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# SULPHUR PROSPECTS IN THE LAKE AMADEUS AND LAKE NEALE AREAS NORTHERN TERRITORY.

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CONTENTS

INTRODUCTION

This report deals with sulphur prospects in the Lake Amadeus and Lake Neale areas of the Northern Territory, and with the related geology of the Amadeus basin as a whole.

It was compiled in connection with the application, by Newmont Pty. Ltd. for two tenements, Area A and Area B, in the Lake Amadeus and Lake Neale areas respectively.

GENERAL.

Sulphur is one of the few remaining minerals in which Australia is at present deficient. Most of her requirements are imported.

Native sulphur, as such, is not mined in Australia, but some production is obtained from the treatment of pyrite.

Australian imports of sulphur in 1965 amounted to 387,869 tons, worth $7,496,000, and 1966 434,045 tons, worth $11,930,000 were imported.

While sulphur is not an evaporite mineral, most of the world's production comes from deposits associated with evaporites - especially salt domes - which have resulted largely from bacterial action on gypsum and anhydrite.

It has been known for some time that the Amadeus Basin has had a considerable evaporitic history, both in the Upper Proterozoic and in the Cambrian, and that these evaporites played a considerable role in the tectonic history of the basin. However, the absence of abundant evidence for salt tectonics, together with a lack of knowledge on the detailed geology of the basin, has led most observers to be conservative in their estimate of the magnitude of the Upper Proterozoic evaporite deposits.

It is our opinion that substantial geophysical, well and surface evidence does exist to support the theory that an evaporitic basin of considerable size was deposited in the Amadeus Basin during the Upper Proterozoic. Further, it is felt that the reason this evaporitic sequence did not manifest itself clearly through normal salt structures, so evident elsewhere in the world, is that the basin was subjected to considerable orogenic forces which modified normal salt tectonic stresses.

A discussion of the geological history of the Amadeus Basin follows below. Particular emphesis has been placed on the Bitter Springs Formation and its underlying evaporitic sequence, and its special significance to the Lake Amadeus and Lake Neale areas. This is supported with diagrams shown in Figures 1 to 5 and by a structural cross-section drawn to scale in Figure 6.

GEOLOGICAL HISTORY.

The geological history of the Amadeus Basin began in what is now the south east margin, with the extrusion of Pre-Cambrian Lavas (Mount Harris Basalt) and the sedimentation of the Bloods Range Beds. The age of these formations is uncertain, but is thought to be Lower Proterozoic.

This was followed by up-warping and erosion of these beds in the Bloods Range Area.

In the Upper Proterozoic, wide spread deposition of sandstone, siltstone and basal conglomerate occurred as represented by the Heavitree Quartzite in the north and the Dean Quartzite in the south. These formations are thought to be correlatable equivalents. The Heavitree Quartzite has a maximum measured thickness of 1440 feet of Ellery Creek in the MacDonnell Ranges. The Dean Quartzite varies in thickness between 3900 feet in the Robert Range to about 1500 feet in the Piultarena Range. The blanket type deposits were laid down on a mature surface in a shallow epicontinental sea (see Fig. 1). The rate of clastic sedimentation fell off in the later stages of deposition.

At this time, the sea appears to have become deeper but very restricted, possibly as the result of algal reef growth, and deposits of halite and gypsum were laid down. These deposits are generally considered to be the lower part of the Bitter Springs Formation (see Fig. 1).

Unfortunately, as might be expected, these deposits are not well exposed at the surface. The only recorded surface expressions occur in the Goyder Pass diapir structure in the MacDonnell Ranges and also as a number of small gypsum plugs and diapirs on the Mount Leibig, Mount Rennie, Bloods Range and Lake Amadeus map areas. The Goyder diapir is the only good exposure, showing the underlying evaporites intruding and doming the overlying carbonate member of the Bitter Springs Formation. Of the other small gypsum plugs referred to, some appear to be true diapirs which have intruded the overlying Upper Proterozoic, Cambrian and Ordovician sediments, while others appear to have been intruded along fault zones, and still others are associated with anticlines which have been breached down to the Bitter Springs formation, thus exposing gypsum in the core of the anticline.

The Johnstone Hill diapir located in the Mount Rennie map area, is one of the largest. It has a surface diameter of intrusive gypsum in the structure of one mile and rises about 100 feet above the plain.

The gypsum mass has an amorphous friable weathered crust with some secondary selenite. The primary laminated and contacted gypsum is exposed in deeply incised gullies. Several isolated large masses of angular blocks of weathered crystalline dolomite, crystalline dolomitic limestone and brecciated crystalline dolomite lie on the surface of the gypsum. Much of the dolomite which is contorted and brecciated contains possible stromatolites which is lithologically identical with the Bitter Springs Limestone.

Similar masses of gypsum occur in the core of an anticline south of Cleland Hills and extend from the south east corner of the Mount Rennie map sheet to the south west corner of the Mt. Liebig map sheet. A south-east continuation of this trend corresponds to the culmination south of Ocher Hill Anticline (see Fig. 6). Most of the outcrop is secondary amorphous, friable, white, gypsum with some secondary crystalline selenite. However, there are several exposures of brecciated primary gypsum in small gullies. There is no evidence in these outcrops that the gypsum has pierced the overlying sediments, but the brecciation and shearing of gypsum demonstrates that the mass has been mobile.

At Mount Murray on the Lake Amadeus sheet, highly weathered, sheared, laminated gypsum overlain by isoclinally folded, brecciated dolomite and limestone crops out in the core of an anticline in Upper Proterozoic and Palaeozoic rocks. The isoclinal folding of the carbonate rocks is much smaller and tighter than the main anticline. This exposure extends into the Bloods Range area. Two other similar exposures of gypsum occur in the north east portion of the Bloods Range map sheet; however, the stratigraphic relationship suggests diapiric intrusion of the gypsum.

Several other probable diapirs occur in the Lake Amadeus map area between Inindia Bore in the south east, and Mount Murray. They are roughly circular in shape, often have a core of sheared gypsum with some sink holes up to 35 feet deep, and are surrounded by steeply dipping beds. One suspected diapir is a circular depression which is covered by mounds of secondary gypsum, surrounded by hillocks of travertine. In most cases exposures in and around the diapirs are poor.

Only the Ooraminna No. 1 Well and the Mt. Charlotte No. 1 well penetrated the evaporite sequence in the subsurface. The Ooraminna well drilled 187 feet into red-brown crystalline salt below 1514 feet of Bitter Springs limestone. The well was not taken deeper because of poor petroleum prospects. However, seismic sections across the Goraminna structure show a large thickness of underlying salt, and suggest that this structure is the result of a salt dome of a salt pillow.

The Mt. Charlotte well encountered two salt beds up to 134 feet thick in the basal 837 feet of the Bitter Springs formation. This was overlain by 1051 feet of Bitter Springs limestone. This domal structure is also probably due to salt tectonics. Other structures in the Amadeus Basin are no doubt also associated with the evaporites in the Upper Proterozoic, but wells have not been drilled deep enough to penetrate the salt.

Some conception of the magnitude of this evaporitic sequence can be obtained if one accepts the B.M.R. depth to basement maps based on aeromagnetics and compares it with known surface geology (see Fig. 6). In some areas, up to 20,000 feet of evaporites must be interpreted to account for the difference. Only in the Missionary Plains Synclinorium does the depth to basement correspond to the known sedimentary section, and even here, there is often a discrepancy of between 5 and 10 thousand feet.

Thus, a considerable thickness of evaporites can be interpreted as having been laid down at this time. Wells, Ramford and Cook (B.M.R. Record 1963/51 p.11) state "The diapiric structures indicate the possibility of an inclusion of thick evaporites in the formation" (Bitter Springs).

As the sea became less restricted, extensive algal carbonates of the Bitter Springs Limestone were deposited, and to the south, the Pinyinna Beds of similar lithology were laid down.

The Bitter Springs Limestone has a maximum known thickness of 2500 feet at Elling Creek and is thought to be no thicker than 300 feet elsewhere. The total thickness of the Pinyinna Beds is not known and only 700 feet have been measured.

The Bitter Springs limestone consists dominantly of dolomite with a few interbeds of calcareous dolomite and limestone. The dolomite is commonly dark blue grey with common pink, red, maroon and purple variations. It is mostly fined grained with some medium and coarse grains. Oolitic dolomite is found in some localities as well as a trace of sand grains. They are laminated or thinly interbedded with siltstone, shale and medium, friable sandstones. Small thickness of silty sandstone with pseudomorphs after halite occur as well as calcium and sodium sulphates, the former being more common. Irregular chert bands and lenses are common and stromatolites are often present. The dolomite is often foetid.

Only one section was measured and described in detail on the Lake Amadeus map area and this was in the core of the Parana Hill Anticline. A thickness of 1672 feet was recorded, but the base not exposed. It comprised mainly dolomite which was hard, dark grey, in places purple, brown, pink or yellow, fine grained laminated thin or medium bedded, with variable amounts of white, grey and pink chert. In some places the dolomite contains up to 5% detrital quartz. Interbedded with the carbonates are red-brown and white spotted siltstone and mudstone. A sandstone bed was reported near the top. Algal stromatolites are abundant in the lower 300 feet and occur also as small bioherms in the upper few feet.

The Ocher Hill No. 1 well penetrated 1124 feet of interbedded dolomitic limestone and the calcareous siltstone of the Bitter Springs formation without reaching the base. The East Johnny's Creek No. 1 well drilled 1374 feet into the Bitter Springs Formation encountering interbedded cherty dolomite, calcareous siltstone and shale.

In the north and north-east portion of the basin the Bitter Springs has been divided into a lower Gillen member and an upper Loves Creek member. The lower member is often intricately folded and contorted. Some residual hydrocarbons have been recorded from the Bitter Springs formation in wells.

In the type section at Pinyinna Range, the Pinyinna beds comprise basal beds of grey-brown and white laminated siltstone overlain by grey and pink, fine to medium grained, laminated dolomite, foetid dolomite, grey dolomite with stromatolites and pale grey limestone.

It is felt that the Bitter Springs limestone was deposited in a fairly stable shallow water shelf environment. While the Pinyinna beds were laid down in the south east, considerable clastic sediments were still being derived from the south and deposited together with evaporites. This was followed by wide spread algal limestone deposition (see Fig. 1).

Subsequent to the deposition of the Bitter Springs formation and Pinyinna beds, epeirogenic movements took place which resulted in some blocks being eroded and glaciated. During this period and immediately following it, the Inindia Beds were deposited in the south and the Areyonga Formation in the north (see Fig. 2).

The Inindia Beds have a compiled maximum thickness which is estimated to be about 7000 feet at Mount Connor, located south east of Lake Amadeus. It comprises mainly sandstone and siltstone with some tillite.

The Areyonga Formation and Inindia Beds are considered to be partly aqueoglacial in origin. Interbeds of oolitic and algal limestone were deposited in warmer interglacial periods.

Increased instability occurred, both in the south and in the west during the later Upper Proterozoic. In the south, thick clastic deposits of the Winnall Beds were laid down, while in the north, the Pertatataka formation was deposited (see Fig. 2).

The thickness of the Winnall Beds is thought to vary between 3000 feet and 5000 feet and may be as much as 7000 feet in the south east corner of the Lake Amadeus map area.

The Pertatataka formation comprises mainly sandstone, siltstone and shales with minor limestones. It is thought to be about 5500 feet thick in the western portion of the Macdonnell Range, but thins rapidly to the south east and is absent in the Mereenie and Ocher Hill Anticlines (see Fig. 6). This thinning is thought to be due to pre-Cambrian erosion rather than non-deposition.

Upper Proterozoic sedimentation was terminated by major orogenic movements in the south (see fig. 2). This resulted in the Petermann Ranges or Lake Neale Folding in late Upper Proterozoic or early Cambrian time, which caused recumbent and isoclinal folding of the sediments beneath the Pinyinna Beds or Bitter Springs formation as well as metamorphism. The Dean Quartzite and less evaporitic Pinyinna Beds were extensively infolded, while the overlying sediments slid northward on a decollement surface in the evaporitic sequence. Probably in early Cambrian time some 20,000 feet of Mount Currie Conglomerate and Ayers Rock Arkose were deposited as molasse type sediments against the first of the main recumbent fold mountains.

The effect of this orogeny on the evaporitic sequence was to squeeze the evaporites northwards into the Lake Amadeus area. It is also quite likely that some flowage of evaporites took place prior to the orogeny because of an overburden of some 10,000 to 15,000 feet of sediments in the south. It is generally accepted that salt becomes very plastic with an overburden of 7000 to 9000 feet of sediments and that it flows towards fold crests or areas of minimum load.

Normal salt structures which would have formed because of this overburden were disrupted by the orogeny, and thus stresses were relieved and normal fold structures formed.

In the northeastern portion of the Amadeus Basin sedimentation was apparently uninterrupted, and the only effect of the Petermann Orogeny was to change the sedimentation from siltstones, shales and carbonates to arkosic sandstone. Erosion of the newly raised land surface during the Cambrian provided clastic material which was deposited in a fluviatile, deltaic and paralic environment. These sediments are represented by the Cleland sandstone (see Fig. 3). North and eastward, the Cleland sandstone intertongues with and grades laterally into the siltstones, shales and carbonates of the Pertacorta Group.

In the extreme north east corner of the basin, a restricted environment prevailed and Pertoorta Group evaporites were deposited. The Cleland Sandstone has a thickness of 1568 feet in the Lake Amadeus map area and thickens northward to 3500 feet in the Mount Liebig area. Still further north in the Idirriki Range, the Pertaorta Group is reported to be 7000 feet thick.

This overburden of sediments in the north would probably have started evaporites flowing southward in to the central position of the basin where the overburden was less (see Fig. 3)

As the basin subsided during the Cambrian, the marine environment became more widespread.

This transgression continued into the Ordovician with minor reversals resulting in the cyclic interfingering of marine shales and limestones with deltaic sandstones and siltstones of the Larapinta Group (see Fig. 4). Each successive transgression appears to have been more widespread than the previous.

A maximum of 9500 feet of Ordovician Larapinta sediments, including the Mereenie sandstone, were laid down in the Idirriki Range.

By the end of the Ordovician, some 25,000 feet of sediments were pressing down on the underlying evaporitic sequence in the northern portion of the basin. This overburden must undoubtedly have caused considerable flowage of evaporites southward. It is also felt that salt doming must have taken place, probably along anticlinal trends established by the previous orogeny.

Approximately at this time, uplift started to occur in the north, marking the beginning of the Alice Springs orogeny. This resulted in the erosion of Ordovician, Cambrian and Upper Proterozoic rocks in this area during the Devonian. The derived clastic sediments were deposited immediately to the south as the Pertnjara formation (see Fig. 5).

It is estimated that some 10,000 ft. to 20,000 ft. of conglomerate and sandstone were deposited in the Missionary Plains synclinorium adjacent to the uplift area, but these thin rapidly to the south.

Orogenic movements continued into the Carboniferous causing recumbent folds in the Bitter Springs Formation and underlying older rocks along the northern margin of the basin. Sediments younger than the Bitter Springs Formation slid south and were folded and faulted in a manner typical of decollement sliding. This resulted in most of the structures now obvious at the surface. Again orogenic movements must have modified the stresses resulting from salt tectonics.

Essentially, the structural picture has remained the same from the Carboniferous to the present. (see Fig. 6). There is one notable difference between the Alice Springs Orogeny and the Petermann Ranges Orogeny. In the Petermann Orogeny, the intensity of folding dies out to the north away from the orogenic area. However, in the Alice Springs orogeny, the folding appears to become more intense to the south. The reason for this is thought to be two-fold.

1. Some anticlinal trends were already established in the central portion of the basin by the previous Petermann Orogeny. These were intensified by salt tectonics during the Cambrian, Ordovician and Devonian.

2. The thickness of competent sediments is less in the central portion of the basin and thus less likely to resist the tectonic stresses applied during the orogeny.

The Carboniferous, Permian and Mesozoic were times of long continued erosion. The net result is that successively older beds are exposed in the cores of anticlinal structures in a southward direction. It is our opinion that this trend culminates in the vicinity of Lake Amadeus, Lake Neale and possibly also in Lake Macdonald and Lake Hopkins. In these areas, the Bitter Springs formation would be exposed in the cores of anticlines. Although outcrops are poor in the vicinity of Lake Amadeus and Lake Neale, it is significant that if one continues the Lake Neale trend to the west, the largest exposure of Bitter Springs formation on the Bloods Range map, is found. This has also been stated by Wells, Forman and Ranford (B.M.R. Report 65-1964 p.13): "Lakes Macdonald and Hopkins may have formed in part over the Bitter Springs Limestone." Once erosion had stripped off the overburden down to the Bitter Springs, downward percolating ground waters would dissolve the underlying evaporites and cause a collapse of the overlying caprock. The resultant depression would form lakes during the Tertiary and the Quaternary.

A crust of gypsum and halite, together with aeolian sand have been laid down in the lakes. These have not been examined very closely, nor have the underlying beds. Deposits of travertine and gypsum border the lakes and occur as mounds up to 25 ft. high within the lakes. In places near the lake shore, sand has been blown over the evaporite crust. Some of these evaporites may have been dissolved from the underlying caprock.

An analysis by S. Baker (B.M.R.) of the crust in Lake Neale yielded the following water soluble components:

Cl. 12.3%, $SO_4$ 10.8%, Ca 0.58%, Mg 0.32%, Na 12.8%, K.O. 1%

Other samples collected at M65 and M59 on Lake Macdonald and at R107 on Lake Hopkins gave the following analysis of water soluble salt:

| | M59A | M59B | M59C | M65 | R107 |
|---|---|---|---|---|---|
| Cl | 57.7% | 4.75% | 4.75% | 41.25% | 42.1% |
| $SO_4$ | 1.93% | 12.42% | 16.0% | 13.47% | 6.44% |
| Ca | 0.4% | 4.57% | 6.41% | 2.24% | 0.24% |
| Mg | 0.19% | 0.27% | 0.24% | 1.63% | 0.53% |
| Na | 36.8% | 2.95% | 3.35% | 28.0% | 30.0% |
| Total: | 97.02% | 24.96% | 30.75% | 86.59% | 79.31% |

An analysis of a grab sample from a mound in Lake Macdonald gave:

$S.O_2$ 10.36%, CaO. 27.20%, $SO_3$ 39.35%, $H_2O$. 18.13%, $Fe_2O_3$ ?, $Al_2O_3$ 1.50%

Unfortunately, no wells have been drilled in the vicinity of Lake Amadeus or Lake Neale which could be used to prove or disprove the collapse theory. The nearest water bore is Inindia bore located to the south east of Lake Amadeus. The formation in which the well bottomed is unknown, and the well has been abandoned because the water was so saline.

RELATIONSHIP OF SULPHUR TO EVAPORITES *

Although sulphur is not an evaporite mineral, most of the worlds production comes from deposits associated with evaporites. These deposits can be grouped under primary and secondary deposits.

Primary Deposits.

The initial restriction of a marginal basin usually manifests itself in the development of a sapropel facies in the deeper parts of the basin. There, bitumenous marls, free from benthos, accumulate. The overlying water is contaminated with hydrogen sulphide. In large marginal basins this "poisoned" zone may extend to within 200 meters of the surface. Only in the well oxygenated surface waters can normal plant and animal life survive. The remains of these organisms shower down on the sea floor where they give rise to the sapropels. When such restricted basins are located in very arid regions, the surface waters are usually super saturated, at least with calcium carbonate. A very important facies change results, with the bitumenous marls of the deeper parts of the basin grading into limestones with rich benthonic faunas, at depths of less than 200 meters. When the $H_2S$ content of the deeper waters and the oxygen content of the surface waters are favourable, bacteria may cause a great deal of native sulphur to precipitate.

Secondary Deposits

Secondary deposits of sulphur can be formed by the bacterial action on gypsum and anhydrite, and by the reaction of bitumen and "oil field waters" with calcium and magnesium sulphate.

Bitumens, rising into a gypsum caprock, can cause epigenetic reduction of calcium sulphate. The hydrogen sulphide produced may react with oxygenated ground waters to produce native sulphur. Important sulphur deposits of this type are to be found in Texas, Louisiana and New Mexico (e.g. Boling Dome, Texas).

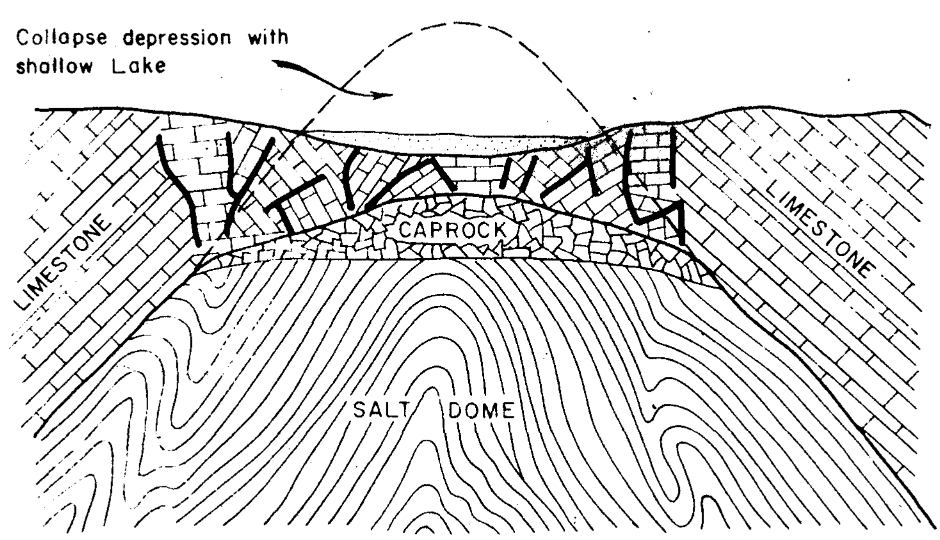
In the Hildesia field in Germany, rising solutions were mostly impregnated with bitumen from the underlying sapropels. In places they reduced magnesium sulphate to native sulphur, and radioactive decay of the uranium content produced blue halite. These "Oil field waters" are still frequently encountered, especially in pore space of the main anhydrite.

* Taken mainly as extracts from "Salt Deposits" by Hermann Borchert, & Richard O. Muir.

The gypsum in evaporite deposits in Sicily has been reduced by bacterial action and by hydrocarbons to give rise to formerly important sulphur deposits in basins five miles long by half a mile wide. Since the initial gypsum was associated with carbonates, the sulphur is usually disseminated throughout the cellular limestones. Halite and potash salts were also precipitated at times from more concentrated brines.

Probably the most significant sulphur deposits are associated with salt domes or diapirs which have been subjected to solution effects. As these structures rise towards the surface, they encounter downwards-percolating meteoric waters that produce complex retrograde metamorphic changes and also partial or complete solution of the salts around the perimeter of the intrusion. As the more soluble components, halite and the potash salts, are preferentially leached, a residue of gypsum, anhydrite, limestone and clay gradually accumulates. This residual layer, the caprock, is most thickly developed on top of the dome where solution proceeds most rapidly.

But it also mantles the side of the dome, often tapering away and disappearing downwards. The composition of the cap is related to the character of the original evaporites. Calcium sulphates frequently predominate where the original salts were marine; marl and clay where the dome is formed from continental salts.




**Collapse Structure Produced by Solution of Top of Underlying Salt Dome during Development of Anhydrite Cap Rock. (After F. Lotze, 1957)**

Internally the caprock is usually very cavernous. Part of its calcium sulphates may be bacterially reduced to sulphur. Economic sulphur deposits of this type are common in the Gulf Coast. Some 10 million tons have been produced from the Sulphur Dome, Louisiana, and the Boiling Dome in Texas is estimated to contain no less than 40 million tons. The sulphur occurs here in the lower part of the limestone and the top of the gypsum. Both are so cavernous that the bunches, seams and crystals of sulphur make up no less than 20-40% of the total volume of the rock. The sulphur zone varies in thickness between 8 and 100 m., and is overlain by 2-40 m. of barren caprock. Many other minerals occur in small quantities. Solution of salts at the top of the dome may leave the overlying sediments unsupported, and collapse structures are often produced. This topic has been thoroughly dealt with by R. Hundt (1950). A block of overlying sediments, circular or elliptical depending on the shape of the dome, subsides to create a depression that frequently becomes the site of a lake (Fig. 7). The sunken block is usually heavily fractured - even brecciated - and often penetrated by veins of gypsum (Fig. 20.14). In northern Germany, some of these depressions were occupied by Tertiary coal swamps (Geiseltal, Stassfurt, Helstedt, etc.) Thick, circular or elliptical lignite bodies are therefore present above some of the salt domes.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that Lake Amadeus, Lake Neale and possibly Lake Macdonald and Lake Hopkins are associated with collapsed anticlinal structures containing evaporites.

It follows, if this is the case, that economic sulphur deposits could conceivably be found associated with the collapsed caprock portion of these structures.

It is recommended that an exploration programme be undertaken to evaluate prospects covered by Area A (Lake Amadeus) and Area B (Lake Neale)as follows:

1. A detailed literature review be undertaken of all relevant information on these areas.
2. Field work should be conducted to examine outcrops for structural information in the vicinity of Lake Amadeus and Lake Neale, and to closely examine the Bitter Springs formation for lithological information and possible facies changes.
3. A geophysical survey to be conducted if warranted (possibly a detailed gravity survey)over the lakes, and/or
4. A drilling programme to be conducted if warranted, consisting of a few shallow stratigraphic test wells to a depth of between 1000 ft. and 1500 feet.

It is also recommended that consideration be given to applying for an Authority to Prospect on Lake Macdonald and Lake Hopkins from the West Australian Government.

# APPENDIX 1.

Description of areas A and B.

**Area A (Lake Amadeus)**

From a point with the co-ordinate latitude 25°00' S and longitude 131°30' E. 6 miles west on an azimuth bearing 270°true; thence west-north-west for a distance of 6 miles on an azimuth bearing 305° true; thence due east for a distance of 15.2 miles on an azimuth bearing 270° true, to a point with the co-ordinate latitude 24° 57'6" S. and longitude 131° 05' E, thence west-north-west for a distance of 44.5 miles in a direction with the azimuth bearing 305° true, to a point with the co-ordinate latitude 24° 35'24" S. and longitude 130°30' E, thence due east for a distance of 11.5 miles on an azimuth bearing 90° true, thence east-south-east for a distance of 7.5 miles on an azimuth bearing 125° true, thence due east for a distance of 11.4 miles on an azimuth bearing 90°true, to a point with the co-ordinate latitude 24°39'S. and longitude 130° 58'E. thence south-south-west for a distance of 4.5 miles on an azimuth bearing 215° true, thence east-south-east for a distance of 19.7 miles on an azimuth bearing 125° true, thence due east for a distance of 20 miles on an azimuth bearing 90° true to a point with the co-ordinate latitude 24° 52'03" S. and longitude 131° 30'E, thence due south for a distance of 9.1 miles to the point of origin (Approximately 490 square miles)

The attached map shows the location of Area A.

**Area B (Lake Neale)**

From a point with the co-ordinates latitude 24°30' 35"S, and longitude 130° 13'24"E. west-north-west for a distance of 38.3 miles on an azimuth bearing 302° true; thence north-north-east for a distance of 6.5 miles on an azimuth bearing 32°; thence east-south-east for a distance distance of 38.3 miles on an azimuth bearing 122° true, thence south-south-west for a distance of 6.5 miles on an azimuth bearing 212° true to the point of origin. (Approximately 149 square miles)

The attached map shows the location of the Area B.

S.W. N.E.

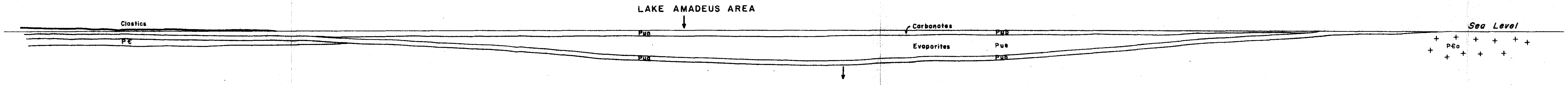



*Figure 1 Early to Middle – Upper Proterozoic*

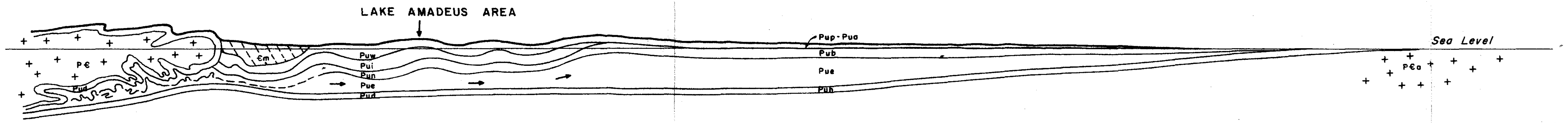



*Figure 2 Late Upper Proterozoic to Early Cambrian*

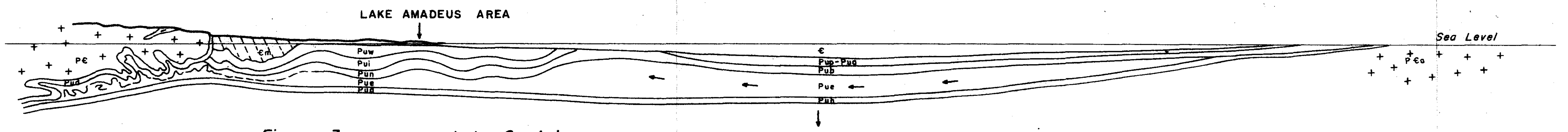



*Figure 3 Late Cambrian*

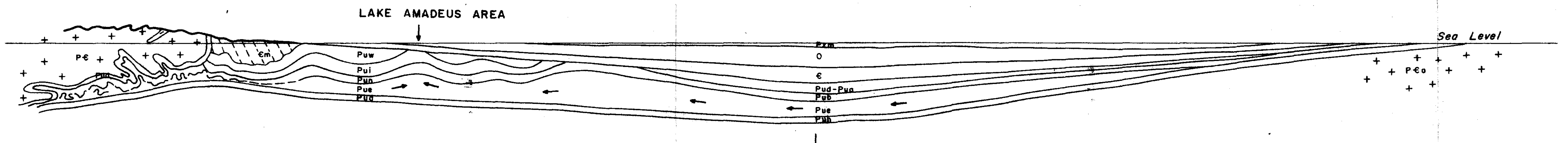



*Figure 4 Late Ordovician*

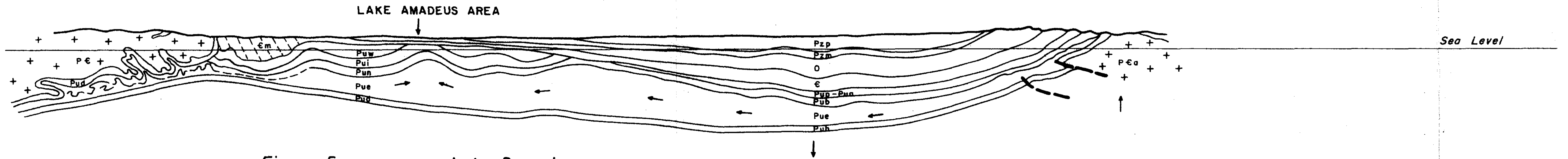



*Figure 5 Late Devonian*

**LEGEND:**

Pzp = Pertnjara
Pzm = Mereenie Ss.
O = Larapinta Gp.
Є = Cleland Ss. Pertaoorta Gp.
Єm = Mount Currie Congl.
Pup = Pertatataka Fm.
Puw = Winnall Beds
Pui = Inindia Beds
Pub = Bitter Springs Lst.
Pun = Pinyinna Beds
Pue = Upper Proter. Evap.
Puh = Heavitree Qtzite
Pud = Dean Qtzite
PЄa = Arunta Complex
PЄ = Precambrian Undiff.

# GEOLOGICAL EVOLUTION OF AMADEUS BASIN

TO ACCOMPANY REPORT ON
SULPHUR PROSPECTS IN THE LAKE AMADEUS-LAKE NEALE AREAS
NORTHERN TERRITORY

*Diagrammatic Only*

Figs. 1 to 5

CR 68/39

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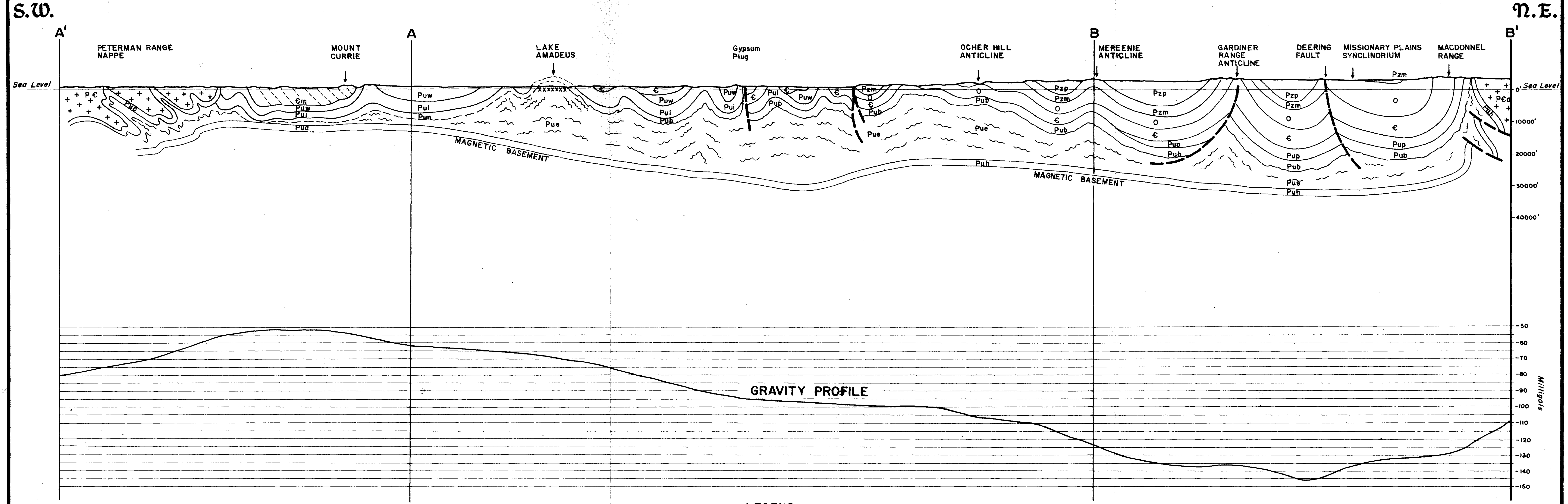


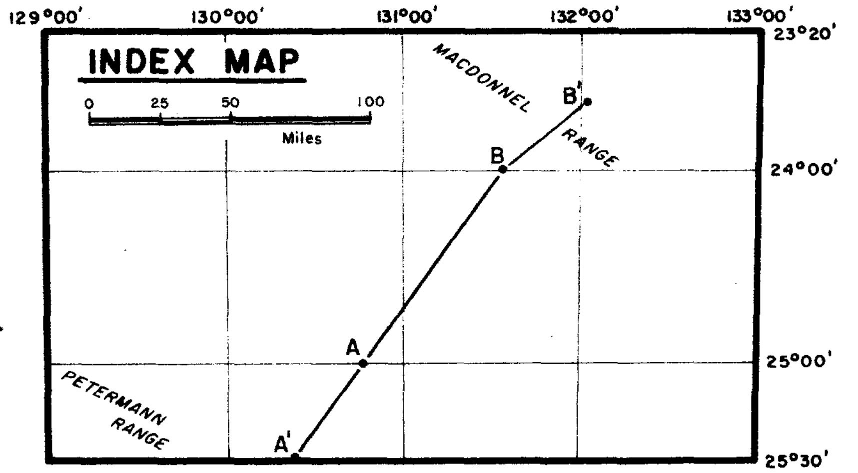


**LEGEND:**

- Pzp = Pertnjara
- Pzm = Mereenie
- O = Ordovician
- € = Cambrian
- €m = Mount Currie Congl.
- Pup = Pertatataka
- Puw = Winnall Beds
- Pul = Inindia Beds
- Pub = Bitter Springs
- Pun = Pinyinna Beds
- Pue = Upper Proter. Evap.
- Puh = Heavitree Qtzite
- Pud = Dean Qtzite
- P€a = Arunta
- P€ Precambrian Undiff.

# CROSS SECTION PETERMANN RGE - MACDONNEL RGE
## (A'-A-B-B' on Maps 1,2 & 3)
## Showing Present Day Structures

TO ACCOMPANY REPORT ON SULPHUR PROSPECTS
IN THE LAKE AMADEUS-LAKE NEALE AREAS NORTHERN TERRITORY

0 2 4 6 8 10 20 Miles

Fig. 6

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PLATE 17


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TO ACCOMPANY RECORD No 1966/230

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

G52/BI-29


MOUNT RENNIE
MOUNT LIEBIG
HERMANNSBURG
ALICE SPRINGS
BLOODS RANGE
LAKE AMADEUS
HENBURY
PETERMANN RANGES
AYERS ROCK
KULGERA
AREA A
AP 1
AP 2
AP 3
MAP 2
AIRBORNE SURVEY, AMADEUS BASIN, NT, 1965
RADIOMETRIC CONTOURS
AND
GEOLOGY
GEOLOGICAL LEGEND
Q QUATERNARY
T TERTIARY
M MESOZOIC
PALAEOZOIC
P PERMIAN Undifferentiated, Crown Point Formation
Pzu Ligertwood Bed
Pzp Pertnjara Formation
Idracowra Formation
Horseshoe Bend Shale
Langra Formation
Polly Conglomerate
Pzm Mereenie Sandstone
€-Ol Larapinta Group
Stokes Formation
Stairway Sandstone
Horn Valley Siltstone
Pacoota Sandstone
€ Pertaoorrta Formation
Cleland Sandstone
Mount Currie Conglomerate
Ayers Rock Arkose
Arumbera Greywacke
UPPER PROTEROZOIC
Puc Carnegie Formation
Pup Winnall Beds
Pertatataka Formation
Pua Areyonga Formation
Inindia Beds
Pub Bitter Springs Limestone
Pinyinna Beds
Puh Heavitree Quartzite
Dean Quartzite
AGE UNCERTAIN
p€ Igneous and metamorphic rocks
Undifferentiated
SCALE
40 MILES
KILOMETRES
TOPOGRAPHICAL LEGEND
Geological boundary
Road
Railway
Stream
GEOPHYSICAL LEGEND
Pertnjara Formation with radioactivity in excess of 37·5 cps
Mereenie Sandstone Outcrop with radioactivity in excess of 37·5 cps
Larapinta Group Outcrop with radioactivity in excess of 37·5 cps
Pertaoorrta Formation with radioactivity in excess of 37·5 cps
AP 1 Diamond drill hole
Radiometric contours
LOCATION DIAGRAM
INDEX TO 1:250,000 SHEETS
Geology after Geological Branch, Bureau of Mineral Resources, Geology and Geophysics, Map NT/A78
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PLATE 16
AIRBORNE SURVEY, AMADEUS BASIN, NT, 1965
MAGNETIC INTERPRETATION
AND
TECTONIC GEOLOGY
MAP 3
MOUNT RENNIE
MOUNT LIEBIG
HERMANNSBURG
ALICE SPRINGS
ORMISTON NAPPE COMPLEX
ARLTUNGA NAPPE COMPLEX
BLOODS RANGE
LAKE AMADEUS
HENBURY
RODINGA
PETERMANN RANGE NAPPE
PETERMANN RANGES
AYERS ROCK
KULGERA
GEOLOGICAL LEGEND
AGE
SYMBOLS
ROCK UNITS
OROGENIC EPISODE
CAINOZOIC
Cz
MESOZOIC
M
Rumbalara Shale
De Souza Sandstone
Undifferentiated
PALAEOZOIC
PERMIAN
CARBONIFEROUS
Pzu
Crown Point Formation
Buck Formation
Undifferentiated
DEVONIAN
SILURIAN
Pzm
? Ligertwood Beds
Pertnjara Formation
Finke Group
Alice Springs Orogeny
Mereenie Sandstone
ORDOVICIAN
Larapinta Group
CAMBRIAN
Pzl
Pertaoorrta Group
Cleland Sandstone
Mount Currie Conglomerate and Ayers Rock arkose
Petermann Ranges Orogeny
PRECAMBRIAN
UPPER PROTEROZOIC
Pu
Pertatataka Formation
Winnall Beds
Maurice Formation
Ellis Sandstone
Sir Frederick Conglomerate
Carnegie Formation
Areyonga Formation
Inindia Beds
Boord Formation
Bitter Springs Formation
Heavitree Quartzite
Pinyinna Beds
Dean Quartzite
Bitter Springs Formation
Heavitree Quartzite
UNDIFFERENTIATED
p€(1)
Bloods Range Beds
Mount Harris Basalt
Undifferentiated volcanics and low grade metasediments
p€(2)
Olia Gneiss and metasediments
Arunta Orogeny
p€
Arunta Complex
Moderate grade gneiss, metasediment, gneissic granite
p€q
Quartzite
IGNEOUS
p€g
Granite
Formed during Petermann Ranges and Arunta Orogenies ? Alice Springs Orogeny
Geological boundary
Plunge of anticline
Plunge of syncline
Overturned anticline
Overturned syncline
Fault
Nappe boundary
Area of Intrusive Gypsum
DIAGRAMMATIC RELATIONSHIP OF TIME ROCK UNITS
Petermann Ranges Nappe
Amadeus
Basin
Arltunga Nappe Complex
GEOPHYSICAL LEGEND
Basement depth estimate corrected for magnetic strike
Basement depth estimate uncorrected
Basement depth estimate corrected for magnetic strike (doubtful)
Depth in feet
Below sea level
Basement depth contour (depth in feet below sea level)
Basement zone and zone boundary
Region of minor magnetic disturbance
Basin boundary magnetically inferred
Magnetic trend
Fault
Magnetic basement features
SCALE
MILES
KILOMETRES
INDEX TO 1:250,000 SHEETS
MOUNT RENNIE
MOUNT LIEBIG
HERMANNS-BURG
ALICE SPRINGS
BLOODS RANGE
LAKE AMADEUS
HENBURY
RODINGA
PETERMANN RANGES
AYERS ROCK
KULGERA
True North
Magnetic North
LOCATION DIAGRAM
Darwin
WA
NT
QLD
SA
NSW
VIC
CR 68/39
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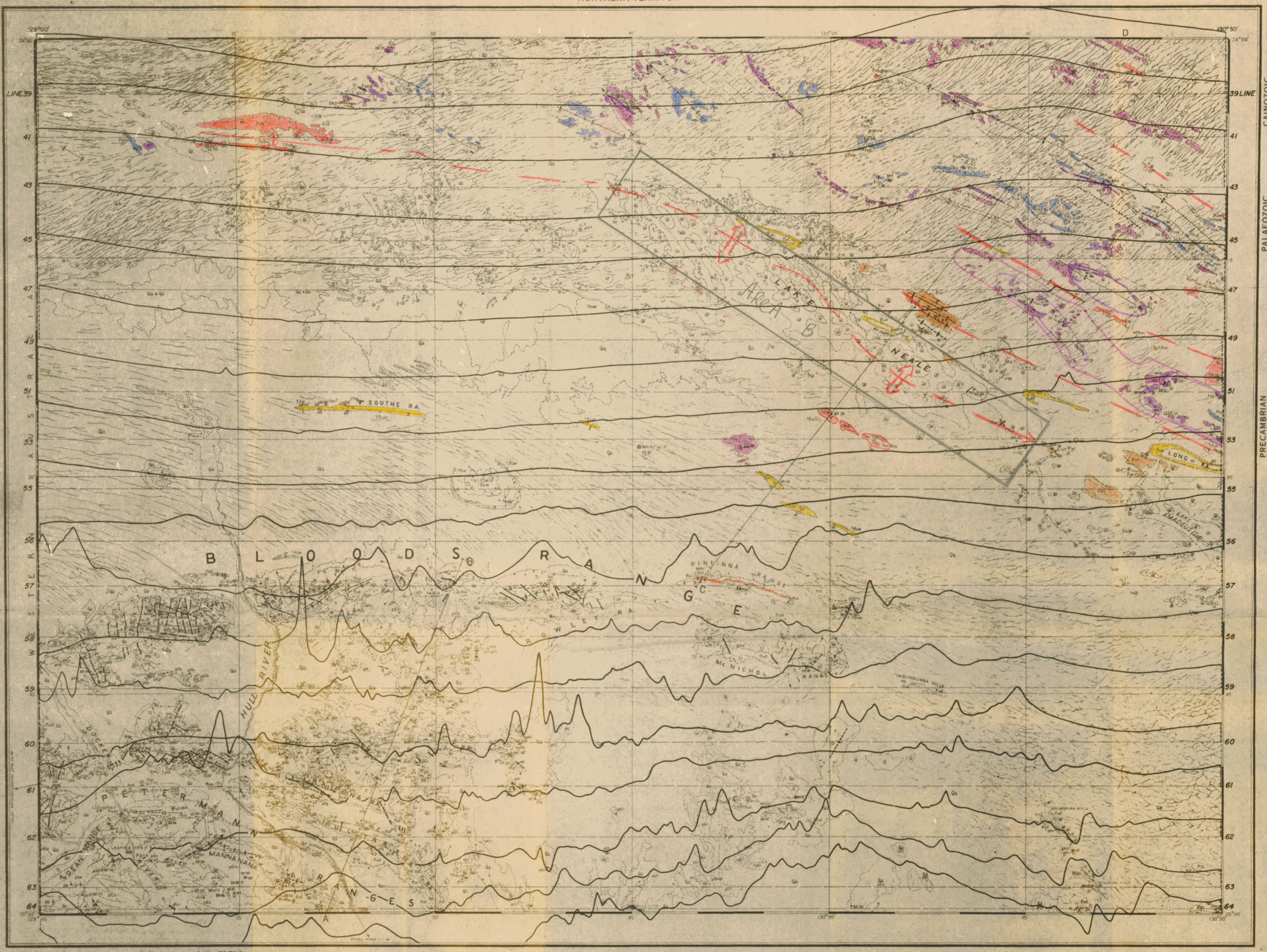
GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
G52/B1-28

AUSTRALIA 1:250,000

# BLOODS RANGE

NORTHERN TERRITORY

PLATE 6




## Reference

| | | | | |
|---|---|---|---|---|
| CAINOZOIC | QUATERNARY | | Qs | Aeolian Sand |
| | | | Qa | Alluvium |
| | | | Qt | Evaporites |
| | | | Ql | Travertine |
| | TERTIARY ? | | Tc | Conglomerate |
| | | | T | Sandstone |
| PALAEOZOIC | CARBONIFEROUS-DEVONIAN | Pertnjara Formation | Pzp | Siltstone |
| | DEVONIAN-ORDOVICIAN | Mereenie Sandstone | Pzm | Brown and white sandstone Large scale cross bedding |
| | ORDOVICIAN | Undifferentiated | O | White sandstone, pipe rock, conglomerate, dolomite, and siltstone, some marine fossils |
| | | Larapinta Group | Ol | Sandstone, siltstone, rare limestone. Marine fossils |
| | CAMBRIAN | Cleland Sandstone | Єc | Crossbedded sandstone and pebbly sandstone, siltstone |
| | | Mt. Currie Conglomerate | Pzc | Conglomerate |
| PRECAMBRIAN | UPPER PROTEROZOIC | Winnall Beds | Puw | Brown and white sandstone, pebbly sandstone, siltstone |
| | | Inindia Beds | Pun | Red siltstone, dolomite, claystone, shale, chert, chert breccia, dolomite and limestone. Stromatolites. |
| | | Bitter Springs Formation | Pub | Crystalline dolomite, limestone, gypsum. Algal stromatolites |
| | | Pinyinna Beds | Pui | Dolomite, limestone and siltstone Stromatolites |
| | | Dean Quartzite | Pud | Quartzite and conglomeratic quartzite, sandstone |
| | UNDIFFERENTIATED | Pottoyu Granite Complex | pЄo | Very coarse porphyritic granite, fine and medium-grained granite gneiss, amphibolite, quartz-epidote rock schist, porphyroblastic schist and quartzite |
| | | | pЄg | Coarse porphyritic granite and medium-graned granite |
| | | Olia Gneiss | pЄn | Fine to medium-grained gneiss, schistose gneiss, porphyroblastic gneiss, granite, schist and quartzite |
| | | Undifferentiated | pЄ | Granite, schist, gneiss |
| | | | pЄm | Porphyroblastic schist, quartz-feldspar porphyry |
| | | | pЄp | Quartz feldspar porphyry |
| | | Bloods Range Beds | pЄb | Sandstone siltstone, shale, arkose, tuff, agglomerate, basalt, acid porphyry and metamorphosed equivalents |
| | | Mount Harris Basalt | pЄh | Epidotized amygdaloidal basalt, tuff, agglomerate, quartzite |

Geological boundary
Syncline, showing plunge
Syncline, overturned

AIRBORNE SURVEY, AMADEUS BASIN, NT 1965

## TOTAL MAGNETIC INTENSITY PROFILES AND GEOLOGY

LOCATION DIAGRAM

INDEX TO ADJOINING SHEETS

GEOLOGICAL RELIABILITY DIAGRAM

APPROX PROFILE SCALE

MAP 4

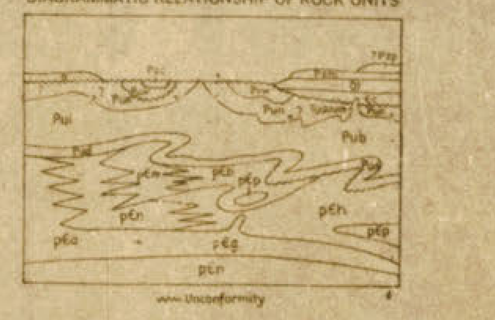
## EXPLANATORY NOTES

THE SURVEY WAS MADE WITH A DC3 AIRCRAFT AT AN ALTITUDE OF 800 FEET ABOVE GROUND LEVEL ALONG LINES SPACED FOUR MILES APART. THE FLIGHT-LINES ARE IDEALISED, AND SERVE AS BASELINES TO THE PROFILES. THEY APPROXIMATE THE ACTUAL FLIGHT PATH WITH A PROBABLE ERROR OF ±¼ MILE.

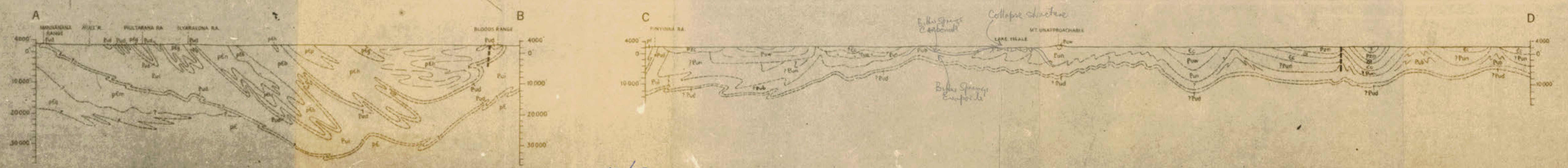
ALL PROFILES RECORDED ARE SHOWN ON THE MAP.

THE PROFILES HAVE BEEN CORRECTED FOR THE SOUTH COMPONENT OF A REGIONAL GRADIENT IN TOTAL MAGNETIC INTENSITY. THIS COMPONENT AMOUNTS TO 9-8 GAMMAS PER MILE.

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



Sections

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