few outcrops of laterite and some patches of sand on the plateau. Bee Hill, Woblegun Hill, and Mount Hodgson (all of which are covered with chert breccia or banded chert) form monadnocks in this plateau.

The concordance of levels of the plateau and its wide areal extent help to demonstrate that silicification in Tertiary times has been responsible for the formation of much of the chert breccia of the area. The Tertiary cycle of erosion has most probably been responsible for much of the present land profile and has exerted some influence on all the chert breccia now exposed. Because of this, no attempt has been made to discriminate between the chert breccias of the two ages.

Laterite : The rocks mapped as laterite include ferruginous and manganiferous laterite, some hardpan, and areas of supergene enrichment of iron and manganese. The supergene enrichment has been responsible for the formation of iron and manganese deposits, which are discussed below. The laterite is correlated with a bed of vitreous limonite which occurs at the base of the Oakover Formation near Carawine Gorge, 35 miles north of the Sheet.

Oakover Formation : Maitland (1908) described the ' Oakover Beds ' from the vicinity of Carawine Gorge in the Oakover River, and Noldart & Wyatt (1962) described the occurrence at the lower Carawine Pool and called it the Oakover Formation. The formation crops out extensively along the Oakover River from its source to the type locality, and beyond ; and along Noreena Creek and across the divide into Kulkinbah Creek, and in the broad valley of the Fortescue River near Ethel Creek Homestead. It is probably 100 feet thick.

The distribution of the sediments indicates that they were deposited as the result of ponding in river channels during Tertiary times. In the type area the Oakover Formation overlies Proterozoic and Permian rocks. In the Balfour Downs Sheet area, as in the type locality, the formation consists of white limestone, which contains sandy beds and river gravels, as well as large developments of opaline silica (usually as a crust 10–15 feet thick, but also in masses up to 70 feet thick). The formation is often referred to as ' calcrete ' The calcium, magnesium, and silica have been derived from the weathering and breakdown of pre-existing rocks.

In the lower reaches of Noreena Creek, as at Carawine Pool, creeks have cut channels through the formation to expose a bed of vitreous limonite at the base. The mesas resulting from this dissection vary in height according to the depth of the basin in which the original deposition took place.

Where the Oakover Formation has not been severely eroded, for example in the upper part of the Oakover River, the formation provides a good source for underground water. Exactly similar developments of calcrete have been seen at Weeli Wolli Springs and at Millstream Homestead, in the drainage area of the Fortescue River to the west of the Sheet, and in both areas the deposits are responsible for permanent supplies of good water. Many other deposits of calcrete are known throughout the North West Division and parts of the Eastern Division, and they all make good aquifers. The Brumby Creek Beds described by Talbot (1920) in the upper part of the drainage basin of the Ashburton River appear similar in age, environment, and lithology, and can reasonably be correlated with the Oakover Formation.

Outwash : Although outwash is generally regarded as Quaternary, some of the outwash to the south of Balfour Downs contains small patches of opaline silica, which suggests a possible Tertiary age of deposition. The outwash contains soil, pebbles, and small boulders, and occurs in wide, gently sloping areas with alternating patches of mulga and open ground. The mulga bands are 20 to 100 yards wide and tend to follow the contours ; the intervening strips of bare ground with no trees and little or no spinifex or grass are up to 300 yards wide.

Conglomerate : There is a loosely-cemented conglomerate on the banks of Coondoon Creek near the centre of the northern edge of the Sheet. It contains boulders and pebbles which have probably weathered from the Coondoon

Conglomerate, or the Beatons Creek Conglomerate at Sunday Hill, and the calcareous cement was probably derived in the same way as the limestone in the nearby outcrops of Oakover Formation. The main deposit is 3 miles long and probably 20 feet thick. Another small deposit of conglomerate, with ferruginous cement, occurs at the foot of a hill where the Coondoon Conglomerate is exposed, 3 miles south-west of Sunday Hill. The rounded pebbles and boulders have been derived from the outcrop of Coondoon Conglomerate.

Quaternary

The Quaternary sediments are mostly unconsolidated. They include outwash deposits, alluvium and river gravels, and sand (in places with sand dunes).

Quaternary rocks cover a considerable area in the south-western and south-eastern parts of the Sheet ; and sand covers more than 100 square miles on the north side of Noreena Creek, in the north-western part of the Sheet.

Outwash : Outwash fans are prominent along the north side of the valley of the Fortescue River, where the tributary creeks meet the flood plain and deposit their loads. These fans may be 50 feet thick.

Alluvium : The deposits of alluvium are generally small and thin, but there is a wide area of red sandy loam on the Fortescue floodplain. It is possibly 20 feet thick in places but is generally only a thin cover on calcrete.

River Gravels : Boulders, pebbles, and sand are deposited to a maximum depth of probably 20 feet in the beds of some of the wider creeks. These deposits are roughly stratified and contain much basalt rubble, as well as pebbles of quartzose rocks.

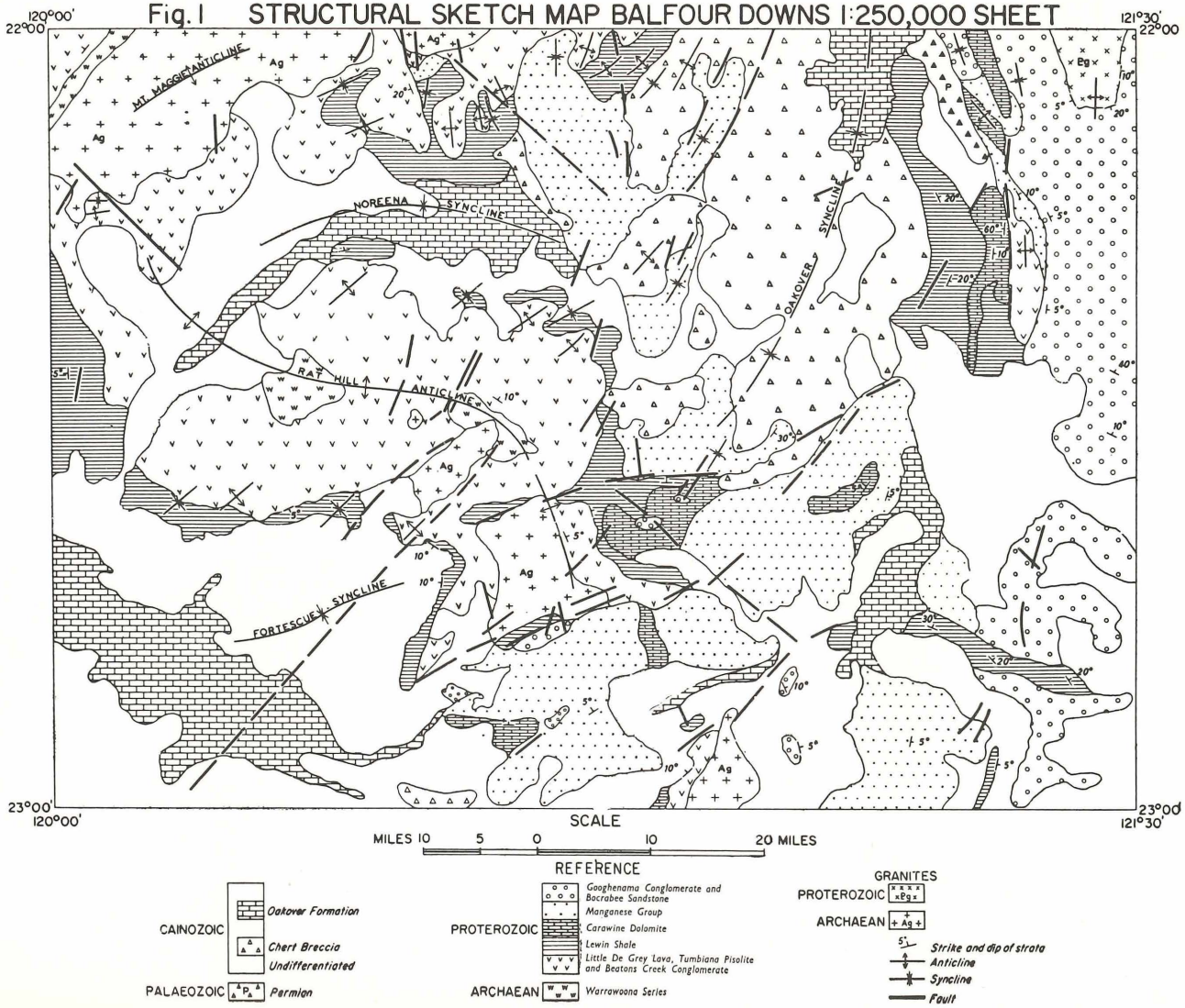
Sand : Red or yellow sand has mostly been transported by wind, especially in those areas containing sand dunes. These are described in the section on Physiography.

STRUCTURE

Figure 1 shows the general structural framework of the Balfour Downs Sheet. Fold axes, faults, and outcrops have a marked trend to the north-east ; the trend-lines are slightly concave to the north-west. Structural elements at variance with this are the Rat Hill Anticline, several faults, and several minor folds in the Ant Hill–Mount Cooke area.

The Rat Hill Anticline has a core of Archaean rocks and separates the Oakover Syncline from the Fortescue Syncline. This barrier has caused a marked difference in sedimentary environment between those areas.

Fig. 1 STRUCTURAL SKETCH MAP BALFOUR DOWNS 1:250,000 SHEET



Folding

The major folds of the area are the Oakover Syncline, Noreena Syncline, Fortescue Syncline, Rat Hill Anticline, and Mount Maggie Anticline (Fig. 1). They were all formed at the earliest period of deformation of the Proterozoic rocks, which was some time after the deposition of the Carawine Dolomite.

The Oakover Syncline was cut off from the Fortescue Syncline after this folding, and, with the exception of the transgression west of Balfour Downs Homestead, the deposition of the Manganese Group was confined to the Oakover Syncline.

The Manganese Group is little deformed, except at Googhenama Creek, where the rocks are tightly folded. This tight folding was probably contemporaneous with the shearing of the Little De Grey Lava of the Gregory Range and with the emplacement of the Gregory Range Granite. The minor folds in the Manganese Group follow the regional trend, as do those in the Lewin Shale on the north side of the Rat Hill Anticline. The Googhenama Conglomerate and the Bocrabee Sandstone include some shallow folds, but these rocks are generally low-dipping and have a regional north-easterly strike. They are restricted to the eastern and south-eastern parts of the Sheet and have a general dip to the south-east.

Permian glacial sediments are present in the Oakover Syncline, and the Tertiary chert breccia is also confined to this basin. The Oakover Formation and other Cainozoic rocks were deposited in all the major synclines, which still form the drainage basins for the present rivers.

Minor folds are generally parallel with the regional trend, but the folds in the Ant Hill–Mount Cooke area trend more northerly. On the north flank of the Rat Hill Anticline the minor folds are oriented north-east, *en echelon*, but farther to the south-east the minor folds have been ruptured where their axes approach parallelism with the curved axis of the Rat Hill Anticline.

Faulting

There are two general sets of faults and joints in this area. One is oriented north-east, parallel with the regional trend, and the other is north-west.

A fault truncates the granite, Little De Grey Lava, and Lewin Shale, along an east-north-east line 14 miles west of Balfour Downs Homestead. There is a parallel fault 12 miles to the north-west and another 10 miles to the south-east. Another fault runs north-west through Noreena Downs Homestead and faults the granite at the western boundary of the Sheet.

A fault line extends 6 miles east of Ethel Creek Homestead past the eastern side of Springo Bore, and its presence indicates that the latest movement could have been in Tertiary or later times.

The Manganese Group generally overlies the Pinjian Chert Breccia with a low dip, but the edges of the minor basins are often faulted, and local steep dips are common.

ECONOMIC GEOLOGY

Manganese and copper deposits have been mined and some columbite and beryl has been produced. Other minerals present, but not in commercial quantities, are gold, iron ore, barite, and radioactive pegmatite minerals such as tant-euxenite. Corundum and alumina-rich schists have also been located. Underground water supplies are sufficient for the pastoral industry in the area.

MANGANESE

The manganese deposits are discussed in detail elsewhere (de la Hunty, 1963). There are more than 120 mineral claims for manganese, but few have produced ore. Producing centres were Ant Hill, Davis River, and Bee Hill. Considerable exploratory work has been done on the deposits at Balfour Downs and Mount Nicholas, but no ore has been shipped from them.

The deposits occur as sheets or mounds on chert breccia, shale, sandstone, dolomite, or conglomerate, which have been partly replaced by manganese dioxide. At Mount Nicholas, as in other parts of the North West Division, the deposits are associated with the Lewin Shale. All the other deposits in the Sheet are associated with the Manganese Group, and it is considered that they have been formed by supergene enrichment of pre-existing manganiferous rocks.

The deposit at Balfour Downs is one of the largest in Western Australia, but the grade is below economic limits.

COPPER

Copper ore has been mined from several small deposits. The largest is 33 miles north of Balfour Downs Homestead and 3½ miles north of Saddleback Hill; it was the only deposit being mined in 1960. Other small deposits have been worked 12 miles to the south, a mile south-east of Coorapline Well, and at Turummunda Rockhole, 4½ miles south-east of Coorapline Well. Other small outcrops of copper minerals occur in this area and a little malachite is present in Googhenama Creek in the north-eastern part of the Sheet.

The copper minerals are everywhere associated with dolomite, usually in joints or faulted zones, and close to outcrops of the Davis Dolerite. No copper minerals were seen in direct association with the dolerite, but Talbot (1920) mapped similar dolerite sills in the vicinity of the copper deposits at Bulloo Downs, Kumarina, and Ilgararrie (south of this Sheet area).

The main copper minerals present are malachite and cuprite, with atacamite and a little azurite. None of the deposits has been mined to a depth exceeding 10 feet, but a cave in dolomite, 100 yards north-east of the deposit to the north of Saddleback Hill, is reputed to expose a seam of malachite at a depth of 180 feet.

Columbite and Beryl

Alluvial and eluvial deposits containing columbite and beryl have been worked near Five Mile Creek, in the north-western corner of the area. The deposits were rather low grade and work stopped when the price of columbite fell.

Gold

Some old potholes occur in conglomerate 2 miles south-east of Turkey Bore, 24 miles north-west of Balfour Downs Homestead. The conglomerate, the basal formation of the Nullagine Series, contains poorly rounded boulders of quartz, jaspilite, quartzite, and schist. The quartz contains some silver-coloured pyrite, but there is no evidence of any gold having been won from the conglomerate. Talbot (1920) reported alluvial workings in this vicinity, but they have not been located.

A quartz reef in an island of schist in the Gregory Range Granite in the north-eastern corner of the Sheet is auriferous. A sample of chips taken across the reef, 8 feet wide, contained pyrite and assayed 17 grains gold per long ton.

Iron

Sofoulis (1960) took fourteen samples from an iron ore body 6 miles north of Roy Hill Station and immediately adjoining the western boundary of the Sheet. He quoted an inferred tonnage of 10 million tons at a grade of better than 60 percent metallic iron. The deposit is the result of supergene enrichment of iron in ferruginous shale and jaspilite of the Lewin Shale. Similar deposits are present elsewhere in the Lewin Shale, but they were all considered too small to be worth sampling.

None of the laterite in the area contains enough iron to be ore.

Barite

Some barite is present in a fault-filling in association with quartz, in Little De Grey Lava about 15 miles east of Rat Hill. A grab sample assayed 84·5 percent $BaSO_4$. Other outcrops of barite occur in dolomite at Billinnooka Homestead, 16 miles south of Balfour Downs Homestead (2 miles south of the Sheet area).

Tant-euxenite

Some radioactive minerals such as tant-euxenite have been reported from the pegmatites near Five Mile Creek, but in small quantities.

Corundum

Corundum and alumina-rich schists (Archaean) crop out in the Rat Hill area in the middle of the Sheet area. These rocks may have some use as refractory material at a later date, but have little economic value at present.

Water

There are a few permanent natural watering places, in the form of pools and rockholes. Although many pools form in the non-perennial streams after rain, only three could be classed as permanent : Kallona Pool, Carrowina Pool, and Meercardagunna Pool. The rockholes are mainly in the eastern part of the area and are usually difficult of access. Nooganoonga Rockhole is probably the biggest and it would probably hold 100,000 gallons when full.

The average depth to water of wells and bores in basalt country is about 40 feet, and supplies in shale country are usually a little deeper. Water from both types of rock is usually good and supplies of 1,000 to 3,000 gallons per day are usual.

In the plain area in the south-western part of the Sheet the water level is about 40 feet deep, near the main drainages. The water tends to become more saline downstream and also away from drainage channels. Away from drainage channels the wells range in depth up to 100 feet. This plain area is mostly underlain by the Oakover Formation, which is an excellent aquifer in other parts of the Sheet and in other parts of the North West Division.

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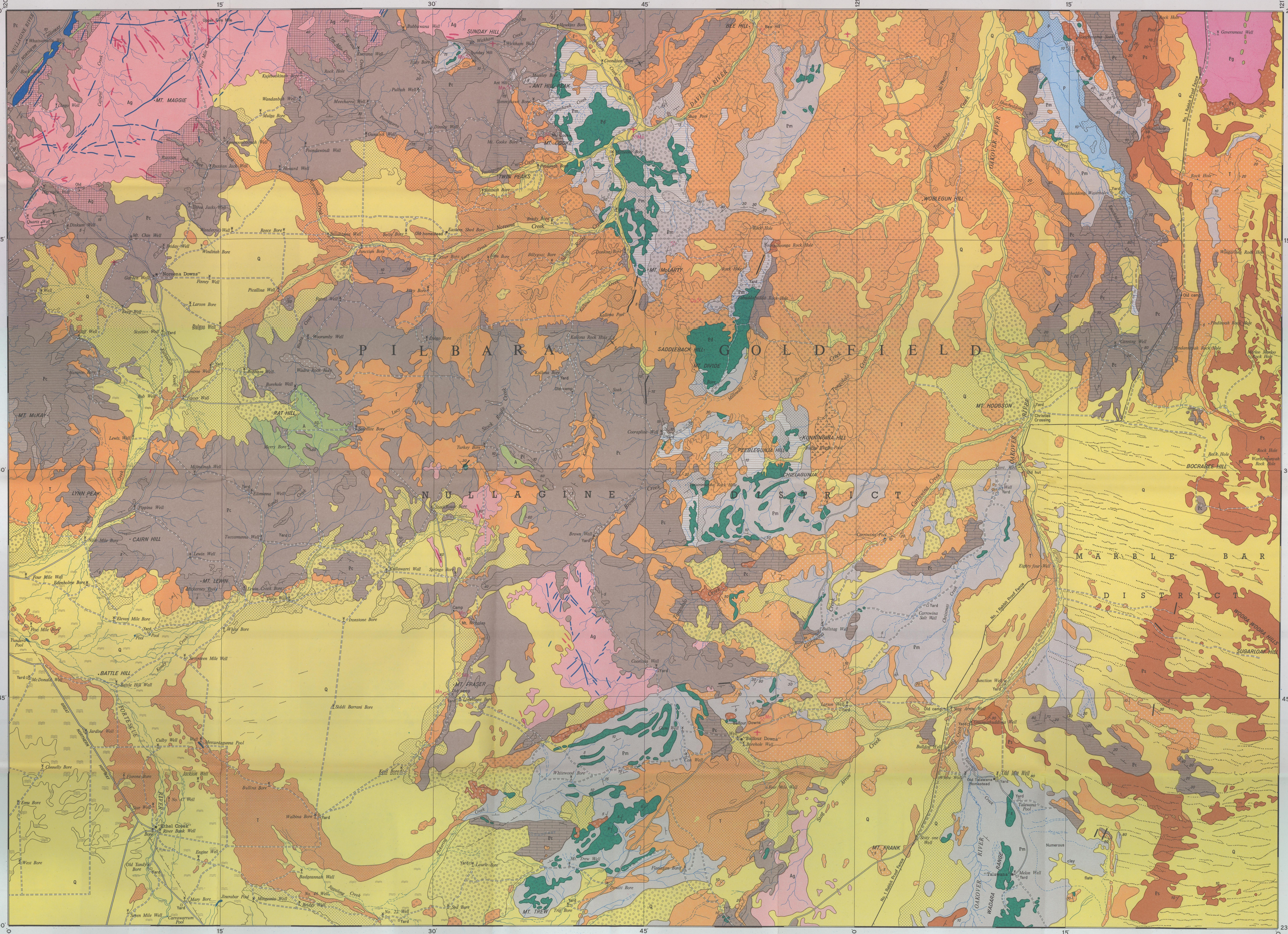
BALFOUR DOWNS

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SF 51-9 ZONE 2



REFERENCE

Era	Period	Formation	Symbol	Description
CAINOZOIC	QUATERNARY		Q	Sand.
				Aeolian sand.
				River gravels.
				Alluvium.
				Alluvium over Oakover Formation.
				Fine outwash.
				Coarse outwash.
	TERTIARY	Oakover Formation	T	Poorly cemented conglomerate, seven miles east of Sunday Hill.
				Outwash with some opaline silica and grit.
				Limestone with opaline silica cap.
				Laterite, including ferruginous deposits at Mt. Lewin and manganiferous deposits at Mt. Nicholas.
				Chert breccia, not differentiated from Pinjian Chert Breccia.
				Quartzite cap.
PALAEOZOIC	PERMIAN	Bunmardie Beds	P	Cross-bedded sandstone with some faceted boulders.
		Braeside Tillite		Tillite with unsorted, faceted, striated boulders.
PROTEROZOIC		Bocrabee Sandstone	Ps	Cross-bedded white sandstone.
		Googhenama Conglomerate		Coarse boulders (50 ft. band) and pebble conglomerate.
	Manganese Group	Noreena Shale	Pm	Chocolate-coloured blocky shale-siltstone with pellets of braunite.
		Balfour Shale		Green shale, micaceous to sandy, calcareous and cherty.
		Bee Hill Sandstone		Banded cross-bedded reddish sandstone with pebble bands and white spots.
		Coondoon Conglomerate		Conglomerate containing angular boulders and sandy, ferruginous and manganiferous shales. Overlies Pinjian Chert Breccia.
		Carawine Dolomite	Pc	Impure red-grey crystalline dolomite with some chert bands and some *collenia*.
		Lewin Shale		Shales, banded chert, mudstone, thin dolomite bands with iron and chert concretions.
				Thin bedded dolomite.
		Little De Grey Lava		Green amygdaloidal basalt in several flows.
				Agglomerate.
		Tumbiana Pisolite		Grey-blue to grey-green pisolite; oolitic, sandy or cherty in places — some *collenia*.
		Beatons Creek Conglomerate		Boulder conglomerate with bands of grit and sandstone.
ARCHAEAN	Warrawoona Series		A	Volcanics, schists and jaspilites.

IGNEOUS ROCKS

Era	Formation	Symbol	Description
PROTEROZOIC	Davis Dolerite	Pd	Fine- to medium-grained dolerite sills.
		Pg	Gneissic granite.
ARCHAEAN			Quartz veins and pegmatite dykes.
			Dolerite dykes.
		Ag	Gneiss.
			Granite.

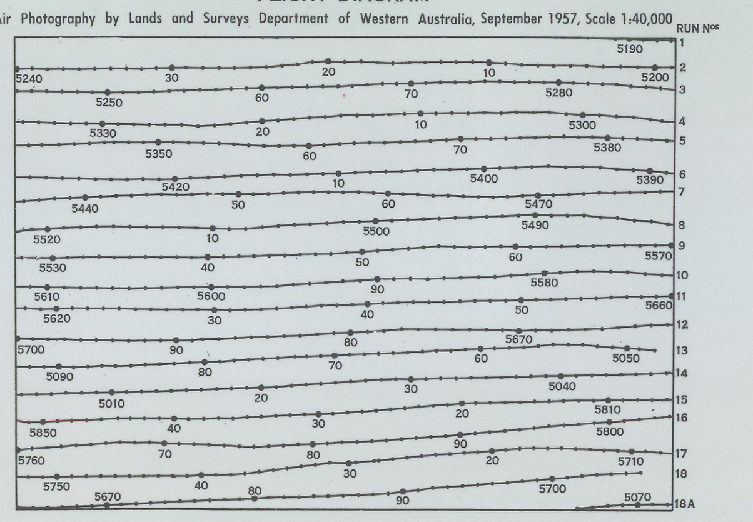
SYMBOLS

Geological boundary
Anticline
Syncline
Fault
Strike and dip of bedding
Vertical bedding

Goldfield boundary
Highway
Formed road
Track
Telegraph line
Fence
Homestead, hut
Landing ground
Bore or well with windpump
Bore, well or waterhole — *Laurie Bore*
Soak — *Emu Soak*
Rock hole — *Rock Hole*
River or stream with pool
Mining area — Mt. Cooke
Current workings — Copper — Cu
Manganese — Mn
Beryl — Be
Tantalite — Ta

FLIGHT DIAGRAM

Air Photography by Lands and Surveys Department of Western Australia, September 1957, Scale 1:40,000



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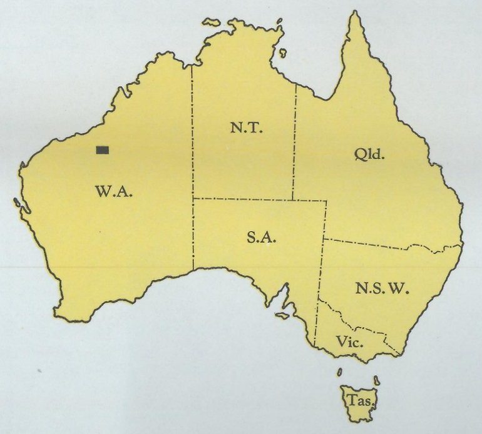
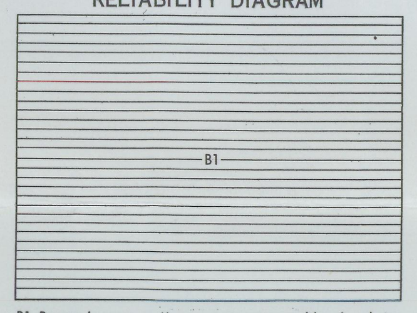
Copies of this map may be obtained in Perth from the Geological Survey of Western Australia or the Bureau of Mineral Resources, Geology and Geophysics in Canberra, A.C.T.



RELIABILITY DIAGRAM



B1 Reconnaissance — Numerous traverses with air photo interpretation.

HON. A. F. GRIFFITH, M.L.C.,
MINISTER FOR MINES.
J. H. LORD, GOVERNMENT GEOLOGIST.

Scale 1:250,000

TRANSVERSE MERCATOR PROJECTION

Geology by L. de la Hunty and J. Sofoulis.

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ROY HILL SF 50-12	BALFOUR DOWNS SF 51-9	RUDALL SF 51-10
NEWMAN SF 50-16	ROBERTSON SF 51-13	GUNANYA SF 51-14

DECLINATION DIAGRAM

Annual change is negligible

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SHEET SF 51-9

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