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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

REGIONAL SURVEYS DIVISION

GEOLOGY OF THE BELTANA 1:63,360 MAP AREA

By

Brian Leeson
Geologist
REGIONAL MAPPING SECTION

D.M. 1651/65

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2nd September, 1966.

Frontispiece: Large raft of Willouran Quartzite in the Beltana Diapir.

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ABSTRACT

Rocks belonging to the upper part of the Adelaide System and the overlying Cambrian, outcrop in the eastern part of the Beltana area in the Nuccaleena Dome, and form the basement underlying the more recent sediments to the west. In the central and western areas they have been block faulted to form two partly connected basins in which Tertiary deposits accumulated. These are now completely masked by Recent sand and scree. Willouran rocks are exposed in the Beltana Diapir, and in faults radiating from the centre of the Nuccaleena Dome. Diapiric movements, during late Marinoan times, locally influenced sedimentation. Syngenetic lead and copper deposits are present at Ediacara. Elsewhere in the area copper is present both ac stratiform and cross-cutting lodes which may be related to diapirism.

INTRODUCTION

The Beltana 1:63,360 geological map covers an area of approximately 500 square miles extending from the western edge of the Flinders Ranges to the eastern margin of Lake Torrens. The township of Beltana after which the map is named, is situated on the main road from Hawker to Marree, some 320 miles north of Adelaide and 25 miles south of Leigh Creek (fig. 1).

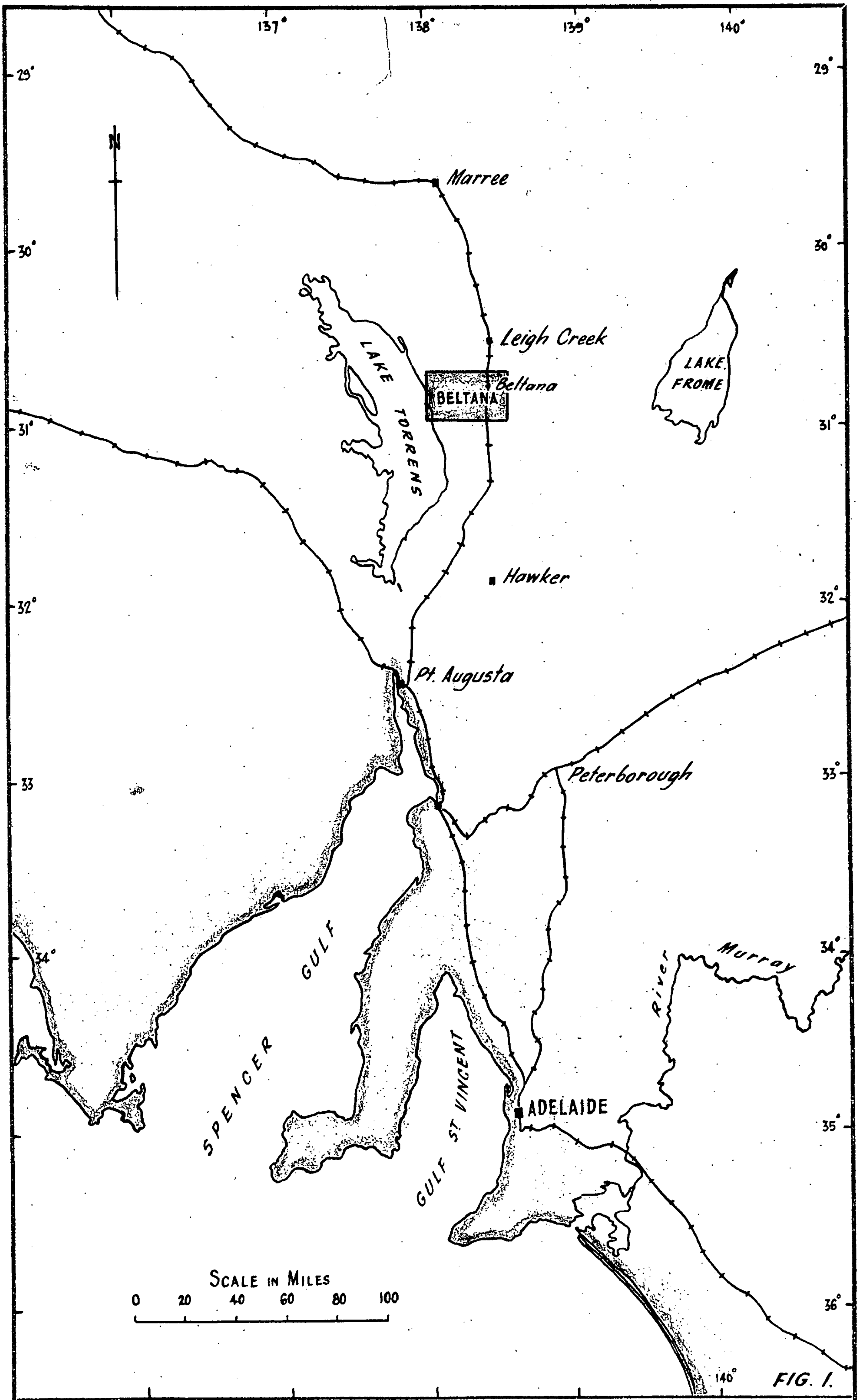

FIG. 1.

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	Drn.	BELTANA 1 Mile GEOLOGICAL MAP LOCALITY PLAN	SCALE:
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The topography of the area strongly reflects the geological structure. The hilly country in the east is formed by the dissection of the Nuccaleena Dome. The rocks forming the Dome belong to the Precambrian Adelaide System, and are exposed as a series of scarps and low hills arranged in an arcuate fashion, swinging around from southeast to northeast and running roughly parallel with the main road for some distance (See Fig. 2). To the east of the road are the scarps forming the core of the Dome. To the west, Red Range trending north-south forms the most western extent of the Dome where it has been limited by diapiric and fault movements. North of Beltana township, the road passes through two miles of very broken country formed by the Beltana Diapir. This is bounded to the north by Mt. Bayley Range, a very prominent southeast facing scarp, which extends from Beltana R.S. to Puttapa Gap, three miles north of the map area.

The rather sinuous line formed by the western edge of Mount Deception Range and Red Range is a fault-scarp determining the western limit of the hilly country. To the west, the flat plains and table-lands of the central region are formed of Quaternary boulder deposits and Recent flood and outwash scree, covering flat-lying Tertiary sediments. These deposits accumulated in a basin created by block faulting. The down faulted block tilted towards the east, hinging on the north-south belt of hills running from Mt. James to Mt. Michael, which forms the western limit of the central plains.

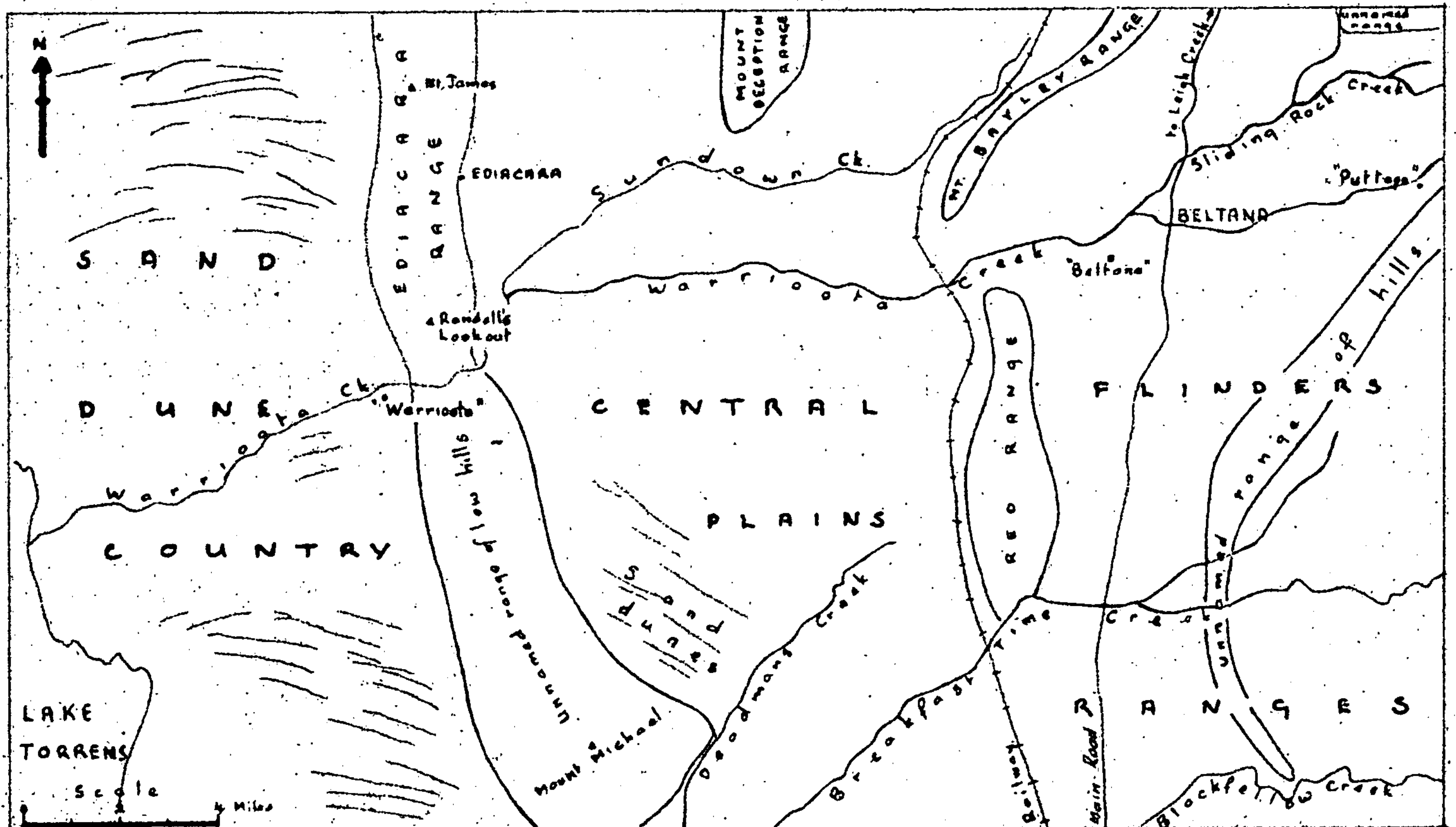


Fig. 2. Sketch map showing main geographical features of the Beltana area

The western edge of this range is formed by the Ediacara Fault, which is a major feature in the zone of structural lineaments between the Stuart Shelf in the west, and the highly folded part of the Adelaide Geosyncline exposed inthe Flinders Ranges to the east. The fault forms the eastern structural limit of the Lake Torrens Sunkland (part of the Torrens-St. Vincent Rift) in which Tertiary sediments have accumulated over low-dipping Precambrian strata. These Tertiary deposits are now covered by a flat expanse of sand dunes stretching westwards from the Ediacara Fault to the edge of Lake Torrens.

The main drainage channels of the area run westwards or southwestwards from the Flinders Ranges to Lake Torrens. From south to north these are Blackfellow Creek, Breakfast Time Creek, Deadman's Creek, Warrioota Creek, Sliding Rock Creek, and Sundown Creek. All the creeks are dry throughout the year, except for occasional flash floods.

The Beltana area is well served by roads and tracks. The main route north-south is a wide dirt road, well-graded and kept in good repair. Tracks reach all part os the area and most of them can be used by conventional vehicles; only in the south-eastern area is a 4-wheel drive vehicle needed.

The average annual rainfall measured over the last 91 years is 8.16 inches. The land is entirely given over to sheep farming. The larger portion of the area belongs to the Beltana Pastoral Company's Beltana Station. Bounding it to the west, south and east is the Nilpena run, and to the northeast the Puttapa Station. The land was opened up by pastoralists in the 1850's. Beltana Station formerly consisted of four smaller properties. These were combined by Thomas Elder in 1867 after the great drought. In the early days Elder bred camels on the property. Beltana Station was the departure point in 1875 of the expedition led by Ernest Giles, which crossed the continent to Perth. A monument erected at Beltana Station records the expedition.

The township of Beltana was laid out in 1873 on the line of the Overland Telegraph. There was an influx of people from the nearby town of Cadnia (now a ghost town) when the Sliding Rock Mine closed in 1877. The completion of the rail-link with Port Augusta in 1881 brought importance to the town as a centre serving the local mining and farming communities, and as a railhead for the dispatch of ore mined in the district, particularly from the Ediacara Mining Field 15 miles to the west, (see fig. 8). At the height of its prosperity the town supported two hotels and a small brewery. In 1891 the township of Ediacara was built on the Mining Field to serve the mines. Now scarcely any ruins remain to mark the site.

In 1895 the Smith of Dunesk Mission was opened in the town by the Reverend Robert Mitchell. Until 1933, when the Mission was absorbed by the Australian Inland Mission, the ministers served a large area of the Northern Flinders Ranges. The most famous of these men was John Flynn whose activities led to the founding of the Australian Inland Mission in 1912, and eventually to the setting up of the first Flying Doctor Service at Cloncurry, Queensland, in 1928. Between 1912 and 1945 a nursing hostel established by the Australian Inland Mission existed at Beltana. During the Ministry of the Reverend William Grey (1924-1928) accommodation for tuberculosis victims was provided at the Manse and in the town.

Beltana township had its heyday between 1880 and 1920 when the mining activity was at its height. Since that time it has steadily declined in importance. In 1956 the new Commonwealth Railway was opened to replace the old narrow gauge line. The new line swings to the west of Red Range and Mount Bayley Range, bypassing the town, (see fig. 2). The fine old railway station stood empty for some time but has recently been reopened by Mr. P.M. Ross, as the local Post Office and General Store.

Footnote:-

The inscription on the cairn built at Beltana H.S. to commemorate the Giles expedition of 1875 reads as follows:-

"This cairn commemorates the setting out of the exploring expedition which left Beltana Station on 6th May 1875, and after enduring great hardships reached Perth, W.A. on 18th November 1875. The return journey was made from January to August 1876. The expedition was financed by the Hon. (Sir) Thomas Elder and consisted of Ernest Giles (Leader), W.K. Tietkins, J. Young, A. Ross, Peter Nicholls, Saleh, Jimmy, and Tommy".

HISTORY OF INVESTIGATIONS

The area covered by the Beltana 1:63,360 map has not until now been completely surveyed. However, during the past 100 years parts of the area have received a considerable amount of attention from geologists. Frequent visits have been made by geologists and mining inspectors to the various mines and mineral prospects. A particular focus of repeated surveys has been the silver-lead-copper mineral field at Ediacara. Interest from a different aspect was stimulated in this locality by the recent discovery of rare Precambrian fossils.

The history of investigations revolves mainly around the examination of mines, and prospecting for new mineral occurrences. Mining probably started around the middle of the last century and reached its peak of activity during the years 1880 to 1920. Only minor production has been recorded during the last 40 years. None of the mining ventures proved economically rewarding over any great length of time.

The first geologist known to have visited the area was Ulrich in 1872, who examined and reported upon the Beltana Mine at Ediacara. He observed, (Ulrich, 1872), the confinement of mineralization to the zone of contact between underlying soft shales (Parachilna Formation) and the overlying limestone (Ajax Limestone).

Scoular (1882) noted that the flaggy limestone, which he termed marble, outcropping to the south of Beltana township, was of sufficient quality to be regarded as a building flagstone. The rock he described is placed in the Wonoka Formation.

The Government Geologist H.Y.L. Brown visited the Ediacara Mineral Field in April, 1888 and reported on the Beltana Broken Hill Mine and the Beltana North Mine. His reports are contained in the 1890 edition of the "Record of Mines of South Australia", which also contains accounts of all known mining ventures in the Beltana area up to that date.

Krause (1891) examined the Ediacara Mine for the

Ediacara Consols Silver Mining Company. In his report he compared the lead deposits to those of the Mississippi Valley. This is the first known suggestion of their origin and it is worthy of note that this theory was re-affirmed as a result of Nixon's recent detailed investigations into the Field, (Nixon, 1963b).

Various officers of the South Australian Geological Survey visited the Ediacara Mineral Field between 1888 and 1907. Their findings are summarized by Brown in the 1908 edition of the "Record of Mines of South Australia." Brown's summary also contains a précis of the report (Brown, 1892b) on the investigations which he made in 1892. The sketch map (Brown, 1892a) which accompanied this report shows the Field to have a basinal structure with one fault in the northwest (the Gap Creek Fault), Brown recognised three groups of rocks:-

1. an upper dolomitic limestone group with flat lying mineralized breccia zones forming an upper argentiferous lode of galena, lead carbonate and iron gossan.
2. a middle group of mineralized argillaceous shale and sandstone up to 60' thick forming the lower lode containing segregations of lead carbonates, gossan, ironstone and copper carbonate.
3. a lower quartzite group.

Brown's groupings correspond very closely to the present formational divisions of Ajax Limestone, Parachilna Formation and Pound Quartzite.

In 1897 a fossil from Ediacara was identified by Etheridge as an Archaeocyatha of Cambrian age. This is the first recorded age determination of the sediments of this area.

The years from 1880 to 1920 were the time of the most active mining and mineral search over the whole of the Beltana area. Inspectors of Mines visited the area on various occasions during this period to report upon the progress of mining. Detailed accounts of the history and nature of these mines will be found in the section dealing with mineralization.

In 1925 R.L. Jack studied the structure of the Beltana area west of the Ranges to elucidate the hydrological problems of the northern part of the Pirie-Torrens Basin. He recognized for the first time (Jack, 1925), that the west facing scarps of Mount Deception and Red Range, and Ediacara Range with its continuation south to Mt. Michael, were caused by normal faults downthrowing to the west.

A revival of interest in the potential economic value of the Ediacara Mineral Field prompted visits by a number of geologists during the following years. Boundy and Gibson surveyed the area between Gap Creek and the Warrioota Mine for Austral Development Pty. Ltd. Their work was summarized by Gustafson (1938), who considered that a possible duplication of the southern workings could be found in two places but there was little probability of a large low-grade ore-body being discovered.

Segnit (1939) mapped the Ediacara area from Warrioota Creek to Mt. James. His map shows a profusion of faults few of which are now considered to exist and his work is marred to some extent by incorrect correlations of isolated outcrops. However, his observations of the lithology added valuable knowledge to the geology of the area. Segnit described in some detail the lithology and sedimentary features of the Flinders Range Sandstone-Quartzite Series (Pound Quartzite), which he considered indicated a shallow water origin. This concept was confirmed by Sprigg in 1949 on palaeontological evidence. Segnit correctly placed the ~~Cambrian~~-Precambrian boundary at the top of the Pound Quartzite and considered that an erosional break or disconformity existed in places at the base of the Cambrian. The latter observation is now discredited in this area. Segnit recognized Brown's middle group as a basal unit of the Cambrian, but did not regard it as a formation or group separate to the overlying limestones. He described for the first time the presence of bedded cherts in the Cambrian limestone.

From 1940 to 1947 the Austral Mining and Smelting Company and Austral Development Pty. Ltd., subsidiaries of Zinc Corporation, held special mining leases over the Ediacara area. During this period the South Australian Mines Department carried out a programme of investigations, which included the remapping of the area by Broadhurst. His map (Broadhurst, 1947, 1953) shows the structure much the same as it is considered to be now, with only one fault of importance (the Gap Creek Fault). He named the Transition Beds which Brown had previously noted. Broadhurst's approach was from an economic point of view and was followed, on his recommendation, by a programme of drilling and geophysical investigations.

In 1946 Sprigg discovered rare Precambrian fossil jelly-fish near the top of the Pound Quartzite, southwest of the Southern Workings at Ediacara, (Sprigg, 1947). Later work by Sprigg (1949); Sprigg and Mawson, (Sprigg, 1949), Glaessner and Daily (1959), and Nixon (1963a), extended the known occurrence of the horizon around all parts of the Ediacara basinal structure except the west and north, and increased the number of identified faunal elements. The suite has become known as the Ediacara fauna and includes representatives of the Hydrozoa, Scyphozoa, Anthozoa, and Annelida. In May, 1958, the southern portion of the field was declared a fossil reserve under the auspices of the Minister of Education and the South Australian Museum. On this occasion Glaessner prepared a review of the fauna, (Glaessner and Daily, 1959 op. cit).

Coats (1961) conducted a brief hydrological survey of the south-western part of the Beltana area covered by the Nilpena sheep-station.

Thomson (1961a) examined the deposits at Ediacara and noted the lack of persistence in depth of the ore. He suggested that secondary enrichment of a low grade primary ore horizon during weathering had played an important part in the formation of the then known ore-bodies.

The South Australian Mines Department commenced an intensive programme of investigations into the mineral deposits at Ediacara in 1961 under the supervision of L.G. Nixon. Geophysical and geochemical surveys were carried out concurrently with a programme of detailed mapping and diamond drilling. The survey was completed in 1963. A large tonnage of low grade mineralization was proved. The results of this survey are outlined in the section dealing with ore-deposits. The Conzinc Riotinto Australia Co. Pty. Ltd. have continued investigations to the present date.

STRATIGRAPHY

Most of the rocks present in the Beltana area belong to the Precambrian Adelaide System of which a total thickness of 20,700 feet is exposed. There is an essentially uninterrupted succession from the middle Umberatana Group into the Middle Cambrian; followed by a long break before the terrestrial and freshwater deposits of the Tertiary and Quaternary Periods. Figure 3 is a diagrammatic presentation of the succession; thicknesses of formations have been calculated from outcrop widths on aerial photographs.

The Adelaide System has been divided into 4 groups (Thomson et al. 1964). In order of succession from the base upwards these are the Callanna Beds, the Burra Group, the Umberatana Group, and the Wilpena Group. The equivalent time terms; Willouran, Torrensian, Sturtian, and Marinoan are discussed in the same paper. In the Beltana area three of these groups are represented. Rocks ascribed to the Callanna Beds (Willouran age) are diapirically emplaced in the Beltana Diapir and will be described in the section dealing with diapirism. The Burra Group and the lower part of the Umberatana Group are not seen. The upper part of the Umberatana Group and Wilpena Group are well

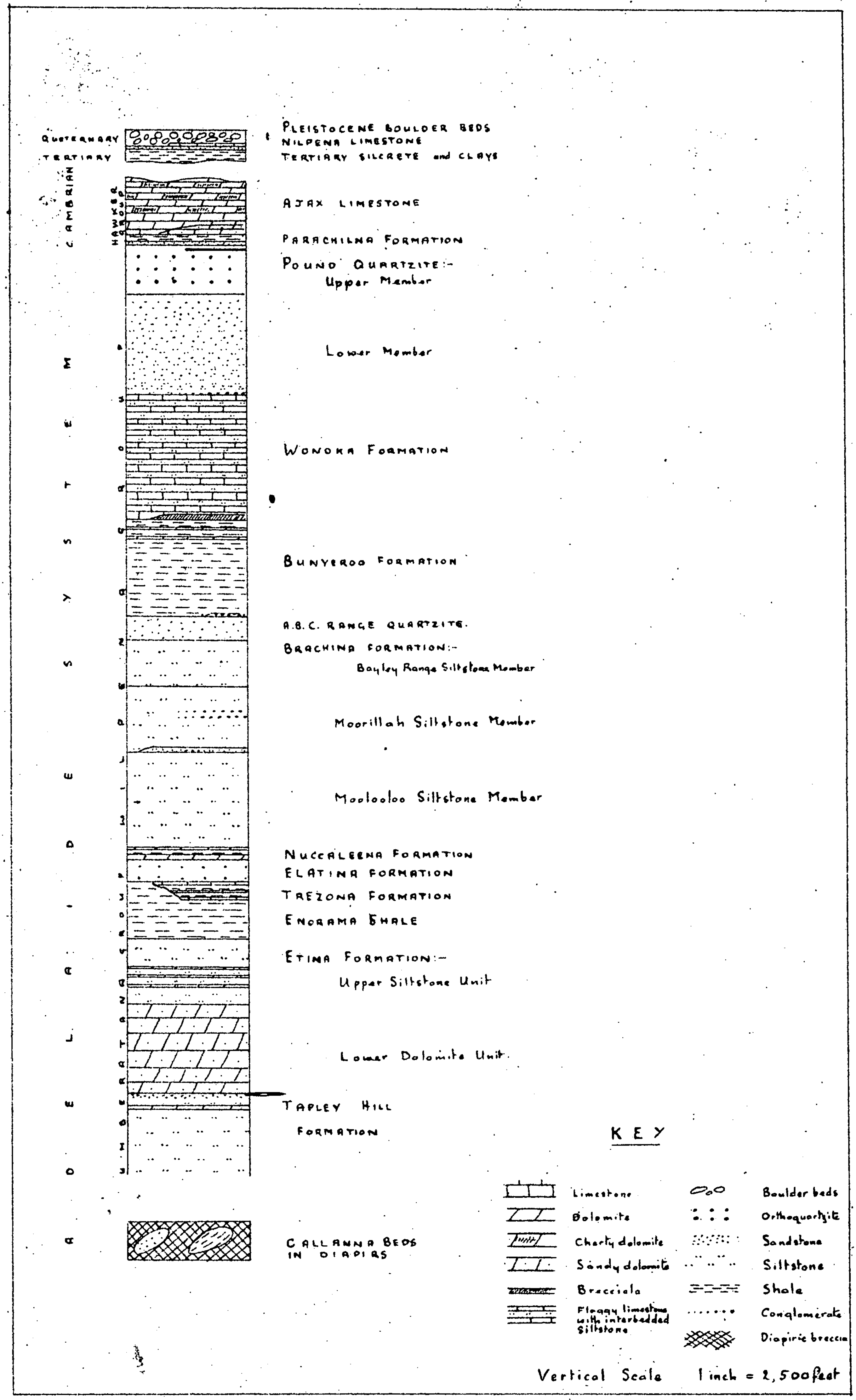


Fig. 3. OF MINES 31/8/66. Stratigraphical Column. S 5453 C+F FIG.3

exposed.* These rocks are mainly of Marinoan age. The exact placing of the boundary between the underlying Sturtian and the Marinoan is not certain. In the Beltana area it is perhaps best taken at the base of the Etina Formation.

Only the lower part of the overlying Cambrian is present and attains its best development in the Ediacara Range. Minor outcrops of Tertiary duricrust and Quaternary limestone and gravel beds occur particularly in the central and western areas.

The Adelaide System

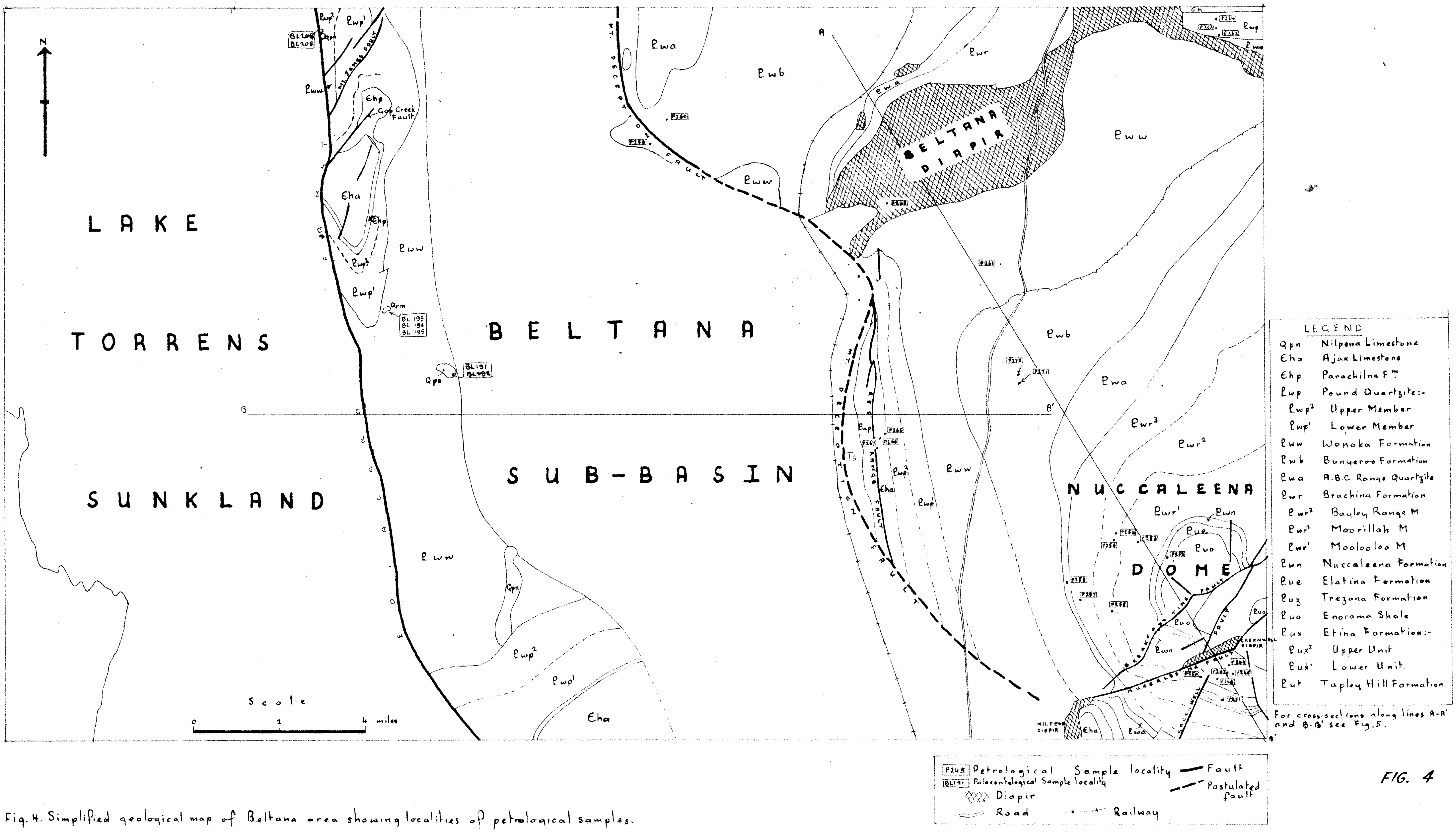
Umberatana Group

Only the upper part of the Umberatana Group is present in the Beltana area. The succession is exposed in the core of the Nuccaleena Dome in the south east (Fig. 6).

The lowest beds belong to the Tapley Hill Formation of which the upper 3,500 feet are exposed between Blackfellow and Nuccaleena Creeks, where it forms low undulating country cut by many minor stream channels. The formation consists of well-bedded brown weathering, fairly coarse-grained siltstone characterized by fine, straight laminations. The siltstones are occasionally cross-bedded. A 6 inch thick, bluish-grey silty dolomite occurring near the top of the formation may be the equivalent of the Wockerawirra Dolomite mapped to the south by Dalgarno and Johnson (1964a).

The uppermost beds of the Tapley Hill siltstones are notably coarser-grained and contain at least one horizon of soft, red-weathering sandy siltstone and are considered to be the lateral equivalent of the Yankaninna Formation of the Northern Flinders (Coats in Thomson et. al. 1964). The uppermost bed is a medium-grained quartzite.

* Figure 4 is a simplified geological map of the Beltana 1:63,360 area to which reference should be made throughout this section.



For enlargement of S.E. corner see Figure

FIG. 4

Fig. 4. Simplified geological map of Beltana area showing localities of petrological samples.

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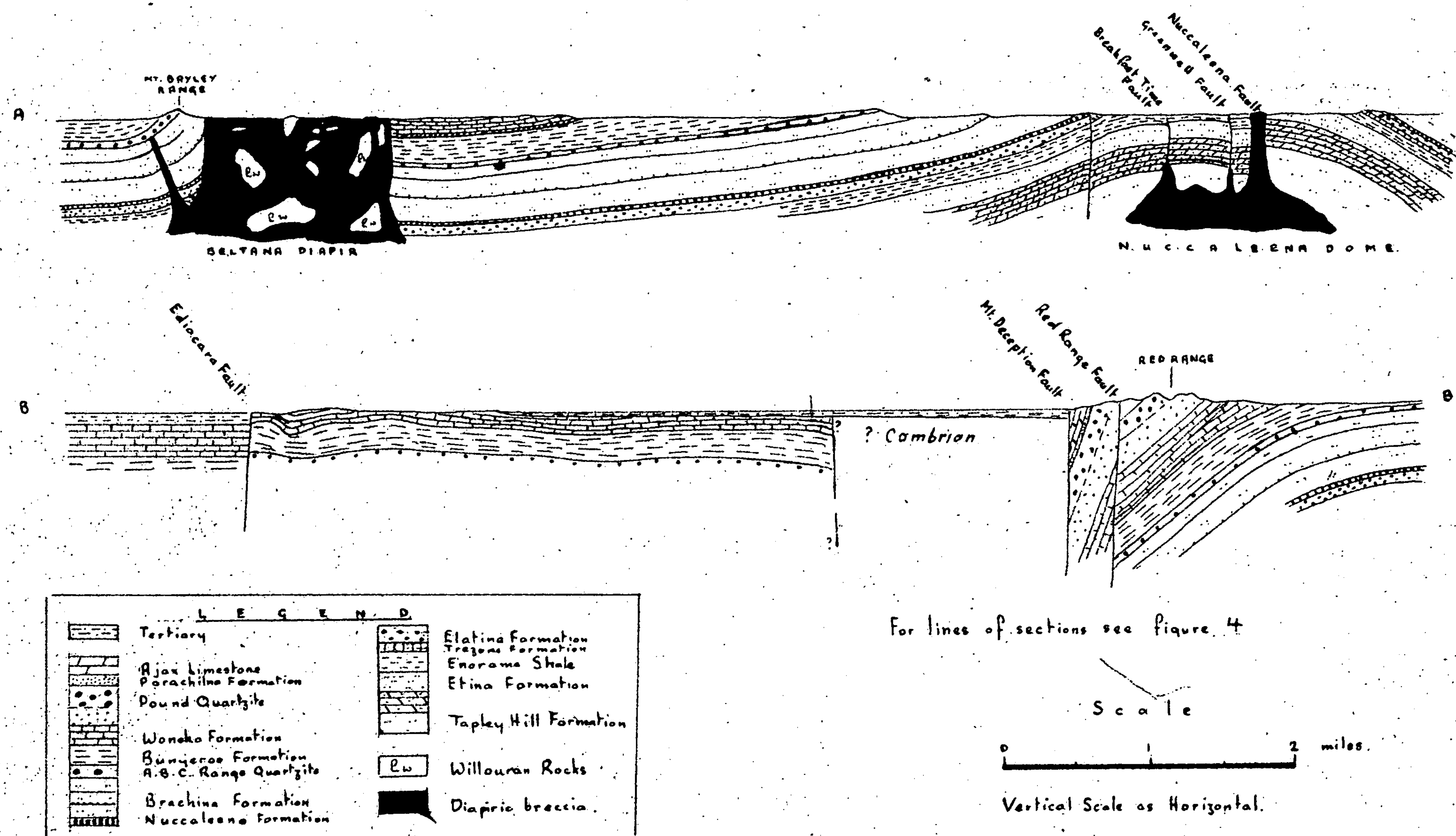
Fig. 5. Geological sections across the Beltana area.



S 5454 C+F

FIG 5

S. A. DEPT. OF MINES C+F

The Tapley Hill Formation passes upwards into a thick sequence of well-bedded sandy dolomite (1900 feet thick) regarded as the basal unit of the Etina Formation. The transition from the siltstone of the Tapley Hill Formation is a rapid one, with a few thin, gritty dolomites interbedded with siltstones at the base. The boundary is placed at the first dolomite. The unit forms a southeast trending belt of very rugged country with a thick covering of mulga, south of Greenwell Diapir. Above the basal transition beds the formation is composed of massive yellow-brown weathering, rather sandy dolomite (P245/66)* with occasional lenses of coarse-grained red siltstones. Some beds are particularly sandy containing up to 25% of poorly rounded quartz grains in a matrix of slightly oolitic primary dolomite (P246/66).

The thick dolomite passes up into massively outcropping, brown and grey-green weathering, bluish-grey sandy siltstone (P247/66) with a slight suggestion of fine laminations, which together with the overlying similar medium grey siltstones (P248/66) forms the upper part of the Etina Formation. This unit is distinguished from the overlying Enorama Formation on grain size and the presence of three thin dolomite bands. The lowest of these is very gritty with a brecciola texture in places. The upper two bands are smooth reddish-brown weathering dolomites (P249/66) separated by soft reddish-weathering coarse-grained siltstone. The massive flat-lying siltstones outcropping north of Greenwell Diapir are placed in the upper unit of the Etina Formation. Here several bands of dolomite are interbedded with the siltstone. The lowest dolomite is notably sandy to the extent of passing along strike into lenses of massive quartzite.

The total thickness of the Etina Formation is 3170 feet.

The top of the Etina Formation is defined by the base of a thin bed of purple siltstone which forms the basal unit of the

* The numbers in brackets refer to descriptions of thin sections of samples by I. F. Scott, contained in Appendix I. Locations of samples are shown in figures 4 and 6.

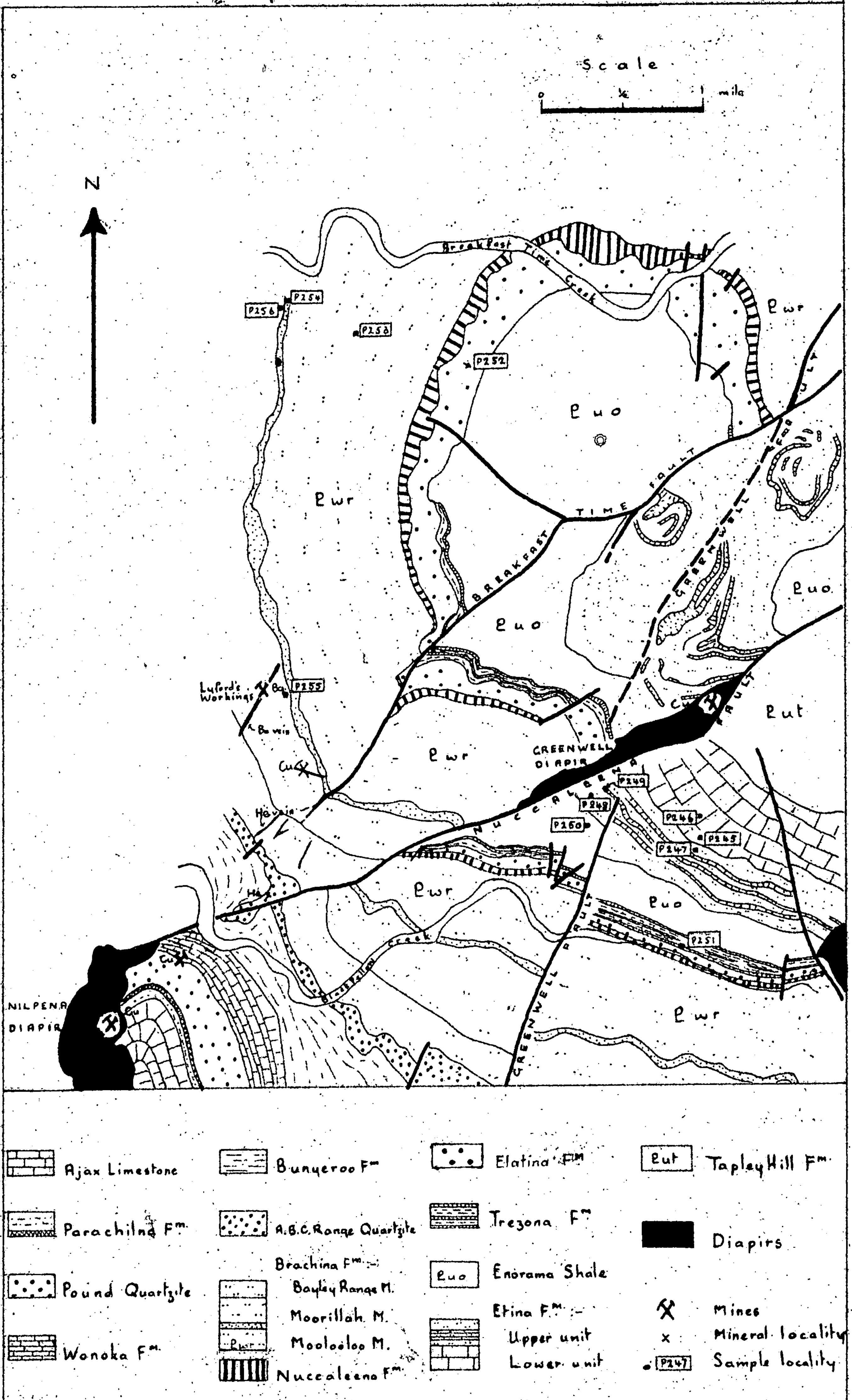


Fig. 6. Enlargement of S.E. corner of Beltana 1:63,360 geological sheet, showing geological formations, and localities of mines, mineral lodes and petrological samples.

S. A. DEPT. OF MINES
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S 5455
C+F

FIG. 6

Enorama Formation. The siltstone is overlain by 800 feet of thinly bedded light green weathering, grey-green silty shales (P250/66) passing upwards into drab grey shale. Slumping occurs near the top of the formation in Nuccaleena Creek, (photos 1 and 2). The siltstone/shale sequence of the upper part of the Umberatana Group is completed by the Trezona Formation. This formation is composed of 280 feet of grey calcareous shale but distinguished by several interbedded bands of flake-breccia dolomite (P251/66). The Trezona Formation is exposed beneath the Elatina Formation around the western and southern parts of the faulted Nuccaleena Dome. Around the northern part of the dome the Trezona Formation is absent, the dolomite bands progressively lensing out northwards. The best exposure for examination of the Formation is the section along the north side of Blackfellow Creek.

The sequence of the Umberatana Group is completed by the Elatina Formation. This is the equivalent of the Marinoan tillite (Yerelina Formation; Pepuarta Tillite), seen elsewhere in the Flinders Ranges. However, in the Beltana area it is not of immediate glacial origin. The Formation here consists of a pink to reddish coarse grained, well-sorted sandstone (P252/66). The coarse fraction is composed mainly of well-rounded granules of quartz, but with a notable scattering of distinctive granules of red chert. The chert is a feature which can be recognized in other areas of the Northern Flinders Ranges where this facies of the Marinoan glacial occurs. Sparse pebbles (up to ½" diameter) were found in the sandstone. Dalgarno and Johnson (1964b) have recorded, from Brachina Creek, glacial striated pebbles from a thin red mudstone at the top of the Elatina Formation. This has not been located in the Beltana area.

Thus the upper part of the Umberatana Group in the Beltana area is essentially a shale-siltstone sequence with only one major carbonate phase (the lower unit of the Etina Formation) and minor interbedded carbonates, and is completed by a sandstone.

Plate 1—Slumping near top of Enorama Formation in Nuccaleena Creek.

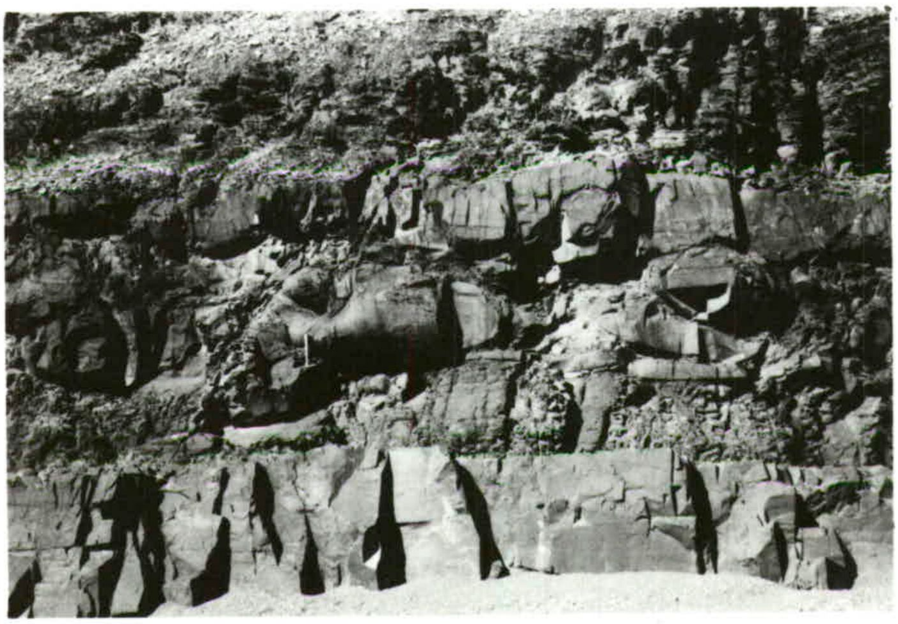


Plate 2—Slumping near top of Enorama Formation at above locality.

Plate 3—Upper unit of Nuccaleena Formation; purple shales with interbedded dolomite (white bands). Black-fellow Creek.

Wilpena Group

The Wilpena Group (Upper Marinoan) conforms closely to the description of the type areas by Dalgarno and Johnson (in Thomson et al. 1964). There is evidence within this group in the Beltana area of local tectonic instability related probably to diapirism, and of a change in thickness towards the western margin of the geosyncline.

The Wilpena Group is exposed over much of the eastern half of the map area on the flanks of the Nuccaleena Dome (see Fig. 4). Part of the Group is repeated to the north of the Beltana Diapir by the faulting associated with that structure. The upper two formations of the group - the Wonoka Formation and the Pound Quartzite-are exposed in the isolated north-south hill mass of the Ediacara Range and its continuation southwards to Mount Michael.

The lowest formation of the group is the <u>Nuccaleena Formation</u>, which is exposed in the south-eastern part of the area. The Formation lies conformably upon the Elatina Formation, in the faulted rim of the Nuccaleena Dome. Elsewhere in the Flinders Ranges the Nuccaleena Formation consists of an unnamed basal dolomite overlain by purple shales with interbedded thin dolomites. Here the basal unit is well exposed, forming a prominent scarp. It consists of well bedded, cream weathering, pink dolomite with a blocky appearance. The overlying purple shales with interbedded thin dolomites are very poorly exposed because of scree covering. They can be seen in creek sections on the north-west and north-eastern parts of the dome, and along the southern bank of Blackfellow Creek (plate 3). The total thickness of the Formation is 120'. Overlying the Nuccaleena Formation are 300' of red siltstones. These are excluded from the Nuccaleena Formation by definition (Dalgarno & Johnson, in Thomson et al. 1964) and are here regarded as the basal unit of the Brachina Formation.

The <u>Brachina Formation</u> is exposed over a large area east of the Hawker-Leigh Creek road, and north of Beltana Diapir (Fig. 4). It is possible to divide the Formation into three members and new names are proposed for these. The type section is along Bitter Springs Creek from 30° 57' 30"S; 138° 25' 30"E; to 30° 57' 16"S; 138° 27' 21"E.

<u>Moolooloo Siltstone Member</u>. The lowest member of the formation conformably overlies the Nuccaleena Formation. The 300 feet of basal red siltstones are overlain by 1,700 feet of well bedded, unbanded drab olive green micaceous siltstones (P253/66) with very fine scale cross bedding seen in hand-specimen. Slumping occurs at the base of the green shales near Walter's Well. The uppermost siltstones are ripple-marked.

<u>Moorillah Siltstone Member</u>, 1,340 feet thick. The basal units of this Member form the prominent scarp south of Moorillah H.S. which, in the vicinity of Temple Bar Spring, swings southwards towards the faulted area around Blackfellow Creek. The basal unit in the type-section is a buff coloured, fine-grained sandstone 30 feet thick (P254/60). On the right bank of Bitter Springs Creek the sandstone is interbedded with thin shales. To the north a local lense of conglomerate occurs within the sandstone. Northeastwards from Temple Bar Spring, the buff sandstone lenses out into the overlying fine-grained, purple-red sandstone (P255/66; P256/66; plate 4) which becomes the main scarp-former.

In the upfaulted area north of the Beltana Diapir the basal buff-coloured sandstone again outcrops. On the western side of the main road, where the basal unit is in contact with the northern edge of the diapir, a thick lense of conglomerate replaces the sandstone.

The bulk of the Moorillah Member consists of massive, coarse grained, dark purple to purplish red siltstone sometimes unbanded, though usually with strong prominent banding (bands $\frac{1}{4}$" thick). In the lower part of the succession in the type locality,

Plate 4—Banded purple-red sandstone in lower part of Moorillah Member of Brachina Formation, near Temple Bar Spring.

Plate 5—Slump disconformity between Bunyeroo Formation and overlying Wonoka limestones on west side of road, 2½ miles south of Beltana township.

beds of this siltstone alternate with softer, finely laminated grey and purple siltstone. In the uppermost parts, thin quartzite bands are present. North of the Beltana Diapir the lithology above the basal sandstone is similar, although there is a predominance of unbanded siltstones. Two thin beds of conglomerate in the middle part of the succession may be related to periods of erosion of the diapir. The upper part of the middle unit here contains a number of thin beds of quartzite with heavy mineral bands.

Bayley Range Siltstone Member, 840' thick. The upper member is lithologically similar to the lower member. Drab olive green siltstones (P257/66) predominate, with occasional interbeds of hard, grey weathering fine-grained arkose.

The Brachina Formation is overlain by the ABC Range Quartzite. South of Beltana this Quartzite forms the range of low hills seen to the east of the road, running parallel for some distance and then curving away northeastwards as a prominent scarp south of Puttapa H.S. Repeated to the north of Beltana Diapir by faulting, it forms Mount Bayley Range, through which the Hawker - Leigh Creek Road passes at Puttapa Gap 7 miles north of Beltana township. The A.B.C. formation consists of a basal, clean white orthoquartzite, the main scarp-former, overlain by medium grained heavy mineral banded feldspathic sandstones and drab siltstones. At the top of the formation ripple-marked quartzites are overlain by a few feet of purple siltstone, and green shale. The main quartzite (P258/66) is rather flaggy in places, generally well-bedded, and occasionally ripple-marked and heavy-mineral banded. Good cross bedding is present at Trebilcock's Gap. South of Puttapa H.S. a lens of purple siltstone occurs in the middle of the quartzite. There is a general reduction in thickness of the unit from 550' in Mount Bayley Range to less than 300' south of Blackfellow Creek.

The Bunyeroo Formation overlying the A.B.C. Quartzite forms characteristic low-lying red shale country, either as solid outcrop or a covering of small talus. The formation consists of well-bedded, thinly-laminated dark red shale (P259/66). Towards the top, in the section east of Red Range, thin bands of yellow-weathering dolomite are interbedded with the shale. Bands of grey-green shale are a notable feature of the Formation. The Hawker - Leigh Creek road crosses one such band in the middle of the Formation. The grey-green shales are occasionally cupriferous (P260/66). East of the main road a narrow green shale band carrying copper staining on shale-partings has been worked as an ore-body at Walter's Copper Mine.

There is a considerable variation in the lithology of the lower part of the Bunyeroo Formation in the areas east of Red Range and northwest of Mt. Bayley Range. The lower part of the Formation east of Red Range is largely covered by superficial deposits. However, it is exposed in the locality of Blackfellow Creek where it is seen to consist entirely of red shale with no grey-green shale bands. This is strongly contrasted with the lower part of the formation in the Mt. Deception - Mt. Bayley Range section. Around the southern end of the Mt. Deception Range, the lower part of the formation is composed of red shale with two thin bands of grey-green shale carrying copper staining on partings. These have been prospected on a small scale at the Caines Lease workings north of Teatree Well. However, from this locality southeastwards to Mount Bayley Range, there is a rapid facies change to thick grey-green shales with a few prominent interbedded dolomite bands and only minor red shales. The presence of two small diapirs on the northern side of this range suggest local diapiric movement may have played a part in controlling sedimentation here. The dolomite bands are best developed in the vicinity of these diapirs and lens out to the southwest and northeast along strike. Near Trebilcock's Gap a local conglomerate is present at the base of the Formation.

Mawson (Mawson and Segnit, 1949) examined the red shale facies of the Bunyeroo Formation near Mt. Deception H.S. 5 miles north of Teatree Well. His description of a thin section of the shale is reprinted below:-

"The microscope slide reveals that it is principally composed of grains of quartz, altered particles of feldspar and minute flecks of mica. The quartz grains are clear and frequently very angular; they tend to be concentrated in the lighter bands of the shale. The mica is clear and colourless in tiny flakes so thin as to give only red and yellow interference colours. The feldspars have evidently been largely decomposed to a featureless matrix, possibly mainly composed of the kaolinite group of mineral. It is this matrix that is stained purplish-brown by the ferric oxide content of the shale, thus imparting that colour to the rock as a whole. Calcite is distinguishable, distributed throughout in irregular grains. It is sufficiently abundant to link up with the 5% of carbon-dioxide found to be contained in the rock. Also there is present a small amount of chlorite, haematite, and a highly refracting mineral, possibly zircon".

The chemical composition of the shale is given as follows (Mawson and Segnit, 1949, op. cit.):-

SiO_2	58.30	H_2O+	2.56
TiO_2 } Al_2O_3 }	15.64	H_2O-	0.30
		P_2O_5	0.16
Fe_2O_3	1.94	MnO	0.10
FeO	2.80	BaO	0.10
MgO	3.87	CuO	0.02
CaO	4.31	Cl	0.01
Na_2O	1.81	S (Sulphide)	0.02
K_2O	3.16	CO_2	5.13
			100.24

Mawson and Segnit considered that the shale represents loessal material deposited under shallow-water terrestrial conditions. It may be noted here that at two places in the Beltana area mud cracks are present within the shale. On the western side of the main road 6 miles south of Beltana township, opposite the old railway huts, mud cracks occur in the red shales of the upper part of the Formation. The mud cracks are associated with structures interpreted as minor slump structures, and with small scale cross bedding, and are immediately overlain by red shales with flute casts. Similar associations are seen in the shales a few hundred yards south of Teatree Well.

South of Beltana there is a local sedimentary discordance (plate 5), marked by a slump brecciola (plate 7) at the upper boundary of the Bunyeroo Formation. This is believed to have been caused by local slumping of semi-consolidated sediments during the deposition of the early Wonoka. Local instability may have been produced by movements of the Beltana Diapir, since away from the immediate area of diapiric influence sedimentation was undisturbed. Coats (1964a) has recorded similar large-scale slumping of sediments from this horizon elsewhere in the Northern Flinders Ranges.

The brecciola passes southwards along strike into a dolomite, 3 feet thick, lying conformably on the upper shales of the Bunyeroo Formation. In the vicinity of Blackfellow Creek the boundary is also conformable, there being a progressive increase in carbonate bands into the Wonoka Formation.

The <u>Wonoka Formation</u> outcrops over a large area south of the Beltana Diapir, and as a north-south trending belt of hills continuing southwards from the Ediacara Range, (fig. 4). The Formation is composed of interbedded flaggy blue-grey siltstones and limestones (P261/60). A common feature of the lithology is the occurrence of siltstone-limestone brecciolas, (plate 7), representing local slumping of semi-consolidated sediment. There is a noteworthy increase in these brecciolas towards the Beltana Diapir, suggesting that this structure was a focus of instability during upper Marinoan times.

Plate 6—Slumping in Wonoka Formation near Beltana township.

Plate 7—Brecciola in Wonoka Formation associated with major slump disconformity (Plate 5)

Plate 8—Upturning of beds against joints due to weathering. Wonoka Formation, ¼ mile south of Beltana township.

A cross-section through a particularly fine example of slumping can be seen in Warrioota Creek on the southern edge of Beltana township, where the track from Moorillah H.S. crosses the creek. In the lower part of the cliff, forming the southern bank of the creek at this point, the beds are fragmented, with disorientation of the fragments and clear examples of slump-rolls (plate 6). The slumped material is overlain by a brecciola with flat-lying parallel elements formed by fragmented, semi-consolidated material settling under the more peaceful conditions following the slumping.

In two localities flute-casts occur in the siltstones. At the locality mentioned in the previous paragraph, long flute-casts suggest a current direction from the northwest. Flute-casts occurring in the siltstones in Warrioota Creek, south of Ediacara, suggest a current direction from the west or south-west.

A feature of the Wonoka Formation where it outcrops with a shallow dip on comparatively flat ground, is the arcuate outcrop which it forms. The outcrop, of the appearance of a series of interfering saucers, often masks the direction and degree of the true dip. This phenomenon is explained by the swelling of the upper beds during weathering (due to expansion of clay minerals), with an upwards compensating movement against major joint fractures. A cross-section clearly demonstrating this action can be seen in the old railway cutting on the southern edge of Beltana township (plate 8).

<u>Pound Quartzite</u>. The uppermost formation of the Adelaide System was named the Pound Quartzite by Mawson (1938). In the Beltana area the formation is exposed in five widely separated localities; in the west around Mount Michael, and on the southern, eastern and northern flanks of the Ediacara Range; Red Range in the centre of the area; an east-west trending range north of Puttapa H.S.; and a south-trending range in the south-eastern corner of the area.

Although for purposes of regional correlation, the Pound Quartzite has been divided into two members, a more meaningful three-fold division can be recognized in the Beltana area. This division has been adopted for the present study, although the two-fold division is shown on the published map.

1. Upper member - massive to flaggy white orthoquartzite.
2. Middle member - buff to red-brown weathering white feldspathic sandstones and siltstones with occasional bands of white orthoquartzite.
3. Lower member - red beds consisting of red siltstones, flaggy red sandstones and massive cross-bedded red sandstones.

The lower and middle members correspond to the Lower Member shown on the published Beltana 1:63,360 geological map. The thickness of the formation varies between 860 feet at Ediacara, 1,350 feet in Mount Michael range and in the southeast, and 3,000 feet in Red Range and in the northeast. There is however a remarkable similarity in the lithological profile throughout the area. Three sections are given below for comparison:-

RED RANGE
2970'

570' massive to flaggy white orthoquartzite.
60' hard, flaggy quartzite weathering red-brown; white with red grains when fresh.
60' well-bedded white orthoquartzite (4" beds) with heavy mineral bands.
380' white sandstone.
1070'

190' rusty weathering white sandstone.
60' micaceous red sandstone.
610' buff weathering ripplemarked white feldspathic sandstone with interbedded flaggy red sandstone and minor red micaceous siltstone. Few quartzite bands.
860'

210' red and red-brown sandstones and siltstones.
830' flaggy and massive crossbedded red sandstones and micaceous red siltstones. Few thin bands of feldspathic sandstone near base.
1040'

NORTH OF PUTTAPA H.S.
2960'

1185' massive clean white orthoquartzite (P264/66). Some heavy mineral banding and ripplemarks.
1185'

395' red-brown weathering crossbedded felspathic white quartzites, with interbedded red sandstones (P263/66).
195' reddish feldspathic sandstones with one band of massive hard clean orthoquartzite.
590'

1185' red micaceous sandstones and siltstones (P262/66) with two thin bands of feldspathic quartzite near the base.
1185'

RANDELL'S LOOKOUT
856'

330' massive to flaggy white orthoquartzite weathering red-brown in part. "Jellyfish" horizon 60' from top.
330'

72' feldspathic quartzite with two horizons of flaggy red sandstones.
38' gritty red feldspathic sandstone.
221' white and reddish feldspathic quartzites; cross-bedded and flaggy red sandstones with interbedded red siltstones and hard white quartzite at the base.
330

190' massive to flaggy medium to coarse grained red sandstone with interbedded red siltstone. Strongly cross-bedded.
190'

A similar lithological profile is present in Mt. Michael range, but is less easily recognized in the low range in the southeast.

Segnit (1939) noted the shallow-water character of the sediments at Ediacara. Cross-bedding, ripple-marks and mud-pellets are common features throughout the succession in the southern part of the Ediacara Range. North of Mount James and in Mount Michael range, shallow-water features are still common although there is an increase in the thickness of the formation.

Shallow-water conditions were obviously widespread over the whole of the Beltana area during the deposition of the lowest member of the Pound Quartzite. At Red Range and in the range north of Puttapa H.S. where the formation reaches its greatest development, ripple-marks and cross-bedding are well-developed in the lowest member. Indeed, along the northern part of Red Range there is a thin basal conglomerate. Here conditions of sedimentation may have been locally modified by positive movements of the Beltana Diapir, although the elements forming the conglomerate cannot be definitely identified as having come from the Diapir. Generally the lower boundary of the Pound formation intertongues with the Wonoka sediments.

Features indicating shallow-water conditions are less common in the middle and upper members. It is clear that deeper water conditions prevailed over the eastern half of the area during these times, while a near-shore environment persisted in the west.

<u>Ediacara Fossil Horizon</u>. Interest has centered on the Pound Quartzite in the Ediacara Range because of the discovery there in 1946, by R.C. Sprigg, of a horizon of fossils near the top of the formation (Sprigg 1947). The horizon contains a rich fauna of soft bodied Medusae, Anthosoa and Annelida of Late Precambrian age.

Sprigg's original discovery was 300 yards southwest of the Southern Workings. The known fossil occurrence was extended along strike during the next few years by Sprigg and Mawson (Sprigg 1949). In May, 1958, the southern part of the Ediacara Range was proclaimed a fossil reserve under the control of the Minister of Education and the authorities of the South Australian Museum. Glaessner and Daily (1959) further extended the fossiliferous horizon and produced a sketch map of its known extent. Nixon (1963a) made further additions in the southwest and eastern flanks of the basin.

The fossil horizon occurs 100 feet below the top of the Pound Quartzite. It has been described as a flaggy, white, orthoquartzitic sandstone weathering to a rusty red colour. The weathering of thin argillaceous partings produces flags 2" thick. Crossbedding and ripplemarks are common and slumping occurs near its base. The fossil impressions and casts occur almost entirely on the underside of the flags. Nixon (1963a, op. cit.) has observed that the distribution of fauna is uneven throughout the horizon, there being distinct concentrations along the strike with one fossil type sometimes being the dominant member of the concentration.

The Ediacara fauna consists of coelenterates, annelids and two new types of invertebrates. It was originally described by Sprigg (1947; 1949), and has been reviewed and added to more recently by Glaessner (1958; 1959; in Glaessner and Daily 1959; 1960; 1962). The interested reader is referred to these papers. The Coelenterata is represented by scyphozoan and hydrozoan medusoids of which the most common are Pseudorhizostomites, Cyclomedusa, Spriggia and ?Protolyella; and by the anthozoan octocorals Rangea and rare specimens of Pteridinium and Charnia. The phylum Annelida is represented by Spriggina and Dickinsonia. Two fossils, Parvancorina and Tribrachidium are ascribed to new phyla. Glaessner (1960, 1962 op. cit) has expressed some doubt concerning the classification of the medusoid fossils.

Glaessner has given a late Precambrian age to the fauna and has noted affinities with fauna of this age from the Nama System of South Africa and the Charnian of England.

In 1964 R.B. Major* discovered a second location of ?Ediacara-type fossils on the western side of Red Range, a short distance southeast of Range Range Bore. Here faint impressions of soft bodied invertebrates, apparently similar to those preserved at Ediacara are found in light grey, very flaggy, fine-grained sandstone. Only one fossil locality is known here and it proved impossible to follow the horizon for any great distance to the north or south. No description of these fossils has been published to date. It is worthy of note that here the fossil horizon is 600' below the base of the Cambrian.

The Cambrian System

In the Cambrian there was a return to a fully marine environment following the terrestrial and deltaic conditions of the upper Marinoan. The transitional beds of the Parachilna Formation give way to the thick marine carbonate sequence of the Ajax Limestone. Only the lower part of the Cambrian is present in the Beltana area. It is not known whether the upper part of the sequence was deposited and has been subsequently removed by erosion.

The transition from the deltaic conditions of the upper Proterozoic is represented by the beds of the Parachilna Formatic which conformably overlie the Pound Quartzite in the five localities noted previously. However, only the sections at Red Range and Ediacara are well-exposed over any great distance. The base of the Formation is marked everywhere by a bed of argillaceous sandstone with tubular worm burrows at right angles to the beddin. These were first reported by Mawson in 1938 and have been studied over a large area of the Northern Flinders by Dalgarno (1962). Their use as a marker bed for the base of the Cambrian was

*B.Sc. Honours Thesis, University of Adelaide. (unpublished).

appreciated by Nixon during his mapping of the Ediacara Mineral Field, and this observation is confirmed from all parts of the Beltana area. The worm burrow bed is 20-25' thick and is overlain at Red Range by sandy shale and argillaceous sandstone. The profile described by Nixon (1962) from Ediacara is thicker, averaging 50' and contains interbedded dolomite lenses. 30' of sandstone and shale with 10' of worm-burrow beds at the base were recorded from the Mines Department drill-hole E24 in the centre of the Ediacara basin, (see fig. 9).

The Parachilna Formation is overlain conformably by the Cambrian dolomitic limestones. The carbonate sequence of the Cambrian in the Beltana area is referred to the Ajax Limestone. This follows the practice adopted by Nixon for the Ediacara area. To my knowledge no detailed palaeontological work has been done on the Cambrian of this area to determine its exact stratigraphical position, and the naming of the carbonate sequence has been determined by drawing analogy to the limestones of the nearby Mount Scott area (Parkin et al, 1952), which furnished the type area for Daily's redefinition of the Ajax Limestone (Daily 1957).

In the Ediacara Basin Nixon (1963b) recognised a threefold division of the Ajax Limestone into a lower cross-bedded sandy dolomitic unit, a middle unit of algal dolomites, and an upper unit of cherty dolomites with Archaeocyatha, (see fig. 9). The lowest unit is present only in the north and south of the basin lensing out towards the centre into the overlying algal dolomites. This was interpreted as indicating shore-line conditions in the north and south with a trough occupying the central area. The sandy dolomites are crossbedded and interbedded with fine-grained grey or greenish-grey dolomites which are frequently brecciated and mineralised e.g. at Greenwoods Lode. The overlying algal beds consist of pale-grey laminated dolomites with interbedded lenses and beds of massive dark grey dolomites. Large Collenia-type algae over five feet in diameter occur in this sequence. Northwards the algal facies changes along strike into oolitic dolomites. The uppermost unit, the Archaeocyatha dolomite, is a massive, crystalline light and dark grey dolomite with nodular and bedded chert and common Archaeocyatha. The total thickness of Cambrian at Ediacara is 1000'.

The basal unit of the carbonate sequence in Red Range is an oolitic dolomite (P265/66). Dolomitic oolites are set in a matrix of primary dolomite. Calcite has partly replaced the dolomite of the oolite-structures in preference to the matrix. The sequence above this basal unit is perhaps best regarded as a dolomitic limestone (P266/66; P267/66) although the composition of the carbonate seems to be very variable.

Above the carbonate sequence of the Cambrian there is a long break in the geological succession until the terrestrial deposits of the Tertiary Period. The intervening Systems are not represented in the Beltana area.

Tertiary

There are remnants throughout the area of a formerly widespread Tertiary capping of duricrust. Whether this formation covered the whole area westwards from the foothills of the Flinders Ranges as a continuous sheet cannot be determined, but it is assumed to have done so. All that now remains are isolated outcrops of silcrete and laterite and the evidence in a few places of silicification of the older rocks. The duricrust unconformably overlies the Cambrian and Precambrian rocks, and is overlain by gastropod limestone or by Pleistocene gravel beds. The relation between the laterite and silcrete within the duricrust profile is at present a matter of some controversy. The evidence from the Beltana area is not sufficiently clear to determine even the local relationship.

Laterite and silcrete occur as isolated outcrops in widely separate localities. The silcrete is best exposed as a long narrow outcrop along the western edge of Red Range, where it is massive, grey, with white rounded quartz "concretions". The silcrete here is underlain by silicified (or duricrusted) quartzites of the Pound Quartzite. Coats (pers. com.) recorded a dip of 30^{o} to the west on this outcrop, suggesting late or post-Tertiary faulting on the western side. A second good exposure occurs three-quarters of a mile southeast of Randell's Lookout where it is overlain by Pleistocene gravel beds.

From the western side of Ediacara, Nixon (1963b), recorded a laterite profile dipping south to southwest at 30-40^{o}, with an upper ferruginized zone, a central mottled zone, and a lower pallid zone. West of Mount Michael range, laterite with well-rounded quartz pebbles dips 5^{o} to the west. The pallid and mottled zones are not well developed. The laterite here is overlain by basal gypseous clays of the Nilpena Limestone. A long narrow strip of duricrust runs north-south near Pigeon Bore to the western edge of Mt. Michael Range. Jack (1925) recorded a rock type identifiable as silcrete from a depth of 92' in Pigeon Bore. This suggests a post-Tertiary movement of 100' on the Ediacara Fault.

Pre-Tertiary or early-Tertiary block-faulting along the lines of the Ediacara and Mt. Deception Faults, created two partly connected basins in which were accumulated early Tertiary (i.e. pre-duricrust) sediments. The subsidence of the Beltana sub-basin was probably greatest in the east, with hinging along the line of present hills formed by the Ediacara Range and its continuation southwards to Mount Michael, producing a half-graben (see section B-B', fig. 5). This acted as a partial barrier to the westward movement of sediment. West of the hinge-line, subsidence along the Ediacara fault formed the Lake Torrens Sunkland in which a greater thickness of pre-duricrust sediment accumulated.

These sediments can nowhere be seen at the surface. However, the logs of bores recorded by R.L. Jack (1925 op. cit.) give an indication of the lithology. The log of Nursery Well and bore (formerly called Millya Millyana) is reproduced below:

Shaft :-	1 - 16'	Dry sand and stones.
	16 - 38'	Conglomerated stones.
	38 - 58'	Red clay.
	58 - 61'	White sandy clay.
	61 - 70'	Yellow clay.
Bore* :-	63 - 150	Red and white clay.
	150 - 184	Blue-clay.
	184 - 250	Soft blue rock.

The profile from 38 to 184ft. is probably early Tertiary.

Three miles west of Mount Michael, the log of the disused West Paddock Bore records 515 feet of similar clays overlying bedrock, the lower 400 feet probably being pre-duricrust. These sediments may be safely correlated with those recorded in Lake Torrens stratigraphic bore 3A, 19 miles south of West Paddock Bore.

Quaternary

Pleistocene

Along the line of low hills formed by the Wonoka and Pound Quartzite formations stretching from Randell's Lookout to Mount Michael, are isolated outcrops of a yellow-brown freshwater limestone with abundant small gastropods. Gypseous clays overlying the laterite west of Mt. Michael are considered to be the basal unit of this limestone. The name Nilpena Limestone is proposed for this formation. The type-section is one mile south of Randell's Lookout at lat. 30°51'35"; long. 138°9'.

Nixon (1963b) recorded the gastropods as Coxiella. Specimens submitted to Dr. N.H. Ludbrook were identified as freshwater gastropods unrelated to Coxiella. Their exact identity has not been determined. Similar limestone outcropping near Nilpena H.S. contains a mixture of the small gastropods, and larger ones resembling Coxiella, (see Appendix III).

*Bore drilled 1926. Log recorded in Dept. Mines S.A. Bore records; Millya Millyana Bore No. 179.

The limestone is best exposed at the type locality given above, and as a long narrow outcrop a mile north of Mt. Michael.

Evidence of a once extensive deposit of Pleistocene gravels can be seen over the whole area, in places forming quite distinct mesas. The beds are best exposed in Warrioota Creek near Winnowie Well where they form cliffs along the north and west side of the Creek, (plate 9). In the southwestern part of this locality they can be seen clearly overlying Tertiary Duricrust. The gravel beds are composed of large well-rounded gravels and boulders; the cementing material is not easily examined because of weathering. The deposits represent a period of strong subaerial weathering, with erosion and peneplanation of outstanding surfaces and infilling of hollows. Traced eastwards towards the Ranges, the conglomerates thin out, and in the foothills several flat topped mesas with only thin veneers of boulders can be related to this period of erosion and infilling.

Beneath the boulder beds in several places are thinly laminated green and red shales, often weathered to a soft clay. These are exposed in the cliffs in the extreme southeast area; along the northern edge of the Pleistocene boulder beds south of Warrioota Creek on the track from Beltana H.S. to Teatree Well; and in the vicinity of Winnowie Hut. It is not certain whether these are Pleistocene clays or should be correlated with the pre-duricrust sediments noted in the previous section.

Difficulty was encountered in delineating the boundary of the Pleistocene gravel deposits in the central plains because of the resemblance of the recent scree formed partly by the reworking of the gravels.

It is possible that minor east-west and north-south faulting may have affected the Pleistocene deposits, and played a part in determining the present outcrops. Dalgarno and Johnson (1966) have recorded such faults from the Parachilna area.

Plate 9—Pleistocene Boulder Beds in Warrioota Creek near Winnowie H.S.

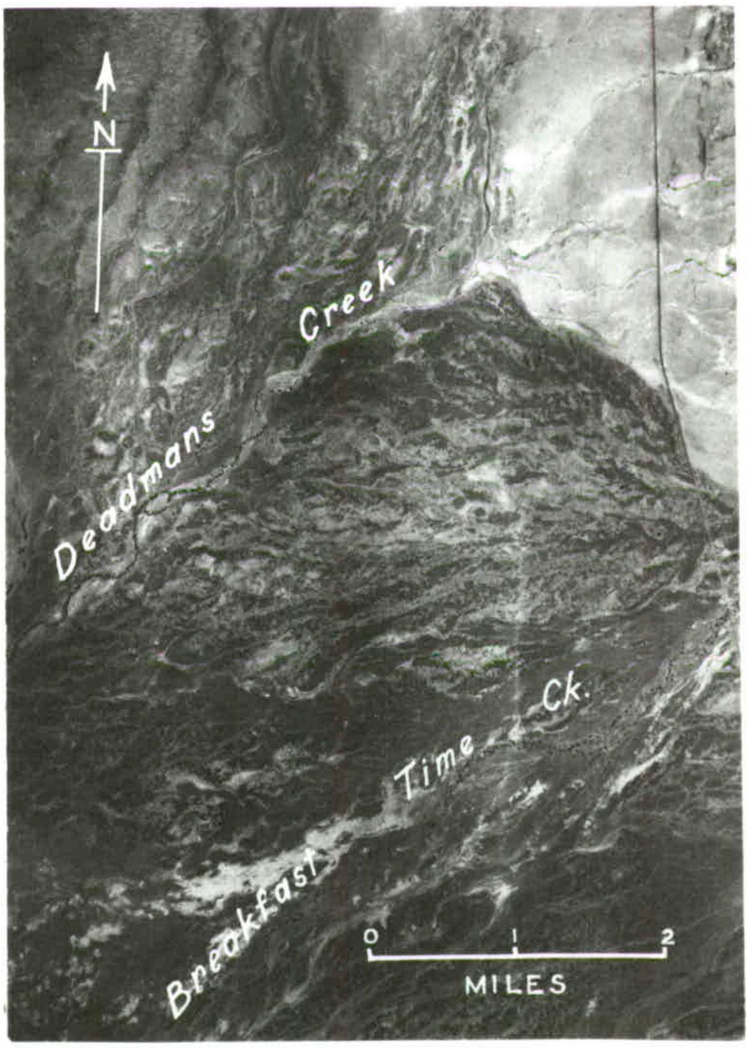


Plate 10—Aerial view of Qrt-covered plains SW of Red Range showing complex of old stream channels.

Recent Sand Spread

Recent sand dunes cover the area west of the Mount James-Mount Michael range as far as Lake Torrens, (see fig. 2). There is an additional area of sand cover northeast of Mount Michael on the western edge of the Beltana plains area. The sand dunes show a trend from eastnortheast veering round to a direction eastsoutheast to southeast.

Recent scree

Large areas of the Beltana plains are covered by gibber material. This is thought largely to represent flood and creek material transported from the Ranges westwards. The pattern of former transient streams can be easily seen on aerial photographs, (plate 10).

STRUCTURE AND TECTONICS

Structural Subdivision

The Beltana one mile sheet covers an area on the western side of the Flinders Ranges where there is a transition westwards from the true geosynclinal conditions of the Adelaide Geosyncline towards the stable conditions of the Stuart Shelf, (see fig. 7). The line of the Mount Deception fault-scarp marks the western limit of the Flinders Ranges. This line approximates to the beginning of the transition zone which extends as far west as the Torrens Fault (Johns et al, 1966). Block faulting within this zone has formed two partly connected basins (separated by the Ediacara Fault) - the Lake Torrens Sunkland and the Beltana Sub-basin which together make up the Pirie-Torrens Basin.

The Flinders Ranges

The eastern one third of the Beltana sheet covers the western edge of the Flinders Ranges, formed of Proterozoic and early Cambrian geosynclinal sediments. The dominant structural

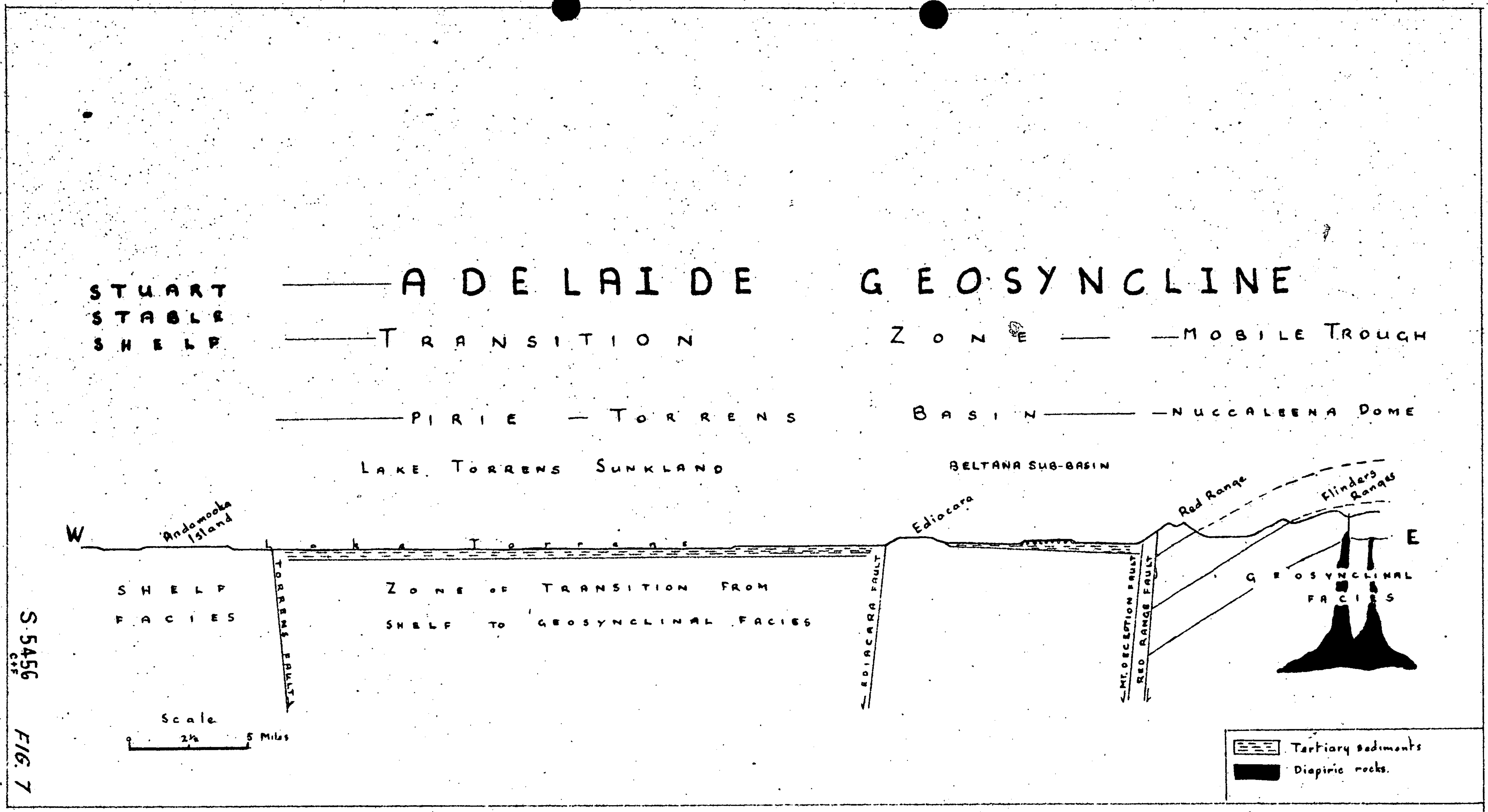


Fig. 7. Idealized cross-section through the western edge of the Adelaide Geosyncline showing the main structural units

S. A. DEPT. OF MINES

element is a dome with its centre in the S.E. corner of the area a little way north of the Greenwell Diapir. This structure is here named the Nuccaleena Dome after the nearby Nuccaleena Mine (Grasso et al. 1956). The flanks of the Dome are truncated to the west by the postulated southern extension of the Mount Deception Fault and to the north by the southwest trending Beltana Diapir, (see fig. 4).

The central part of the Nuccaleena Dome in the south-east corner of the area is cut by a number of more or less radial faults. Diapiric intrusions are associated with some of these structures. The Greenwell and Nilpena Diapirs lie on the Nuccaleena Fault. In the eastern part of the Dome covered by the Cadnia 1:63,360 sheet (Grasso et al. 1956, op. cit.), the Nuccaleena and Warraweena Diapirs and their associated minor diapirs lie along similar fault lines.

Twelve miles to the southsoutheast of the Nuccaleena Mine is the Blinman Dome Diapir. Drawing an analogy with this structure, it is tentatively suggested that the diapiric intrusions of the Nuccaleena Dome are apophyses of a larger domal diapir lying at a shallow depth within the Nuccaleena Dome, (see section A-A', fig. 5).

The Beltana Diapir is of a different type in that it is essentially linear and is intruded along a major fault line, which repeats the upper part of the Wilpena Group, some 5,000 feet of sediments, to the north. The structures within the Diapir and its mode of intrusion will be described later in this section. Dalgarno (pers. com.) has suggested the possibility of the Beltana Diapir being intruded along a south-facing monocline. This is a possibility but it is not favoured by the author.

The hills of the Flinders Ranges are structurally limited to the west by the Mount Deception Fault. This fault was postulated by R.L. Jack (1925, op. cit.) as the eastern boundary of the Pirie-Torrens Basin. Faulted beds can be seen along the western side of the Mount Deception Range particularly at Teatree Well. Along the western side of Red Range, duricrust dips at an angle of 30^{o} to the west, suggesting that the western edge of the Range is a fault scarp. In these two places there is good evidence for a fault. However, between Teatree Well and the northern end of Red Range, and again south of Red Range to the Nilpena Diapir, evidence is masked by a covering of Recent scree. Whether the Mount Deception Fault is continuous from the north to the south of the Beltana sheet must remain essentially hypothetical. However, to postulate its continuity helps to clarify much of the structure of the central Beltana area.

The Pirie-Torrens Basin

The western two-thirds of the area covered by the Beltana sheet forms part of the northern end of the Pirie-Torrens Basin, the eastern limit of which is defined by the Mount Deception Fault along its full length. The basin is divided into two parts by the Ediacara Fault, the western half belonging to the Lake Torrens Sunkland and the eastern half forming the newly named Beltana Sub-basin.

The Beltana Sub-basin

The Beltana Sub-basin was defined, though not named, by R.L. Jack in 1925. It is bounded to the east by the Mount Deception Fault and to the west by the Ediacara Fault. Its formation was controlled by hinging of the block along its western edge with greatest subsidence in the east. The hinge-line is represented by the rocks forming the Ediacara Range and its continuation southwards to Mount Michael.

The subsided basin was infilled with sediments during the Tertiary and Quaternary Periods. These sediments mask the fundamental structure of the faulted block and this can only be deduced. The observed structures in the Mount Michael-Mount James range, and Mount Deception Range, suggests a series of gentle folds with north-south axes arranged en echelon. The Mount Deception Fault cuts off the structures seen to the east.

It is probable that the faultline (or monocline) of the Beltana Diapir carries through in a south-west direction cutting the hinge-block in the region of Nilpena H.S. The overlying Tertiary and Quaternary sediments are believed to be essentially flat-lying although post-duricrust movement on the Mount Deception Fault may have tilted them slightly to the east.

The Lake Torrens Sunkland

The Lake Torrens Sunkland is part of the Torrens-St. Vincent rift (Thomson, 1966) which stretches in a north-south direction and contains Spencer Gulf and Lake Torrens (see fig. 1). In its northern part, the eastern boundary is now defined by the Ediacara Fault. The structure of the crystalline basement and the overlying Proterozoic rocks is not known. Evidence from seismic observations and bore-hole information does, however, suggest that the rift is floored by essentially flat-lying rocks of the Wonoka Formation. On top of this has been deposited a thick sequence of Tertiary sediments which are now covered by Recent sand-spread and lake deposits. It is believed that the Tertiary rocks are horizontal

The bulk of the material in these two basins is regarded as early Tertiary in age. In the part of the Lake Torrens Sunkland seen on the Beltana sheet they vary from 500 feet thick in West Paddock Bore (Jack, 1925, op. cit.), to 800 feet thick near Warrioota H.S. In the Beltana Sub-basin, 184 feet of post-Cambrian sediments occur in Nursery Well and Bore, of which the lower 140 feet probably belong to this early Tertiary sequence. Relationships in Pigeon Bore and in the eastern portion of the Beltana Sub-basin indicate that these sediments were deposited prior to the formation of the duricrust.

A second period of movement occurred along both the Ediacara and the Mount Deception Faults in late- or post-Tertiary (possibly late-Pleistocene) times, downfaulting the duricrust on the eastern sides of both basins.

The Ediacara Fault

In 1925, following a hydrological survey of the Beltana area, R.L. Jack (op. cit.) suggested that the west facing scarp of the Ediacara Range and its continuation south to Mt. Michael, might represent a fault-line. Corroborative evidence was available from the logs of two bores sunk in the sandy country to the west.

A re-examination of this evidence suggested to the present author the probable correctness of Jack's thesis. The log of West Paddock Bore (3 miles west of Mt. Michael) struck a basement of ?Wonoka siltstones at 515 feet. In Pigeon Bore, duricrust was cut at 100ft., although it outcrops on the surface only a few hundred yards to the east. The log of bore-hole E1 (fig. 9), drilled on the western side of the Ediacara Range penetrated only gravels to a depth of 100ft., despite Cambrian limestone being present on the surface a short distance to the east.

With the permission of Dr. H. Wopfner (Supervising Geologist, Petroleum Exploration Division) a seismic unit was diverted from its investigations of the Pirie-Torrens Basin south of Nilpena, for 2 days during July, 1965. Under the direction of Mr. G. W. Kendall a single seismic line was shot across the estimated position of the fault in the neighbourhood of Warrioota O.S. south of Ediacara. The results indicated a normal fault dipping westwards with a downthrow of 800 feet to the west (Leeson 1965).

During the seismic investigations near Parachilna Kendall (1966) had discovered a similar fault, though with a greater displacement, in the vicinity of the Motpena Stratigraphic Bore. It is considered that this is continuous with the fault located at Warrioota H.S. and the name Ediacara Fault is proposed for it.

A recent aeromagnetic survey of the Copley 1:250,000 map area by the Bureau of Mineral Resources has indicated that the Ediacara Fault is the surface expression of a major dislocation deeply affecting the crystalline basement, and associated with deep-seated meridional anomalies (G. Young, pers. comm).

Diapirism

Structure

Officers of the Geological Survey of South Australia have for a long time recorded large bodies of intensely brecciated rock in the Flinders Ranges. Webb (1960) recognized that many of these structures owed their origin to diapiric processes of intrusion. Coats (1964b) listed twenty-six such structures from the Flinders Ranges. The Beltana Diapir is one of the largest of these.

The Beltana Diapir (plate 11) occupies much of the country to the north of Warrioota Creek in the northeast portion of the Beltana 1:63,360 map area, on the northern flanks of the Nuccaleena Dome. The bulk of the diapir lies to the west of the Hawker - Leigh Creek road. To the east thin apophyses have been injected into the beds of the Wonoka and Pound Formations, and northwards (on the Copley 1:63,360 map area) along the line of a north-south fault, which separates the Brachina Formation from the Cambrian, (Parkin et al., 1952).

The northern boundary of the Beltana Diapir is a fault-line downthrowing to the south. The fault-line trends in a north-easterly direction to the northern boundary of the Beltana map area, where it takes on the northerly trend noted in the previous paragraph.

On the southern side of the diapir are exposed the flaggy limestones, siltstones and brecciolas of the Wonoka Formation. Except at the eastern end, and in the southwest interfingering zone, the Wonoka is flat lying, with dips generally only a few degrees to the south.

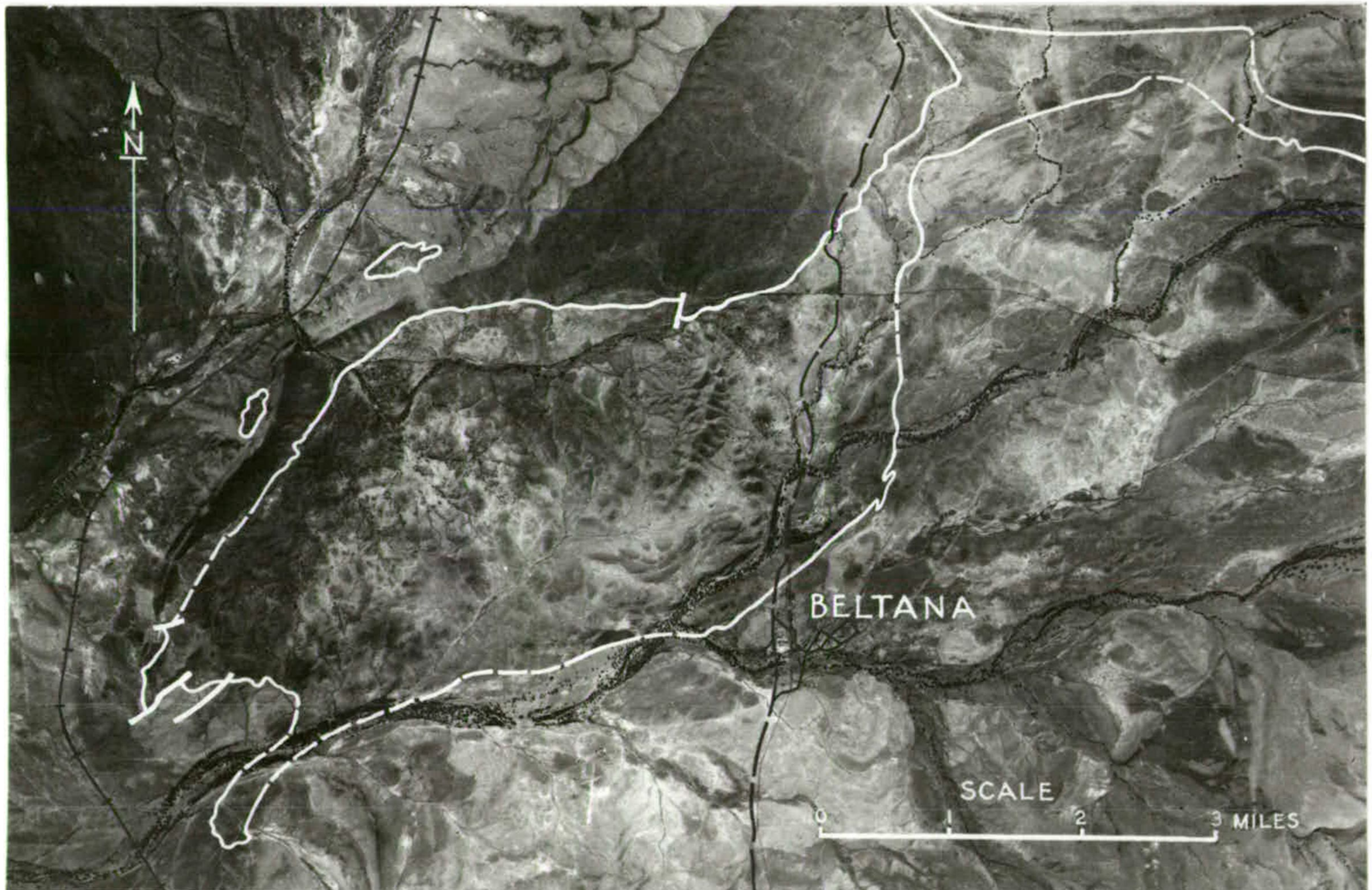


Plate 11—Vertical aerial photograph of Beltana Diapir.

In strong contrast the rocks exposed north of the diapir have a steep dip northwards, becoming vertical in places adjacent to the wall rocks of the diapir. The rocks exposed here belong to the middle and upper members of the Brachina Formation.

Thus, there is a stratigraphical displacement of 5000' or more across the diapir.

Stratigraphy of the Core Rocks

Webb (1960 op.cit.) first recognized that the rocks in the core complex of diapiric intrusions in the central and northern Flinders Ranges belonged to the Willouran Series. Coats (1964b) described in some detail the lithology of the core complex rocks in the Blinman Dome Diapir, which he correlated with the Callanna Beds of the Willouran Series.

There is a great similarity between the rock-types in the Beltana Diapir and those described by Coats from Blinman. A Willouran age is therefore suggested for them. No rock types diagnostic of any horizon above the Callanna Beds have been found within the Diapir.

The rocks within the core complex occur as large disoriented blocks in a matrix of dolomitic breccia. Some of the largest blocks reach up to a mile in length (see frontispiece). It is not possible to arrive at any true order of stratigraphical sequence. For presentation of the map and consideration here the rocks have beem grouped into five lithological types:-

1. A thick sequence of white quartzites with heavy mineral banding. One thin interbed of purple siltstone with pseudomorphs after halite is present in the lower part of the sequence. The uppermost strata are interbedded with blue-grey and purple siltstones, bearing numerous halite pseudomorphs. This sequence passes conformably upwards into blue-grey and purple siltstones bearing pseudomorphed halite.

2. Brown and blue-grey siltstones, thinly laminated with numerous halite pseudomorphs on lamination planes.
3. Heavy mineral laminated sandstones and siltstones, with pseudomorphs after halite, both interbedded with bands of yellow weathering dolomite.
4. Bedded, yellow-weathering dolomites.
5. Two small "plugs" of scapolitized hornblende-quartz rock.

There is a crude arcuate arrangement of the larger blocks with a geometric centre half a mile S.E. of Trebilcock's Gap.

Evidence of movement during sedimentation

Coats (1964b) and Dalgarno and Johnson (1965) have recorded evidence of the movement of diapirs during sedimentation. A similar interpretation is placed upon certain stratigraphical features noted in the upper Marinoan sediments from Beltana. These are:-

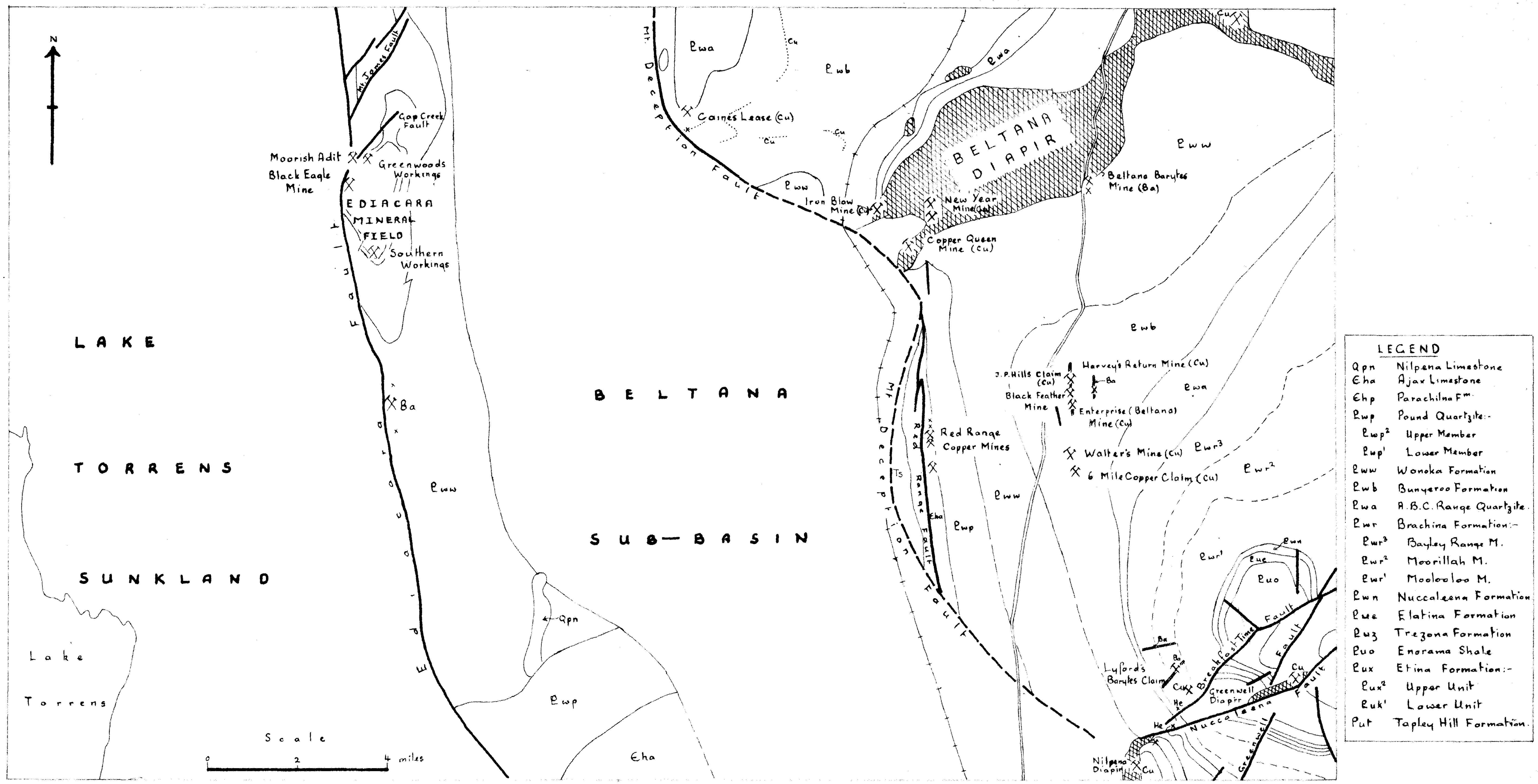
1. A conglomerate lens replaces part of the basal sandstone unit of the middle member of the Brachina Formation on the northern edge of the Diapir.
2. Two thin bands of conglomerate occur in the middle member of the Brachina Formation north of the Beltana Diapir.
3. An increase in thickness of the A.B.C. Range Quartzite across the Diapir may be related to diapiric influence on sedimentation.
4. A thin conglomerate occurs at the base of the Bunyeroo Formation north of the Diapir apparently connected with two small diapiric intrusions on the northern side of Mount Bayley Range. The lower part of the Bunyeroo displays a distinct facies change from Teatree Well south-eastwards to Mount Bayley Range.

5. Coats (pers. comm.) has observed definite diapiric detritus (including siltstone pebbles bearing pseudomorphs after halite) in the lower part of the Bunyeroo Formation from the northern margin of the Beltana Diapir covered by the Copley 1:63,360 geological sheet.
6. There is a sedimentary discordance marked by a slump brecciola at the boundary of the Bunyeroo with the Wonoka south of the Diapir.
7. Slump brecciolas in the Wonoka Formation show a notable increase in frequency towards the diapir.
8. A conglomerate occurs at the base of the Pound Quartzite at the northern end of Red Range where it is in contact with the Diapir. This lenses out southwards and has been found in no other locality.

This evidence suggests that there were positive movements of the Beltana Diapir during Marinoan times, and that the diapir was on occasions actually exposed and eroded.

MINERALIZATION

Mineralization is widespread throughout the older rocks of the Beltana area. Copper and lead form the most important ore deposits, with barytes and haematite in minor amounts. The mineral occurrences are of three types - stratiform, crosscutting and diapiric. The stratiform deposits are believed to be syngenetic although at least in the case of the Ediacara Mineral Field mobilization to a more structurally controlled position has taken place subsequent to deposition. The crosscutting veins often have an obvious structural connection with the diapirs and their genesis must be considered together with the deposits found within the diapirs themselves. The origin of ore-bodies in and associated with diapirs is controversial. However, crosscutting veins are by definition epigenetic whether they are derived from the mobilization of primary syngenetic deposits during diapiric



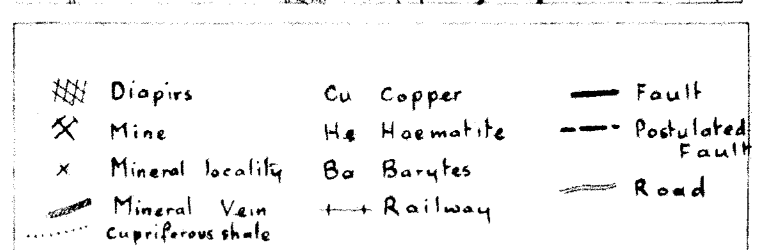


Fig 8 Simplified geological map of the Beltana area showing locations of mines and mineral lodes.

FIG. 8

For enlargement of S E corner see Figure 6.

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upheaval, or from a more deep-seated igneous event in which mineral solutions were introduced during diapirism or later along the lines of weakness provided by the diapirs.

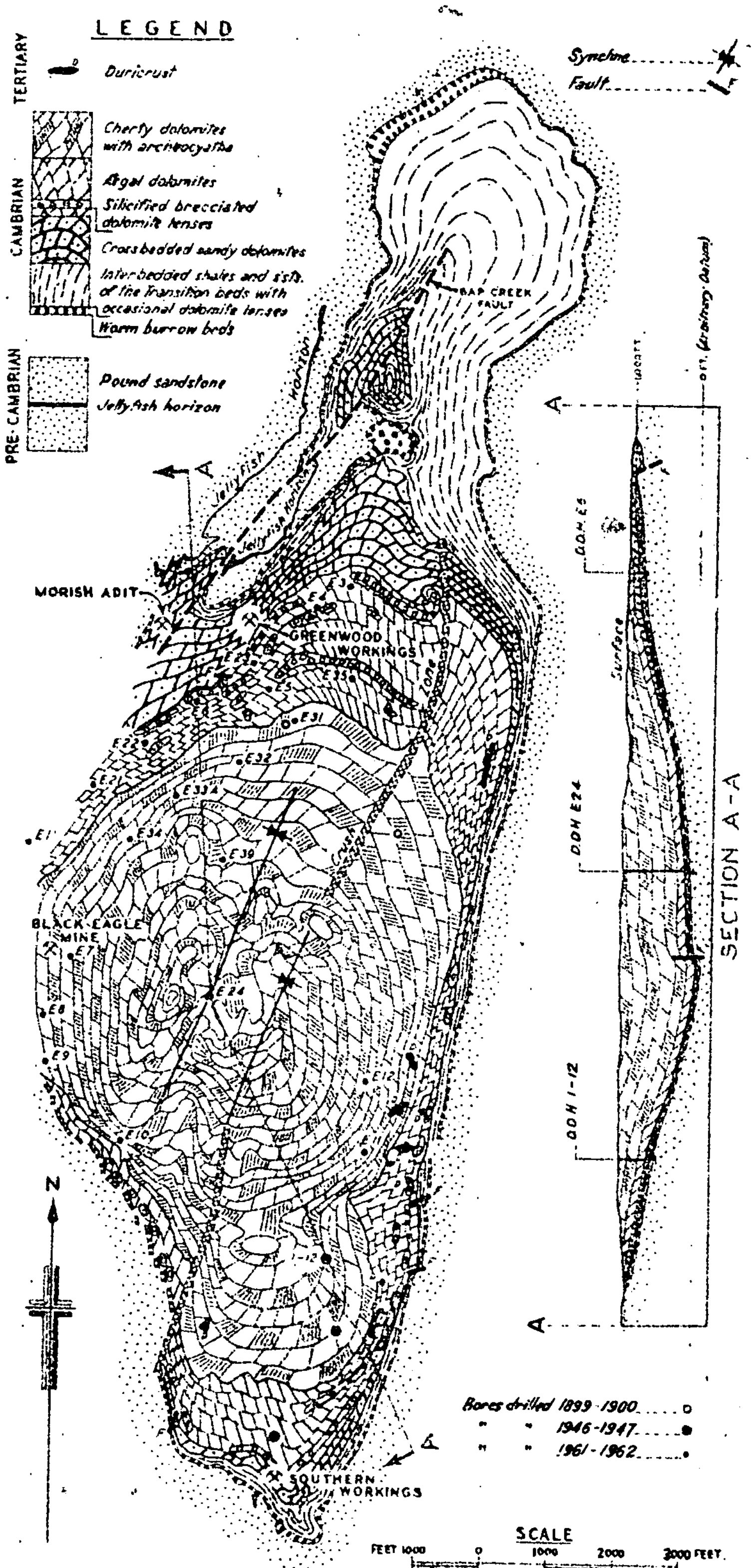
This chapter is devoted to a discussion of the three types of deposit with descriptions of mines and prospects appended to each section. The locations of mines and mineral occurrences are given in figure 8.

Stratiform deposits

Dealt with in this section are the silver-lead-copper deposits of the Ediacara Mineral Field and the cupriferous grey-green shale horizons within the Bunyeroo Formation.

Ediacara Mineral Field

The Ediacara Mineral Field (fig. 9) is the richest mineral deposit in the Beltana area and the only one where silver-lead occurs. The mineral field has attracted the attention of geologists since Ulrich visited it in 1872, and since then has been reported on by Rosewarne 1888 (in Brown, 1908), Brown 1888 (in Brown, 1890), Krause (1891), Brown (1892a, 1892b), Parkes 1892 (in Brown, 1908), Matthews 1892 (in Brown, 1908), Brown (1899, summary of previous accounts), Jones 1907 (in Brown, 1908) Boundy 1937, Gustafson (1938), Segnit (1939), and Broadhurst (1947, 1953). The development of ideas on the nature and origin of the deposits is given in the chapter on the "History of Investigations". Between 1960 and 1963 the South Australian Mines Department carried out an intensive investigation into the mineral resources of the field which included detailed mapping by L. G. Nixon and the drilling of 30 diamond drill holes. The reader is referred to Nixon's reports (Nixon 1962, 1963b, 1964) for descriptions of the ore-field and details of the investigations. No further work has been done on this area during the present survey.



Del B.T. L63-124 Geology by L.G. Nixon S.A. Dept. of Mines

Fig 9 Geological Map and section of Ediacara Mineral Field FIG. 9

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It is proposed for the sake of completeness to give here a brief summary of Nixon's reports.

The Ediacara Mineral Field is located in the southern portion of the Ediacara Range, 15 miles west of Beltana township.

Widespread stratiform lead and copper ores occur in the Lower Cambrian dolomite sequence, locally forming small high grade deposits in sedimentary breccias and fractured rock. The Cambrian has a relatively shallow basin structure. Within this, silver-lead forms an extensive low-grade stratiform deposit extending over a length of approximately 16,000ft. with a maximum width of 7,000 feet and a total stratigraphic thickness of 400 feet from 50 feet above the base of the Cambrian. Two rich zones 50 feet apart occur within the mineralized sequence from 100-200 feet above the base of the Cambrian. Nixon (1964) estimated the following reserves of lead ore for three different grades. 620,000 tons of ore averaging 2.1% lead over a thickness of 20 feet. 17,500,000 tons of ore averaging 1.13% lead over a thickness of 52 feet. 31,800,000 tons of ore averaging 0.9% lead over a thickness of 58 feet. The northern limit of lead mineralization is at Greenwoods Workings. This limit coincides with a northward facies change from algal to oolitic dolomite. There is a gradual fall in grade of ore from north to south. The lower grades of the southern half of the field possibly reflect a similar facies control.

The principal lead mineral is galena which occurs as disseminated crystals throughout the host-rock, as small lenses along bedding planes, as vein-filling, or as the main constituent of the matrix of sedimentary breccias. On the plateau lead occurs as its sulphide, galena, whereas around the perimeter and on the flanks of the plateau the carbonates of copper and lead predominate, implying that the erosion rate on the plateau is faster than the rate of chemical weathering.

Nixon considers that the deposition of lead was contemporaneous with sedimentation, its distribution being influenced to some extent by sedimentary and structural features. Recrystallization and mobilization of the lead into sedimentary breccia zones is considered to have taken place after lithification of the sediments. He regards the Mineral Field as belonging to the Mississippi Valley type of deposit, comparing it to the lead deposits of south-east Missouri.

Thomson at first (1961b) favoured a sedimentary syngenetic origin for the mineralization. Later (1965b), on the basis of regional mapping and stratigraphic geochemical sampling (1962) he proposed that a relationship existed between a major lineament (Ediacara Fault) and the lead mineralization. The lead was derived from a deep-seated source either by a contemporaneous Cambrian volcanic exhalative process or by subsequent Ordovician telethermal solutions.

There are four principal mines on the Field:

<u>Greenwoods Workings</u>

These are located at the northern end of the Field, to the east of the Gap Creek Fault, and were the most important workings at Ediacara. They mark the most northerly extent of the lead mineralization. High grade lead mineralization occurs near the top of the sandy cross-bedded dolomite unit in a 2' thick zone of sedimentary breccia dipping 10° southeast parallel to bedding. Cerussite is the principal lead mineral. Galena occupies fractures in the country rock. The grade of ore from the mine is estimated at 31% lead and 9oz. per ton silver over an average thickness of 2.4 feet.

Production: (Estimated) 8,800 tons averaging 31% lead and 9oz. of silver per ton.

<u>Southern Workings</u>

These are located at the southern end of the Field. Mineralization occurs in calcareous shales and silts which are the lateral equivalent of the sandy cross-bedded dolomite of the northern part of the Field. A narrow ore-body, elongate north-south, dips flatly to the north parallel to bedding. Most of the ore mined was the lead carbonate, cerussite, although records indicate there was some initial mining of copper carbonate. Samplings by Boundy and Gibson (1937) gave an average of 12% lead and 1oz. silver per ton for an average width of 4.7 feet.

Production: (Estimated) 15,000 tons averaging 12% lead and 1oz. of silver per ton.

Black Eagle Mine

Located on the western side of the Field, this mine was worked only for copper which occurs mainly as the carbonate malachite. The copper occurs with haematite and limonite in dolomite breccia and appears to be stratigraphically higher than the lead rich horizons of the northern and southern parts of the Field.

Production: The recorded production up to 1913 was 36.6 tons of copper metal from 264 tons of ore.

Moorish Adit

Located west of Greenwoods Workings in a zone of fracturing associated with the Gap Creek Fault. Barytes is abundant, associated with the fault zone. The lead mineralization is in the same horizon as at Greenwoods Workings - the cross-bedded sandy dolomites. Most of the workings were of an exploratory nature only.

Production: No figures are known, but production was probably very small.

Bunyeroo Formation

Within the red shales of the Bunyeroo Formation are several horizons of grey-green shale. In two localities these are stained with the green copper carbonate malachite on the shale partings. These copper rich horizons can be traced for some distance along strike. The two localities where the horizons are mineralized are at the southern and southeastern end of the Mount Deception Range in the vicinity of Teatree Well, and to the east of the Hawker-Leigh Creek road a mile southeast of Railway Well. At both of these localities the horizon has been prospected as an ore body; at Teatree Well by the Caines Lease Workings, and at Railway Well by Walters Copper Mine and the Six Mile Copper Claim.

The copper horizons in the Mt. Deception area lens out southeastward. On the northern flank of Mount Bayley Range a greater development of the grey-green shale facies occurs at this horizon, but does not carry copper.

Caines Lease.

Location:- 8½ miles west of Beltana, ¼ mile north of Teatree Well

References:- Record of Mines 1899 p. 9.

(This is probably the same mine recorded under "Beltana District" on page 3 of the same volume).

The main workings here are on a small vein running parallel to strike and a description will be found in the next section. However, at this locality two thin bands of grey-green shale within the red shales of the Bunyeroo Formation carry stratiform copper mineralization. Two small pits have been dug on one of the horizons a few yards north of Teatree Hut; these are of an exploratory nature only and no mining is believed to have taken place on this horizon.

Walter's Copper Mine

Location:- 5 miles south of Beltana township; ½ mile east of the Hawker-Leigh Creek road.

References:- Inspector of Mines Report (H. Jones) - 1912. (Printed in M.R. 16, 1912, p. 44).

Jones reports that the lode worked by this mine had a north-south strike with a dip to the west. The lode, described as "clayslate thickly impregnated with blue and green carbonates" was revealed over a strike length of 100' by opencut workings and one shaft to a depth of 20'.

Grade:- (Jones, 1912) 2 samples from the dumps assayed at 8.2% and 4.5% copper.

Production:- No production figures are known.

Six Mile Copper Claim

Location:- ½ mile east of Four Mile Well; to the south of Walter's Copper Mine.

References:- Inspector of Mines Report (H. Jones) April 1912; (printed in Min. Rev. 16. 1912, p.44).

In 1912 Jones reported a north-south striking lode with a shallow dip westwards exposed over a distance of 1½ chains by extensive prospecting opencuts and shallow sinkings (4-15ft. deep). The lode was described as "clayslate, densely impregnated with green and blue carbonates and thin veins of grey-ore in the joints".

Grade:- (Jones 1912) 2 samples from dumps assayed at 11.1% and 7.1% copper.

Production:- No production figures are known.

The cupriferous green shale horizons in the Bunyeroo Formation are considered to be syngenetic. The primary origin of the copper is not known. Coats (1964b) has drawn attention to the possibility that the erosion of the mineralized cores of diapirs during the deposition of the country rocks, provided the copper for syngenetic deposits. Evidence from the Beltana area strongly suggests that the Beltana Diapir was actively moving and being eroded during the Marinoan.

Considering the origin of the copper in the Wearing Dolomite Member of the Bunyeroo Formation in the Central and Eastern Flinders Ranges, Thomson (1965b) suggested the possibility of copper-enrichment of bottom-sediments by submarine springs along hinge-lines. A similar origin can also be invoked for the stratiform copper in the Bunyeroo Formation in the Beltana area. The Beltana Diapir itself might have provided the lines of weakness by which hydrothermal solutions from a more deepseated source reached the surface.

Crosscutting ore-bodies

A number of mineral lodes are of a crosscutting nature. These veins often have a clear structural connection with diapiric areas. The unnamed mines and ore-bodies of the south-east area are of this type. They are located on or near the faults radiating from the Nuccaleena Dome beneath which is a postulated diapiric intrusion of which the Nilpena and Greenwell Diapirs are apophyses. To this group should probably be added the southwest trending barytes vein at Lyford's Barytes Workings.

The copper mines of the Black Feather Group worked a north-south cupriferous carbonate vein. 3,000 feet to the east of this a parallel north-south barytes vein carries copper in its southern part, while an unmineralized carbonate vein also trending north-south is found 2,000 feet to the west. These three veins run roughly parallel to the strike of the Bunyeroo shales but have a considerably steeper dip. A structural and genetic connection with the Beltana Diapir is assumed for all these veins. It should be noted that the association of barytes with copper occurs within the Diapir directly to the north near the old Beltana railway station.

Another north-south copper lode occurs in the base of the Cambrian limestones on the western side of Red Range. The mineralization is confined to one horizon, but a small iron carbonate vein can be traced in places. Structural and genetic connection with the Beltana Diapir is again probable, since there is a group of three copper mines within the southwestern corner of the Diapir, due north of the Red Range vein.

The barytes veins on the western side of the Ediacara Range and its southern continuation are possibly connected with the Ediacara Fault. It is worthy of note that the Gap Creek Fault branching off the Ediacara Fault in the vicinity of Mount James is reported by Nixon (1963b), as carrying considerable barytes mineralization.

There follows descriptions of the mines which worked the cross-cutting lodes.

The Southeastern Area

Mineralization is associated with the diapirs and faults in the south-eastern corner of the Beltana area. The locations are shown in figure 6. The Breakfast Time Fault is occupied by a quartz vein for much of its length. A small north-west trending off-shoot from this fault carries a quartz vein with copper mineralization which has been worked by two shafts and a number of pits. No records have been found of these workings. Southwestwards the Breakfast Time Fault is dissipated in the soft shales of the upper member of the Brachina Formation. However, where it cuts through the ridge formed by the A.B.C. Range Quartzite, there is a large amount of haematite. This would seem to be an example of lateral zoning along a faultline.

Near the northeastern end of the Nilpena Diapir copper mineralization is present in the base of the Pound Quartzite. This has been worked by four shafts and various pits. No records are known of this mine. The lode appears to be of a cross-cutting nature. The proximity both to the diapir and to the Nuccaleena Fault is noteworthy.

<u>Lyfords Barytes Workings</u>

Location:- $1\frac{3}{4}$ miles south-east of Hunter Spring Well.

Reference:- Mansfield (1940). Mining Review vol. II, no. 84, p. 158.

Lyford's Barytes Workings are located at the north-eastern end of a barytes vein which can be followed for a distance of half a mile to the southwest, cutting across the siltstones of the middle and upper members of the Brachina Formation. At the mine the vein dips 75° to the northwest. The mine-workings consist of one large open-cut, 30 feet deep, for a distance of 30 feet along the strike. The barytes is contaminated with iron, but Mansfield considered that a limited tonnage of second grade ore could be producted.

Production:- The only production figures known are 10 tons of barytes valued at £30 for the period 1900-1946.

A second barytes vein occurring along the banks of Bitter Spring Creek to the north of the Lyford's vein, was considered by Mansfield to be of too low grade for commercial purposes because of the iron content.

The Black Feather Group

The Black Feather Vein was worked by a number of mines here referred to for convenience of description as the Black Feather Group. These were from north to south; Harvey's Return Mines, J.P. Hill's Claim, Black Feather Mine, and the Enterprise (Beltana) Mine. They are located between four and five miles south of Beltana township, and about half a mile east of the Hawker-Leigh Creek road.

The barytes-copper vein to the east was prospected intensively at its southern end but it is believed that no production of ore took place.

Harvey's Return Mine
(alternative name - 4 Mile Copper Claim).

Location:- Four miles south of Beltana; and half a mile east of the Hawker-Leigh Creek road.

References:- I.M. Report 1899. (Matthews); (printed in Record of Mines, 1908 p. 62).
I.M. Report 1908. (Jones); (printed in Mining Review 9. 1909 p. 43)
I.M. Report 1909 (Jones); (printed in Mining Review 10. 1909. p.31).

This is the most northerly of the Black Feather Group of mines. Reports for the period 1899 to 1909, state that three shafts 50 feet apart were sunk to depths of 40, 70 and 84 feet respectively on a north-south almost vertical lode 18 inches to 2 feet wide at the surface but opening at depth. The lode material was described as "of a siliceous nature containing chiefly green carbonates associated with iron". The green copper carbonate (malachite) occurred as small seams and "splashes" throughout the matrix. Open-cut prospecting north of the shafts proved the total length of the lode to four chains.

These are probably the workings seen at the northern end of the Black Feather vein. The vein material is siderite with quartz; little copper can be seen in the surface exposures. A small parallel vein of barytes occurs at the northern end. Various pits and shafts are grouped at the southern end of the visible vein.

Grade:- (M.R. 1899) Sorted sample from near surface north of one of the shafts assayed at 20¼% copper.

Production:- The only production figures known are 14 tons of ore assaying 4-16% copper for the period up to 1899. The 1909 report states that a considerable amount of ore was raised by driving and stoping from the shafts. This ore was dressed up to 20%.

<u>J.P. Hill's Claim</u>

Location:- Four miles south of Beltana town. Immediately south of Harvey's Return Mine.

References:- I.M. Report 1909 (Jones). (reprinted in Mining Review 10, p. 3).

This mine is situated in the red shale of the Bunyeroo Formation, immediately south of Harvey's Return Mine. It was worked between 1900 to 1912. From 1907 to 1908 it was worked jointly with Harvey's Return Mine by the Tasmanian Copper Company. Jones (1909) reports that the lode had been revealed by open workings and two shafts to depth of 40 and 60 feet. The lode material was described as "ferruginous material with seams and stains of carbonates throughout".

This is most probably the southern extension of the lode worked by Harvey's Return Mine. There is possibly a small cross fault between Harvey's Return Mine and J.P. Hill's Claim displacing the vein a few feet to the east.

Production:- No production or grade figures are known.

Black Feather Mine

Location:- Four and a half miles south of Beltana township; to the south of J.P. Hill's Claim.

Reference:- I.M. Report 1899 (Matthews); (printed in Record of Mines, 1908. p. 30).

The Black Feather Mine is situated 400 yards south of J.P. Hill's Claim, in red shales of the Bunyeroo Formation (here dipping at 5° to the west). The lode trends roughly parallel to the strike of the shales but dips westwards at a much greater angle (85°).

Matthew reported in 1899 two separate lodes striking north-south and outcropping at the surface 50 feet apart. The main lode (the westernmost) had a width of 6 feet and was proven for a length of five chains. Over this length its surface outcrop showed trace copper associated with iron. In 1899 one shaft had been sunk on the western lode to a depth of 40 feet, and a drive made from this for a distance of 45 feet along the lode. The hanging-wall side carried 2 feet of lode material consisting mainly of green carbonate (malachite) and grey-ore (?chalcocite). The eastern lode had been tested by a trial pit sunk to a depth of 5 feet, revealing green carbonates of copper.

The mine was re-examined during the present survey. Between J.P. Hill's Claim and the Black Feather Mine the lode is poorly exposed. At the mine only the main lode could be identified. This is traceable on the surface for a distance north-south of 600 feet. The lode is 20 feet wide at the mine, thinning southwards to 6 feet. The vein material is siderite with quartz and incorporates a large amount of red shale wall-rock which is impregnated with copper carbonate. The principal ore-mineral is malachite with minor amounts of chalcopyrite.

Grade:- Matthews records an assay of 20% copper on a sample of sorted ore from the drive on the main lode.

Production:- The only figures known are for the production up to 1899 of 10 tons of ore assaying at 17% copper. The mine was worked periodically up to 1917.

Enterprise (Beltana) Mine

Location:- Four and a half miles south of Beltana; a quarter of a mile south of the Black Feather Mine.

References:- I.M. Report 1899. (Matthews) (printed in Record of Mines 1908 p.52)

Mining Records No. 6. (1907) p. 18 (returns)

The only report on this mine was made in 1899. Matthews recorded the lode as outcropping continuously for a considerable distance and in one place reaching a width of 18-20 feet, trace copper carbonates being visible along the length of the outcrop. A long open-cut, 10 feet deep, south of the main outcrop showed bunches and veins of green carbonate and grey ore concentrated on the eastern side of the lode. South of the main lode outcrop and west of the open-cut one shaft had been sunk to a depth of 60 feet, cutting the lode which was described as "siliceous ironstone, with pockets of fair-grade carbonates and grey-ore". A trial pit west of the outcrop also revealed copper-bearing lode-material.

The Enterprise Mine worked the southern continuation of the Black Feather vein. To the north the vein is poorly exposed. Southwards from the Mine the vein is intermittently exposed and has been prospected by several pits. Copper is present in all the exposures. The principal mine-workings consist of a long north-south opencut with a shaft or adit at its southern end. During the present survey the vein was examined in this open-cut. The attitude of the lode is more or less vertical. Thin vertical veins of cupriferous quartz have stoped off sheets of red shale. Malachite is the principal copper mineral with accessory bornite and chalcopyrite.

Grade:- A sample from the shaft assayed at 9½% copper (1899).

Production:- Production figures are known only for the period 1906-1907. 120 tons of ore were mined, 14 tons being treated giving a value of 5% worth £92.

The Red Range Copper Deposits

Copper mineralization along the western side of Red Range is confined to the westerly dipping oolitic dolomites at the base of the Cambrian carbonate sequence. The mineralization has been explored by a number of pits, trenches, and adits. No records have been found of the workings but judging from the size of the tips there was little or no production of saleable ore. The copper occurs as nodules and stainings of malachite. A narrow north-south cupriferous siderite vein can be recognised in places, and the mineralization is considered to be entirely epigenetic. No mineralization is associated with the strike fault, the Red Range Fault, 1,000 feet to the west.

Warrioota Barytes Veins

Barytes veins occur south of Warrioota H.S. for the distance of a mile along the western edge of the Wonoka outcrop. The veins have only short surface outcrops trending north-south with a few trending southwest. A shaft has been sunk on the most southerly vein. No other minerals are known to be associated with the barytes. The mineralization is probably genetically related to the Ediacara Fault a short distance to the west.

Caines Lease

(See previous section on Stratiform Deposits)

The main workings are located on an east-west cupriferous carbonate vein one foot thick which cuts the basal red shales of the Bunyeroo Formation. Copper was discovered here in 1896, and by July of that year a shaft had been sunk to a depth of 14 feet, and an open-cut excavated. The site was examined during the present survey. Four pits were discovered along the strike of the lode. One hundred yards to the south a second lode can be seen in a small pit.

Production:- the only production figures known are $3\frac{1}{4}$ tons of ore yielding 25% fine copper.

Deposits Within Diapirs

It has been noted in the previous section that some of the mineral occurrences have an apparent or assumed connection with diapiric intrusions. There are, in addition, a number of lodes, principally copper, located within the diapirs. The Copper Queen, New Year, and Beltana Edith are mines which worked these copper lodes. The Beltana Barytes Mine produced a limited tonnage of barytes.

The origin of the copper within the diapiric structures is not know. Any theory must take into account also the mineralized veins which cut the country rock and originate from the diapirs. It is possible that the copper was originally syngenetic within Willouran rocks brought up as blocks by the diapiric movements, and has undergone considerable mobilization. It is possible too, that the deposits originate from a more deep-seated hydrothermal source, the diapir having provided major lines of weakness along which hydrothermal solutions could ascend.

The following is an account of the deposits found within a diapiric environment.

The Copper Queen Mine

Location:- Four miles west of Beltana; south of Warioota Creek on the road from Beltana township to Beltana R.S.

References:- I.M.R. July 1908. (printed in Mining Review 9. 1908 p. 42).

I.M.R. 1909. (printed in Mining Review 10. 1909 p. 31).

Mining Review 14. 1911. p. 7.

I.M.R. July 1911. (printed in Mining Review 15. 1911 p. 25).

I.M.R. April 1912. (printed in Mining Review 16. 1912 p. 43).

I.M.R. April 1913. (printed in Mining Review 18. 1913 p. 38).

I.M.R. October 1913. (printed in Mining Review 19. 1913 p. 64).

Mining Review 20 1914 p. 7.

I.M.R. May 1915. (printed in Mining Review 22 1915 p. 6; p. 42).

Mining Review 23. 1915 p. 6.

I.M.R. May 1916 (printed in Mining Review 24. 1916. p. 6; p. 55).

I.M.R. (Winton) 1917 (printed in Mining Review 27. 1917. p. 9; p. 81).

Geology:- The reports contained in the Mining Reviews cover the mine's main period of activity from 1907 to 1917.

Up to 1911 the main lode, 2-5' wide striking northeast to southwest and dipping at an angle of 40 or 50° to the southeast, had been proved over a strike length of four chains by various prospecting shafts and open-cuts. Working was from No. 1, shaft sunk to a depth of 84 feet, located on the surface outcrop of the lode. The lode material was described as "soft ferruginous material with seams and nodules of carbonates, grey ore and ruby oxide". By 1912 this shaft had been abandoned and a new one (No. 2) sunk eventually to a depth of 82 feet. At a depth of 62 feet, this shaft cut the footwall of the lode dipping east at 40°. From the 62-foot level a crosscut was driven eastwards into the ore-body for 50 feet through soft decomposed slate and soft argillaceous sandstone, both with seams, bunches and nodules of copper ore (chiefly malachite) with occasional "strains" of vanadium. In this drive at a distance of 50 feet from the shaft a vertical winze was sunk for 20 feet, and the drive continued at the 77-foot level from the bottom of this eastwards for 21 feet in a lode of quartz and kaolin with carbonates. At the end of this passage a drive was made south for 12 feet.

A drilling programme of nine holes completed in 1916 proved a second lode to the southeast of the main body, almost horizontal and pinching out to the southeast. A third shaft was sunk on this lode to the southsoutheast of No. 2 shaft.

The lode at the Copper Queen Mine is apparently stratiform in highly weathered bleached greenish siltstones. Quartz vein material is present in the surface outcrop and is reported with kaolin from the underground workings. There is insufficient evidence to determine whether the deposits represent originally syngenetic copper which has undergone a certain amount of recrystallization and mobilization during diapirism, or is an epigenetic deposit resulting from hydrothermal solutions, from a more deep-seated source, which had access along lines of weakness in the diapir. The former interpretation seems to be the most plausible.

Operations:- Operations at the Copper Queen Mine were carried out mainly between 1903 and 1917. No production figures are known. However production was sufficient to make worthwhile the installation of a beneficiation plant in 1911, when the mine was under the ownership of the Beltana Rapid Ore Treatment Syndicate. Low grade ore (2-3% copper) was concentrated to 79-80%. The method was successful for a period until a falling water supply from the mine reduce the potential of the machinery to one working day a week.

The Syndicate relinquished ownership in 1917 and the mine was run for a short period by C.F.W. Pfitzner before closing down in 1918. Leases were taken up again in 1937 for a year by the same man.

Grade:- At various times during operations samples were collected from the mine by the Inspector of Mines. The results of assays are tabulated below.

Date	Ref.	Location	Grade
1909	M.R. 10	open cut on main lode	10% copper
1913	M.R. 18	face of eastern drive at 62-foot level, 18 feet from main shaft. Bulk sample.	1.4% copper
"	"	dist. of 15 feet in north drive	2.9% copper
1915	M.R. 22	face of east drive (full width of drive) for 4 feet at 77-foot level.	1.7% copper
		Face of south drive (full width of drive) for 3 feet at 77-foot level	0.8% copper

New Year Mine

Location:- Three and three quarter miles west of Beltana town on the north side of Warrioota Creek.

References:- I.M.R. December 1899. (printed in Record of Mines 1908. p. 102).

The only record of this mine is the Inspector of Mines report for 1899, which notes that several prospecting shafts had been sunk in soft decomposed slate material, most of them revealing green copper carbonates and one of them disclosing a lode formation 4 feet wide. One shaft had been sunk to a depth of 40 feet, two chains south of the pits. This shaft showed small veins and pockets of ore to the bottom. The mine is probably that located within the Beltana Diapir half a mile north of the Copper Queen Mine. Workings are present on the north, east and south side of a prominent black hill of haematitic quartzite (P268/66). Three shafts are present; a northern one in an east-west line of pits, one to the south of the hill and one to the eastern side.

Grade and Production:- The Inspector of Mines records a sample from the base of the shaft giving a grade 7% copper. No production figures are known.

Beltana Edith (Iron Blow) Mine

Location:- ? 1 mile north-east of Beltana railway station.

References:- G.S. Report Book 1. p. 441. H.Y.L. Brown.
Record of Mines 1890, p. 50.
" " 1899, p. 72
" " 1908, p. 194

The only report on this mine is that of H.Y.L. Brown in 1888 which is reprinted in each of the volumes listed above. Brown records that shafts were sunk in soft shales and sandstone near an ironstone outcrop (iron blow), close to an old mine shaft showing signs of copper. It was intended to prospect for silver, but it is improbable that the venture met with success.

There is some doubt as to the identity of the Beltana Edith Mine. It is probably the one recorded as Iron Blow Mine on old plans, and can probably be identified with the workings discovered during the present survey within the western margins of the Beltana Diapir. An examination of the area around the mine during the present survey produced only copper pickings.

Production:- Activity at this mine is recorded for the years 1907 and 1911-1913. No production figures or grades are given.

Beltana Barytes Mine

Location:- One and a half miles north of Beltana Township.

This mine was not definitely located during the present survey. It is recorded that the lease was first taken up in 1941 but production was not started until 1946. The workings consisted of an open cut 5 feet deep along a vein. An association of barytes and copper occurs a short distance to the north of Beltana Post Office. This is possibly the Beltana Barytes Mine.

Production:- Returns - 1946 - 11 tons barytes valued at £55
1960 - 2 tons barytes valued at £14.

Other localities

There are, in addition, small copper deposits within the Nilpena and Greenwell Diapirs. A number of pits have prospected these, but no working is believed to have taken place.

HYDROLOGY OF THE BELTANA AREA

The western portion of the Beltana area forms part of the northern half of the Pirie-Torrens Basin. Lockhart Jack surveyed the water resources of this part of the basin in 1925. He regarded as its eastern limit the western scarp of the Mount Deception and Red Ranges. The Beltana area thus falls naturally into three hydrological entities reflecting the fundamental three-fold structural division of the region outlined in a previous section:- 1) The Hills of the Flinders Ranges; 2) The Beltana sub-basin; 3) The Torrens Sunkland. (See fig. 10).

The Hills of the Flinders Ranges

The Precambrian and Lower Cambrian rocks of the Flinders Ranges forming the most eastern division are folded into a broad dome structure truncated to the north by the southwest trending Beltana Diapir, and westwards by the Mount Deception Fault.

The A.B.C. Range Quartzite outcrops in the eastern part of the area as a broad arcuate range of hills with strata dipping to the north and west. It is underlain by siltstones of the upper member of the Brachina Formation, and overlain by red shales of the Bunyeroo Formation. It probably thus forms a good aquifer capable of supporting a number of bores. Hunter Spring Well is built on a natural permanent spring at the base of the quartzite. The Station bore at Puttapa H.S. possibly taps this aquifer.

A sandstone unit at the base of the middle member of the Brachina Formation probably acts as a second minor aquifer. It is this unit which causes the semi-permanent Temple Bar Spring on Breakfast Time Creek. This aquifer possibly also supports the Station Well at Moorillah H.S.

No wells or bores are found within the Beltana Diapir. However good supplies of fresh water are obtained from Afghan and Beltana H.S. wells in the low dipping Wonoka country rock

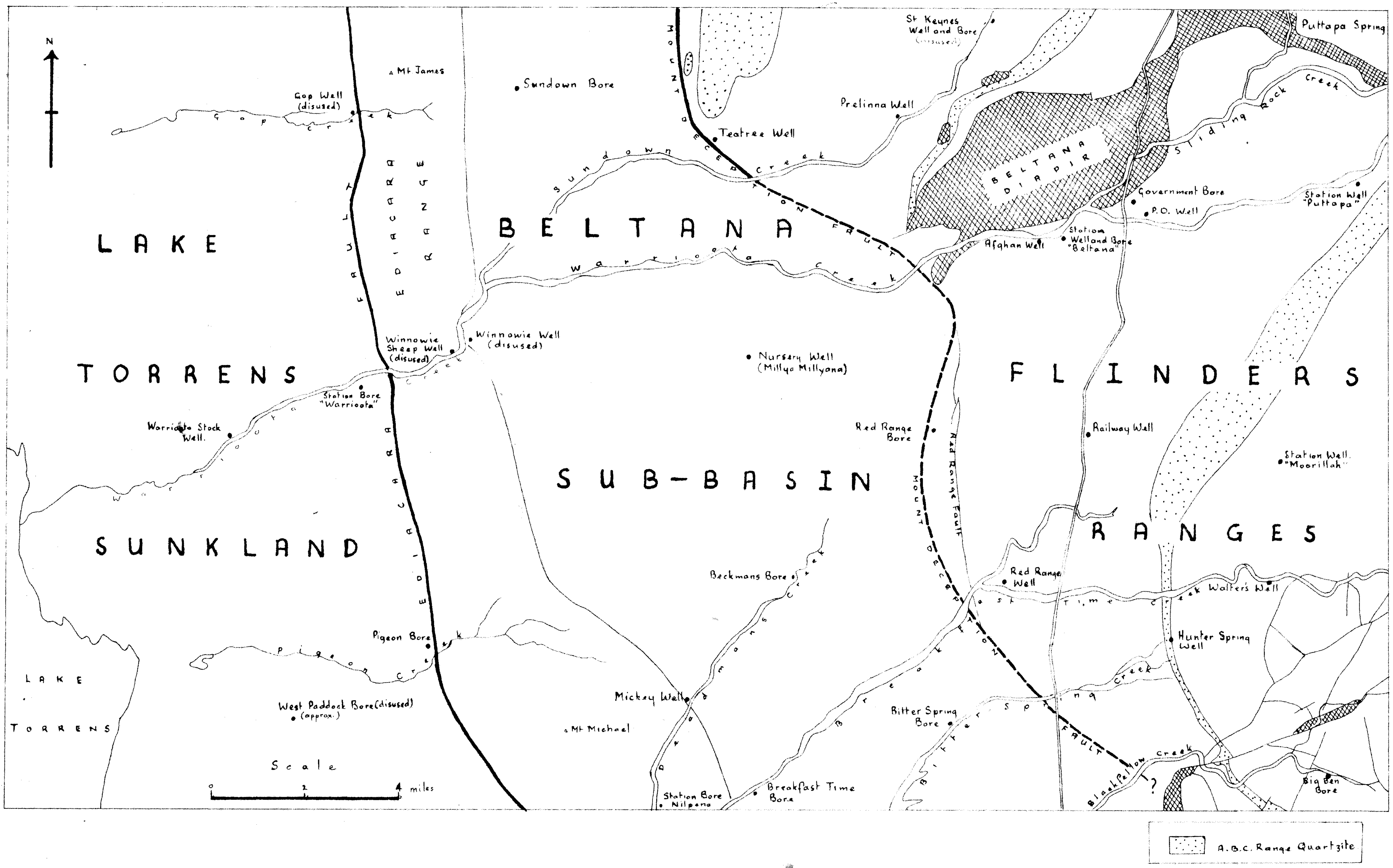

Fig 10. Map of the Beltana area showing hydrological sub-divisions, and locations of ~~bores~~ water bores and wells.

FIG. 10

63/58 66·736 C+F

S. A. DEPT. OF MINES
31·8·66.

on the southern edge of the Diapir. The wells are located on the banks of Warriootta Creek and it is not possible to tell which is the most important factor in the water supply.

Teatree Well taps water from the A.B.C. Range Quartzite aquifer which forms the southern end of Mount Deception range, (see fig. 10). This formation is folded here into a strong north-south anticline plunging south under the Bunyeroo shales a short distance north of Teatree Well. The waters of the aquifer are probably dammed up against the Mount Deception Fault immediately south of the well.

The Beltana Sub-basin

Lockhart Jack (1925 op.cit.) defined the eastern part of the Pirie-Torrens Basin between the western edge of the Mount Deception-Red Range lineament and the Ediacara Fault as a structural and hydrological entity. This is here named the Beltana sub-basin. Jack described the sub-basin as a downfaulted block hinging along the Mount James-Mount Michael range with its greatest downfaulting in the east. Tertiary and Quaternary clays and gravels were deposited within the basin, thickest in the east and thinning to the west, the Mount James-Mount Michael highland acting as a partial barrier to their further movement westwards. The highland barrier would have a similar damming effect to the present movement of shallow groundwaters reaching the basin along the major water courses.

Jack suggested that between these creeks the groundwaters would stagnate and become brackish, but along the creeks there would be a flushing effect of periodic floodwaters which would maintain a comparatively fresh groundwater in their vicinity. Most of the wells and bores in the sub-basin are located along the creeks following Jack's advice. All the wells give good stock water. An exception however is Sundown Bore which is some distance from a sizeable creek but gives extremely good quality water.

The Lake Torrens Sunkland

To the west of the Ediacara Range and its continuation southwards, the Ediacara Fault downthrows the basement rocks 800 feet to form the Lake Torrens Sunkland, the eastern limit of which is now defined in this area by the Ediacara Fault. In the log of the West Paddock Bore, three miles west of Mount Michael, 515 feet of ?Tertiary clays are recorded above the basement. These are believed to be essentially flat-lying, with a resultant lack of groundwater circulation.

Jack considered that the only probable locations for good groundwater were in the eastern part where the major creeks break through the highland barrier and flushing by occasional floodwaters could still take place. The bores at Warrioota O.S, and Pigeon Creek are in such localities and give fairly good stock water. Westwards the groundwater becomes very brackish. West Paddock Bore (abandoned) and Warrioota Stock Well produce a very saline water.

Appendix II tabulates the wells and bores in the Beltana area, giving the salinity of their water, and indicating their relationship to the hydrological pattern outlined above.

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I also wish to acknowledge the preliminary work which Mr. Coats did in this area.

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BL:DLH:SMA
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APPENDIX 1

Petrological Descriptions of Thin-sections of a Representative Suite of Rocks from the Beltana Area, by I.F. Scott, Australian Mineral Development Laboratories

(Note:- the location of the rock type is shown in fig. 4).

P245/66: Etina Formation: lower dolomite unit

This is a reworked dolomite sandstone. Fragments of the original rock, dolomitic oolites and quartz grains are now set in a relatively coarsely crystalline carbonate matrix. Iron-staining is very common on growth zones within individual carbonate grains in the rock.

Approximately 25% of the rock is sub-rounded quartz grains (maximum diameter 1 mm), a few of which exhibit siliceous overgrowths. However there is little evidence to suggest that these have formed after deposition in the dolomite implying that they are probably reworked quartzite components.

It appears that the majority of the dolomite material is primary and has crystallized in situ. However some replacement of quartz grains has taken place but this has most likely occurred during crystallization of the dolomite around the detrital quartz grains during the normal sedimentary processes.

Spherulitic dolomite oolites form a small portion of the rock and a few larger well rounded fragments are also present. One detrital rock fragment contained poorly rounded and much finer (average 0.10 mm) quartz grains.

Accessory amounts of tourmaline, zircon, sericite and a few specks of calcite are also present.

In hand specimen the weathered surface of this rock is a light buff colour and very rough. Minor areas of coarsely crystalline dolomite are visible in vug-like structures.

P246/66: Etina Formation: lower dolomite unit

In hand specimen this rock is coloured a light buff (as for P245/66) but no sedimentary structures are visible. Fractures through the rock are slightly iron or manganese stained.

In thin section the rock is an hypidiotopic (subhedral crystals) quartz-bearing dolomite. Interstitial quartz grains are frequently partly replaced by subhedral crystals of the enclosing dolomite groundmass. Iron staining of the grains is similar to P245/66 but grain sizes are much smaller (average grain size 0.065 mm). Quartz grains are also much smaller than in P245/66.

Accessory zircon, tourmaline and muscovite grains are also present in the rather porous rock. No calcite was observed.

P247/66: Etina Formation: upper siltstone unit

This rock is a well bedded sandy siltstone in which the maximum quartz grain sizes are 0.065 mm.

In hand specimen the rock appears grey and relatively massive although traces of laminations were observed. A weakly developed bedding plane cleavage is evident.

In thin section the rock exhibits graded bedding, the quartz (and minor feldspar) grains being more abundant in the lower portion of the bed while silty material increases towards the upper portion of the bed. This fine-grained interstitial material is mainly chlorite and sericite as well as minor amounts of carbonate (calcite) and opaques.

Accessory zircon and tourmaline are also present.

P248/66: Etina Formation: upper siltstone unit

In hand specimen this rock is very fine-grained, mauve-brown in colour and exhibits a well-defined bedding plane cleavage.

It is only in thin section that the individual beds can be discerned due to the low degree of sorting. The rock is a dolomite-bearing sandy siltstone of similar texture and exhibiting graded bedding (although not as well developed) as in P247/66. However, the rock appears to contain more obvious amounts of feldspar (plagioclase and ?potash) as well as dolomite crystals instead of calcite. Dolomite crystals of similar size to the fine sandy quartz detritus are not uncommon but finer grained carbonate is also present throughout the clayey, sericitic and chloritic groundmass.

Opaques form 2 or 3% of the rock and accessory tourmaline and rutile are also present.

P249/66: Etina Formation: upper siltstone unit

This rock is quartz bearing xenotopic dolomite (majority of grains anhedral and equigranular).

In hand specimen the rock is a typical buff colour and appears massive in nature. Veins cross cut the rock along random directions.

In thin section the rock contains medium sized dolomite grains enclosing and partly replacing remnants (approximately 7%) of quartz grains (and an occasional feldspar grain).

Veins transecting the rock contain subhedral crystals of dolomite, frequently with iron stained growth zones, and the remainder of the veins are filled with calcite. Calcite has replaced a small portion of the dolomite crystals, but in general forms only the interstitial vein material. Iron or manganese stained fractures are also common and a portion of the sample is heavily clouded with dusty iron oxides (surface weathering).

Black minerals in the rock are subhedral crystals consisting of goethite rims on pyrite grains with occasional micron sized chalcopyrite inclusions.

P250/66: Enorama Shale

This sample is a silty shale of a light green-grey colour. Bands of silt sized material are interbedded with graded beds of silt overlain by clayey detritus.

Sericite, chlorite, iron oxides and minor amounts of detrital quartz are the major constituents of the clay size fraction. The silty material contains dolomite crystals which form nearly a third of these bands. Other components, similar to those present in the clayey bands, are also present and in this particular case the coarser layer is bordered by secondary limonitic iron oxides.

A poorly developed bedding plane fracture is evident in thin section.

P251/66: Trezona Formation

This rock is a silty dolomite.

In hand specimen the rock is somewhat multicoloured with narrow dark "vein-like" bands cutting through the buff coloured rock.

The thin section shows that the dark bands are micaceous silty layers which are separated by medium-grained dolomite material. Calcite is not uncommonly associated with the silty detritus and forms less than 10% of the overall volume of the rock. However, because of the irregularity of these narrow silty layers it is difficult to say whether the dolomite has in some way displaced or replaced part of the siltstone along the bedding plane or whether the silty material has infilled a poorly consolidated dolomite sediment.

The rock contains irregular patches of iron staining and also irregular lenses of coarsely crystalline quartz, dolomite and chlorite.

P252/66: Elatina Formation

This rock is a medium to coarse-grained, well sorted, quartz sandstone (orthoquartzite) which appears quite porous, being only partially cemented with clayey minerals.

In thin section the average grain size of the quartz is 0.88 mm or in the upper medium sand size range. More than 95% of the grains are well rounded quartz detritus and associated with these grains are minor amounts of potash feldspar, chalcedony and/or chert. Nearly all grains exhibit strain extinction.

The rock is poorly cemented with clayey material, chlorite, iron oxides and minor amounts of calcite. In some interstices fine sand size grains form part of the cementing medi...

P253/66: Brachina Formation: Moolooloo Siltstone Member

This rock is a greenish grey siltstone which, in hand specimen, exhibits cross-bedding, surface crenulations parallel to minor "folding" and at least three joint planes.

In thin section the rock is well sorted with the majority of grains in the upper silt size range. The major components are quartz, sericite, chlorite, ?biotite, fine-grained ?rutile,?zircon and opaques. Only occasional plagioclase feldspar grains could be distinguished in the quartz-rich groundmass. There is a marked lineation of the white micas indicating their detrital origin.

Cross bedding is evident in thin section due to minor concentration of opaques and heavy minerals.

Cross cutting quartz veins also transect the rock. Minor opaques and chlorite are associated with these quartz veins.

Evidence of any folding is absent and it is assumed that the crenulations seen in hand specimen result from load pressure on an uneven surface.

P254/66: Brachina Formation: Moorillah Siltstone Member

In hand specimen this rock is a buff coloured, fine-grained sandstone exhibiting poorly developed cross-bedding.

The thin section consists essentially of a fine-grained, porous quartz mosaic which has been cemented by silica overgrowths. Secondary sericite has developed along grain boundaries and in grains which were probably originally clay aggregates. Sorting is good and primary grain shapes were sub-rounded to rounded.

Tourmaline, rutile, zircon and opaques form nearly 10% of the rock putting the rock in the protoquartzite group. Cherty grains and occasional potash feldspar grains were also observed. Quartz grains commonly have strain lines through them caused by pressure welding of the sedimentary layer.

An indication of bedding in the rock is given by minor concentrations of opaques and other heavy minerals.

P255/66: Brachina Formation: Moorillah Siltstone Member

This rock is a dark mauve-brown in colour, fine-grained and well bedded. White clay aggregates, easily visible in hand specimen, are set in the dark coloured background.

In thin section individual fine-grained quartz particles are well rounded, well sorted and these primary grains are coated with dark red iron oxides (hematite?). Secondary silica overgrowths have then cemented the grains into a compact mass. Occasional quartz grains reach the medium sand size range and most of the clay aggregates are of this size. This clay detritus forms up to 15% of some beds in the rock. Other indications of bedding are concentrations of secondary, orange coloured iron compounds in bands through the rock. Accessory amounts of opaque grains, tourmaline, zircon and rutile are also present.

The rock is a protoquartzite.

P256/66: Brachina Formation: Moorillah Siltstone Member

This rock is a somewhat lighter mauve colour with dark layers indicating various beds. It is classified as a protoquartzite.

The rock in thin section is very similar to P255/66. Composition, grain size, sorting, accessory minerals are all virtually identical to the previous rock. However individual beds vary in the amount of iron oxide (hematite) coatings on the grains and quartz overgrowths make the rock very well cemented. Clay aggregates, although present in much the same proportions as in P255/66 are more randomly scattered through the rock.

P257/66: Brachina Formation: Bayley Range Siltstone Member

This rock is a poorly sorted sandy siltstone which, in hand specimen in greenish grey in colour. Bedding planes are also visible due to a colour variation.

The thin section contains poorly sorted sandy detritus up to 0.25 mm in diameter but most of the rock is silty material. This silt is mainly quartz, feldspar, and white mica as well as a certain amount of clayey aggregate which is now partly held together with secondary chlorite.

Opaques, red iron oxides and minor amounts of calcite are randomly scattered through the rock or vaguely related to bedding. Other heavy minerals such as zircon and rutile occur in accessory amounts.

P258/66: A.B.C. Range Quartzite

This rock is a light grey, medium grained, massive sandstone in which clay aggregates (of sand grain size) are relatively common.

The thin section indicates that the rock is a fine-grained, well sorted protoquartzite containing less than 10% of opaques, tourmaline and clay aggregates, some of the latter being calcareous. Minor amounts of sericite have developed along grain boundaries after secondary silicification of the original rounded grains.

Accessory grains of rutile and zircon are also present in the rock.

Porosity is difficult to determine due to the clay fraction being a problem in the thin section preparation.

P259/66: Bunyeroo Formation: red shale facies

This rock is a dark massive shale which is occasionally "spotted" in hand specimen.

The colouration of the sample is due to iron oxides forming a large proportion of the matrix. This is readily observable in thin section. Associated with the iron minerals are carbonates (both calcite and dolomite) but fine-grained white mica (aligned parallel to the bedding) and quartz form an important portion of the rock. The rock is a silty claystone but at least 25% to 35% of the rock is carbonate.

Bedding is indicated by darker and lighter iron staining and also by minor grading.

Light coloured "spots" in hand specimen are leached patches without variation in composition.

P260/66: Bunyeroo Formation: grey-green shale facies

This rock is an altered grey shale with coatings of green malachite.

In thin section the rock is highly sericitic and chloritic (over 65%). The remainder of the detrital material is mainly quartz and minor opaques. Small concentrations of more coarsely crystalline quartz grains are usually associated with minor barite grains.

The white mica and much of the chlorite has a strongly preferred orientation, probably a sedimentary feature.

Secondary malachite is a rather common constituent in the rock. The green secondary copper mineral occurs along joints and fractures and also as discrete grains throughout the rock. Permeating copper bearing solutions have penetrated the rock along bedding plane directions and the larger concentration of precipitated copper material are frequently associated with the coarser "lenses" of quartz.

P261/66: Wonoka Formation

This rock is a dark grey, strongly bedded rock with a layer of light coloured travertine-like material on the weathered surface.

In thin section the rock is a well bedded calcareous limestone containing individual beds rich in detrital quartz, feldspar and chlorite. These layers are irregular in thickness and in distribution. Grain sizes reach a maximum of 0.065 mm, on the border between silt and fine sand sizes. Grain boundaries are usually angular and often indented from partial replacement by calcite.

The calcite grains in the interlayered carbonate bands are of a similar size to the quartz detritus and have a xenotopic fabric (anhedral crystals).

Accessory amounts of dolomite grains and opaques are also present.

P262/66: Pound Quartzite: Lower member

This rock is chocolate-red in colour and reasonably well bedded.

In thin section quartz is the main constituent but both feldspars, mica, accessory opaques, zircon and tourmaline as well as numerous deeply iron stained detrital clay aggregates also are present in the sample.

Hematitic(?) iron oxides coat most of the detrital grains which are rounded to sub-angular in shape and average 0.08 mm in diameter (maximum size 0.3 mm). The rock is then classified as a fine-grained feldspathic sandstone. As well as the relatively minor amounts of clay the rock is cemented with silica overgrowths on the iron coated grains. However porosity remains relatively high due to weathering of the cement and clay minerals.

P263/66: Pound Quartzite: Middle Member

The hand specimen of this rock is light buff in colour, relatively massive and minutely speckled with white opaque grains.

In thin section the rock is a well sorted, fine-grained protoquartzite in which clay aggregates form a significant portion of the rock (5 to 7%). Trace amounts of clay or white micaceous minerals have developed along grain boundaries after secondary cementation of the quartz-rich rock by silica overgrowths. However the rock is relatively porous due to weathering of the clay content.

Accessory amounts of muscovite, tourmaline, zircon and opaques are also present.

No bedding features are evident.

P264/66: Pound Quartzite: Upper Member

In hand specimen this rock is of similar colour to P263/66 but has a well bedded texture.

The thin section consists of essentially identical detritus to P263/66 but the grains are poorly sorted and the degree of rounding varies considerably.

A vague suggestion of graded bedding is evident but other bedding features are absent.

The largest quartz grains belong to the medium sand size range. Clay aggregates are not as common as in P263/66 and accessories are virtually absent except for an odd grain of zircon, tourmaline and rutile.

The rock is classified as a fine to medium-grained orthoquartzite.

P265/66: Cambrian: Ajax Limestone

This rock is a somewhat iron stained grey oolitic limestone.

In thin section it is seen that the oolites are generally dolomitic although some secondary calcite partially replaces oolites and interstitial dolomite material. The rock is actually an oolitic dolomite containing frequent interstitial detrital grains of quartz and potash feldspar.

Detrital grains reach a maximum grain size of 0.5 mm while the oolites have a range of diameters from 0.11 to 0.75 mm. Crystallization within the oolites is concentric rather than radial and the crystallinity of the oolitic material is much less coarse than the interstitial carbonate.

In general less than 5% of the rock is detrital quartz and feldspar but bands rich in non-carbonate material contain up to 30% detritus. Calcite, as well as replacing dolomite in the oolites in preference to the matrix, also occurs associated with iron oxides in fractures in the rock. Calcite, although unevenly distributed, forms approximately 25% of the rock. On a large scale a certain degree of packing of the spherical oolite bodies is evident although sorting is relatively poor.

P266/66: Cambrian: Ajax Limestone

This sample is a dark grey, iron-stained crystalline carbonate rock. Numerous vuggy areas are present in the sample due to weathering after fracturing.

In thin section the rock is a fine-grained, xenotopic (anhedral crystals) dolomite. Cross fractures contain iron-stained recrystallized dolomite grains as well as occasional calcite grains or simply voids. Calcite forms less than 3% of the overall volume of the rock.

Accessory grains of fine sandy quartz and feldspar are also present in the sample.

P267/66: Cambrian: Ajax Limestone

This rock, in hand specimen, is a dirty brown colour and quite heavily iron-stained.

The thin section has been cut across a marked textural variation in the calcareous, dolomitic limestone. In hand specimen, after staining for calcite, it is easily seen that three different portion of the rock contain different quantities of calcite. The fine-grained portion is xenotopic (anhedral) dolomite which, across an iron-stained stylolitic boundary, change abruptly to a slightly coarser grained hypidiotopic (subhedral) dolomite with minor amounts of interstitial calcite. This material once again changes abruptly at another stylolitic boundary to a calcite rich matrix enclosing idiotopic (euhedral) dolomite crystals. These crystals exhibit growth zones delineated by iron oxide coatings.

All these various changes occur over a distance of a few centimetres. The stylolites are essentially iron oxides but secondary calcite, which has been introduced along cross-cutting calcite veins, is common. Iron staining of random fractures in the rock was also observed.

P268/66: Willouran: Hematitic Quartzite

This rock is a very dense hematitic quartzite which is a deep red-black colour in hand specimen.

The rock is a hematite-cemented protoquartzite. Individual grains are well rounded but very poorly sorted, the sizes ranging from silt to coarse sandy material.

Other than quartz (85%) and hematite (15%) there are only accessory amounts of muscovite.

As well as the hematite coatings the rock is also partly cemented by silica overgrowths.

Fractures through the rock now contain recrystallized quartz grains which are usually optically continuous with adjacent grains in the body of the rock.

P271/66: Black Feather Vein: Black Feather Mine

In hand specimen this sample is a very dark brown carbonate rock.

The thin section consists essentially of heavy dendritically iron-stained calcite.

Small fragments of siltstone are present as detrital constituents and secondary quartz is found in cavities in the rock. Recrystallized calcite also occurs in some cavities and in veins transecting the rock.

Approximately 60% of the rock is coarse-grained calcite 30% iron oxides or hydroxides and the remainder is detritus or secondary silicates.

The opaque minerals consist of goethite and minor acicular hematite crystals.

P272/66: Black Feather Vein: Harvey's Return Mine

This rock is mottled in appearance with white crystalline material interfingering with dirty brown carbonate material.

The thin section of the rock consists of heavily iron-stained (dendrites) calcite as in P271/66 but any infilled fractures and non-carbonate material is quartz.

Crystals of quartz up to 4 mm in length have grown in situ in the ~~course~~-grained carbonate rock and at a later stage have been somewhat strained. Although irregularly distributed these crystals now form approximately half of the rock.

The opaque iron minerals in the rock consist of goethite.

APPENDIX II

Record of Salinity of Bore and Well Waters

(locations of bores and wells are shown in figure 10).

Name	Depth	Date Sampled	Salinity in p.p.m.	Remarks
Afghan Well	40'	1951 1964 1966	1492 1306 1515	On southern bank Warrioota Creek. Sunk in low dipping strata of Wonoka Formation at southern edge of Beltana Diapir.
Beckman's Bore	120	1951	4507	On creek bank. Sunk in Tertiary sediments in Beltana Sub-basin.
Beltana H.S. Well and Bore	-	1966	1770*	On southern bank Warrioota Creek. Sunk in low dipping strata of Wonoka Formation at southern edge of Diapir.
Bitter Springs Bore	130	1951 1960 1966	5768 5577 5685	Near creek bank. Sunk in Tertiary sediments of Beltana Sub-basin.
Breakfast Time Bore	-	1951 1966	471 no sample	On creek bank in Beltana Sub-basin. Salinity measurement is for adjacent shallow well (29') now abandoned.
Gap Well	200	1951	good stock water	Abandoned. On creek in Lake Torrens Basin on west side of Ediacara Range.
Government Well	24	1942 1964 1966	2018 1829 3170*	Probably located near site of old railway-station bore, Beltana town. 1966 measurement is for this bore.
Hunter Spring Well	-	1966	4700*	Built on natural spring at base of ABC Range Quartzite.
Mickey Well	55	1951 1966	5788 6670	On creek bank in Beltana Sub-basin near Mt. Michael range.
Moorillah Station Well	-	1966	4555	Sunk in Brachina siltstones in the Flinders Ranges.
Nursery Well (Millya Millyana)	-	1923 1926 1951 1966	3821 2525 5474 no sample	In creek complex. Sunk in Tertiary sediments of the Beltana Sub-basin.
Pigeon Bore	174	1951 1960 1966	3157 3546 3730	Near creek on western side of Mt. Michael range. In Tertiary sediments of Lake Torrens Basin.
Post Office Well	-	1966	2155*	Nr. creek bank. Sunk in alluvium overlying Wonoka sediments.

[redacted]

Name	Depth	Date Sampled	Salinity in parts per million	Remarks
Prelinna Well	? 40	1966	3530	On creek bank. Sunk in Bunyeroo shales nr. semi-permanent spring.
Puttapa H.S. Well and Bore	90'	1946	2431*	Near Creek bank. Sunk in Bunyeroo shales possibly tapping ABC Range Quartzite aquifer.
		1952	2420	
		1966	2755	Bore drilled in bottom of well 56' deep.
Puttapa Spring		1966	2355	Permanent Spring on Puttapa Creek at contact of Diapir and country rocks (Wonoka Formation).
Railway Well	59	1966	1830	In Bunyeroo shales in foothills of Ranges.
Red Range Bore	203	1964	2386	Edge of range. Water possibly dammed against fault.
		1966	2685	
Red Range Well	-	1966	2900	On creek bank at southern end of Red Range.
St. Keynes Bore	222	1926	8030	Disused. Probably located near St. Keynes Dam.
St. Keynes Well	-	1926	7170	" " " " " "
Sundown Bore	89	1926	1778	In middle of plain sunk in Tertiary or Quaternary gravel beds within Beltana Sub-basin.
		1951	1774	
		1966	1955	
Teatree Well	30	1966	1170	In Bunyeroo shales adjacent to fault.
Walter's Well		1966	3530	In creek within Flinders Ranges.
Warriootta Stock Well	66	1951	5914	On creek bank sunk in Tertiary or Quaternary sediments of Lake Torrens Basin.
		1960	10225	
		1966	10545*	
Warriootta O.S. Bore	120	1966	7145	On creek bank probably in Tertiary or Quaternary sediments, at eastern limit of Lake Torrens Basin.
West Paddock Bore	515	-	salt	Disused. Exact location not known; approximately three miles west of Mt. Michael, in Lake Torrens Basin.
Winnowie Bore	160	1925	4790	Disused. On west side Beltana Sub-basin nr. Winnowie Hut.
		1925	10172	
Winnowie Hut Well	35	1951	2339	Disused. On creek bank on western edge Beltana Sub-basin at Winnowie Hut.

Name	Depth	Date Sampled	Salinity in parts per million	Remarks
Winnowie Stock	30'	-	-	Disused. North bank Warrioota Creek south of Randell's Lookout.

Note: Maximum acceptability for sheep feeding on saltbush is given as 10,000 ppm (700 grains per gallon) in the Mines Department's "Groundwater Handbook". (14.3 ppm = 1 grain per gallon).

* indicates tank or tap sample only.

APPENDIX III

Edited reports by Dr. N.H. Ludbrook on samples of Nilpena Limestone from the Beltana 1:63,360 map area. The localities from which the samples were taken are shown in fig. 4.

1. Samples submitted by B. Leeson. Date 5th January, 1966.

Locality:- Beltana 1:63,360 geological map.

Samples:-

BL 191/65	-	1 mile due south of Winnowie Hut
BL 192/65	-	" " " " " " "
BL 193/65	-	1 mile south of Randell's Lookout
BL 194/65	-	" " " " " "
BL 195/65	-	" " " " " "
BL 203/65*	-	At Nilpena H.S. (Parachilna 1:63,360 map area).
BL 204/65	-	1 mile west of Mount James.
BL 205/65	-	" " " " " "

The specimens are of freshwater, lacustrine limestone containing a few small gastropods. They appear to be close to the Recent Rivisessor pattisoni (Cotton) which has a wide distribution in South Australia in rivers, creeks, pipes and reservoirs.

2. Samples* submitted by R.P. Coats. Date 19th September, 1960.

Locality; $\frac{1}{4}$ mile east of Nilpena H.S. (Parachilna 1:63,360 map area).

Details: Collected from outcrop.

B1, B3 upper horizon
B4, B5 lower horizon, 50ft. below B1, B2, B3.

Specimens B1, B2, B3 from upper horizon and B4, B5 from lower horizon are of limestone containing moulds of small gastropods 3-5 mm high. It has not so far been possible to identify the gastropods which have some features in common with Coxiella which inhabits salt lakes.

However, as Coxiella species in Australia range in average height from 7 mm to 14 mm, they are more than twice the size of the fossil specimens.

The limestone is regarded as of lacustrine origin, but no information is at present available to date it precisely.

* Not shown on fig. 4.