1974/17
Copy 3

Restricted until after publication.
Manuscript submitted for publication
to: A.I.M.M.

DEPARTMENT OF MINERALS AND ENERGY

085019

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/17

"THE GEOLOGY AND GEOPHYSICS OF THE ALLIGATOR RIVERS REGION"

by

(P.G. Smart, P.G. Wilkes, R.S. Needham, and A.L. Watchman)

Record 1974/17

"THE GEOLOGY AND GEOPHYSICS OF THE ALLIGATOR RIVERS REGION"

by

(P.G. Smart, P.G. Wilkes, R.S. Needham, and A.L. Watchman)

CONTENTS

2

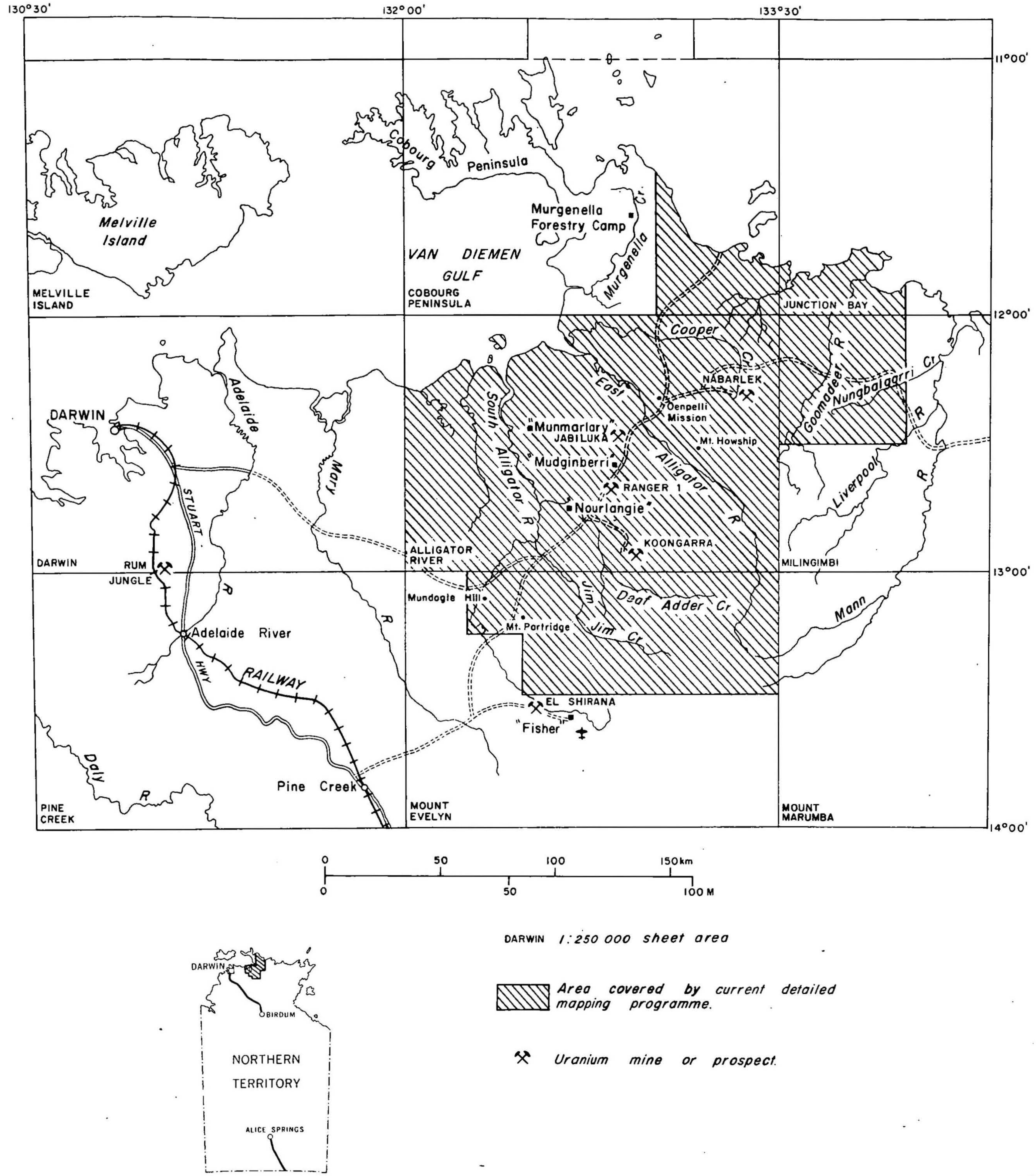


Fig.1 Locality map Alligator Rivers Region

To accompany Record 1974/17

NT/A/396

INTRODUCTION

In the Northern Territory there have been two major phases in the history of exploration for uranium. In the early 1950s the Rum Jungle and South Alligator River valley uranium fields were discovered. The Rum Jungle deposits (Berkman, 1968) were mined between 1953 and 1963 and the South Alligator River valley deposits (Taylor, 1968) were mined between 1954 and 1964. During this period most exploration was directed towards the country between the two areas, but little attention was given to the area east of the South Alligator River. The region was, however, mapped in reconnaissance style at 1:250 000 scale by the Bureau of Mineral Resources (BMR) in the late 1950s (Walpole et al., 1968).

Interest in the area east of the South Alligator River developed in 1969 after apparent analogies between the geology of this area and that at Rum Jungle were noted from the BMR 1:500 000 scale map of the Katherine-Darwin Region (Walpole et al., 1968). Uranium discoveries, described elsewhere in this volume, followed at Nabarlek, Ranger 1, and Koongarra in 1970 and Jabiluka in 1971. Intensive exploration of the region for uranium and base metals has continued to the present (1973). Nothing has been published on the geology of this area since 1968.

Since 1971, a BMR field party has completed semi-detailed mapping, at 1:100 000 scale, of the area shown in Fig. 1; and a regional airborne magnetic and radiometric survey covering the Alligator Rivers region - the 1:250 000 Sheet areas of Alligator River, Cobourg Peninsula, and the northern half of Mount Evelyn. The airborne survey was flown on a regular grid pattern with east-west oriented flight lines spaced 1.5 km apart. Flying height was approximately 150 m above the ground. Geophysical equipment used included a proton magnetometer (of BMR design and construction) and a Hamner four channel differential gamma-ray spectrometer with a sodium iodice detector volume of 3700 cm^3.

Preliminary magnetic contour maps and radiometric 'total-count' profiles were released at 1:100 000 scale early in 1973. Some of the results and interpretation from this survey are included in the geophysics section and Figure 5 of this paper.

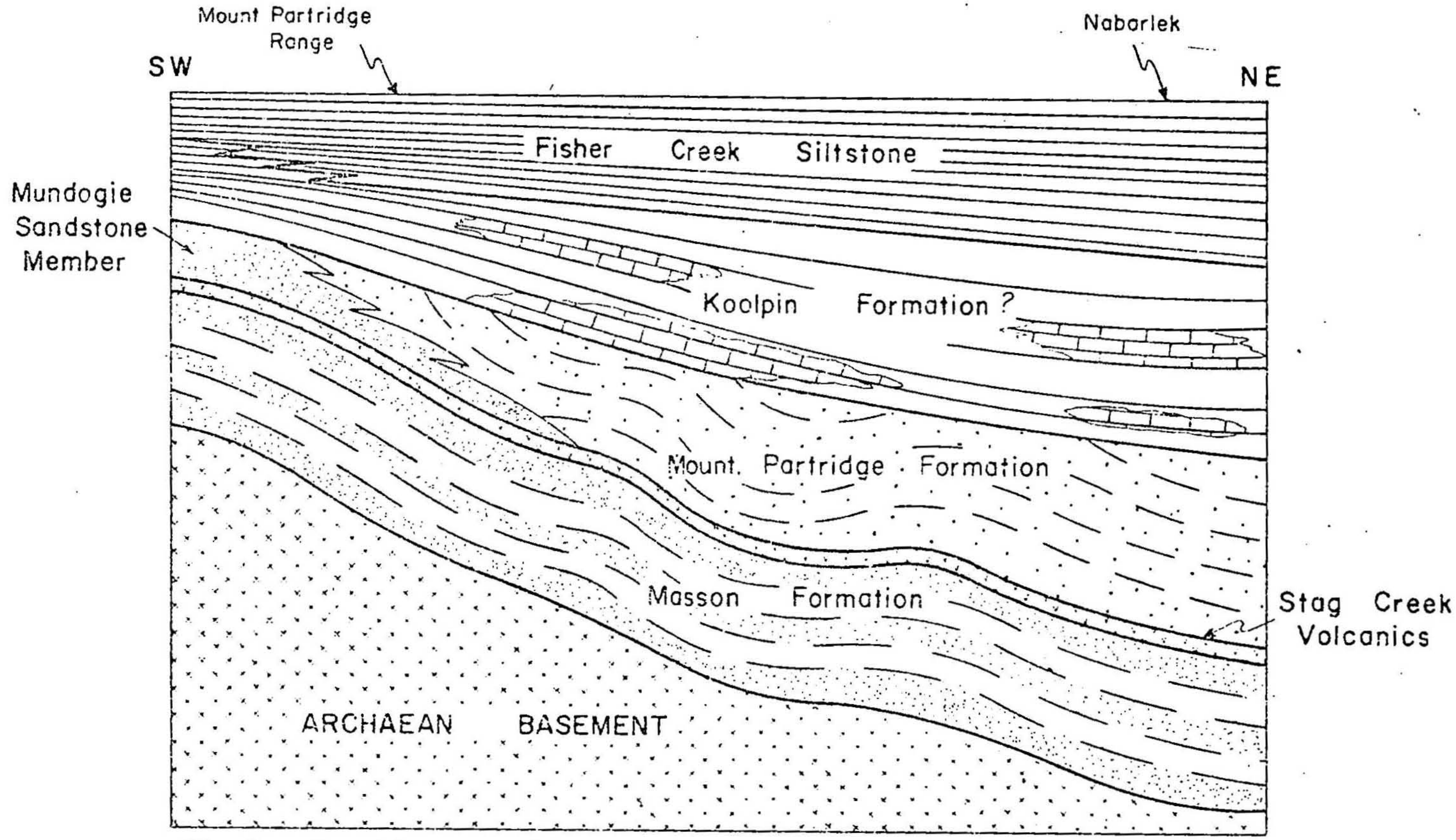


Fig. 2 Pre-Metamorphism facies diagram of the Lower Proterozoic sediments of the Alligator Rivers Region (not to scale)

To accompany Record 1974/17

D53/A1/9

The more significant uranium deposits of the Northern Territory are found in Lower Proterozoic strata of the Pine Creek Geosyncline. These rocks can be divided into two groups on the basis of regional metamorphic grade:

(a) The area between Rum Jungle and the postulated north-south fault west of Munmarlary homestead (see Fig. 3) is occupied by relatively unmetamorphosed sediments whose metamorphic grade rarely exceeds lower greenschist facies;

(b) East of this postulated fault metamorphic grade increases from lower greenschist in the south to upper amphibolite and possibly granulite facies in the northeast. Further east the Lower Proterozoic rocks are concealed by younger flat-lying sediments of the Arnhem Land plateau.

The uranium deposits at Nabarlek, Jabiluka, Ranger 1, and Koongarra all lie within the area between the postulated fault and the Arnhem Land plateau, and it is this region which is described in this paper.

The area is occupied mostly by regionally metamorphosed Lower Proterozoic sediments, some of which have been transformed into migmatite complexes by migmatization and anatexis. Granite stocks, dolerite, and phonolite* intrude the Lower Proterozoic rocks. The granite stocks were intruded before the migmatite complexes cooled. An undulating layered dolerite sheet(at least 250 m thick in places) extends discontinuously through much of the region, and is of similar age to the granite stocks.

*Note: the term "tinguaite" is sometimes used to describe the intrusive equivalent of phonolite lava (Hatch, Wells, & Wells, 1965).

Swarms of narrow phonolite dykes intrude the migmatite complexes in two areas. The phonolite and dolerite may be comagmatic.

The Lower Proterozoic rocks are unconformably overlain by the Kombolgie Formation, a generally flat-lying unmetamorphosed Carpentarian sandstone with interbedded volcanics, which forms the Arnhem Land Plateau.

Mesozoic sediments and Cainozoic sand and alluvium cover most of the Lower and Middle Proterozoic rocks in the north of the region, but are less common southwards.

Many similarities between the geology and uranium mineralization of the Beaverlodge mining area (Tremblay, 1972) and the Alligator Rivers region can be recognized.

REGIONAL GEOLOGY

Lower Proterozoic

The pattern of Lower Proterozoic sedimentation in the Pine Creek Geosyncline presented by Walpole et al., (1968) has been modified as a result of the semi-detailed mapping. The Myra Falls Metamorphics shown on the Alligator River 1:250 000 Sheet as Archaean are now recognized as metamorphic equivalents of Lower Proterozoic sediments to the south and west. The Stag Creek Volcanics, previously thought to represent an Archaean basement ridge in the Mount Evelyn 1:250 000 Sheet area, are considered to be part of the Lower Proterozoic sequence. Stratigraphic relationships between Lower Proterozoic rock units in the Alligator Rivers Region are shown in Figure 2.

The metamorphic grade of Lower Proterozoic rocks increases broadly toward the northeast from lower greenschist to upper amphibolite and possibly granulite facies, and it becomes increasingly difficult to recognize boundaries between units.

Masson Formation and Stag Creek Volcanics

The Masson Formation consists of arenites and lutites, which crop out in the southwest. Walpole et al. (1968) suggested a minimum thickness of 3600 m for the Formation. Masson and Mount Partridge Formation rocks most probably form the bulk of the parent material for the migmatite complexes, and were therefore presumably deposited over the whole of the region. The Stag Creek Volcanics appear to lie near the top of the Masson Formation, and consist of basalt and basaltic agglomerate interbedded with siltstone and arenites. The volcanics are exposed in the core of an eroded dome 8 km south of Mundogie Hill, where they are overlain, apparently disconformably, by a basal member of the Mount Partridge Formation (the Mundogie Sandstone Member). A discontinuously outcropping basic amphibolite layer within the migmatite complexes is possibly a metamorphosed equivalent of the volcanics.

Mount Partridge Formation

The Mount Partridge Formation crops out only in the southwest where coarse immature detrital sediments form the Mount Partridge Range and Mount Basedow. It is also exposed as low strike ridges and small hills. The Formation consists mainly of meta-arkose, meta-conglomerate, phyllite, and quartzite. It has been divided into five sub-units.

Sub-unit	Lithology
Ƀlp$_4$	Feldspathic quartzite, micaceous quartzite, and quartzite
Ƀlp$_3$	Phyllite and subordinate schist
Ƀlp$_2$	Conglomerate, feldspathic sandstone, and arkose
Ƀlp$_1$	Slate, phyllite, and subordinate meta-arkose
Ƀlu	Basal conglomerate, sandstone (in places cross-bedded and ripple marked), minor slate, and siltstone (Mundogie Sandstone Member).

Meta-arkose crops out as far north as Mount Badedow, where it is interlayered with biotite schist indicating at least middle greenschist facies metamorphism. Incipient quartz and feldspar augen show that the arkose was partly converted to gneiss with increasing regional metamorphism. Farther north the Formation has been incorporated in the migmatite complexes as gneiss, schist, and feldspathic and micaceous quartzites. Prominent strike ridges of feldspathic quartzite in the Nanambu Complex near Munmarlary are still recognizable as Mount Partridge Formation rocks.

Koolpin Formation?

Unconformably overlying the Mount Partridge Formation is a poorly exposed sequence of schist, amphibolite, carbonate rock, and chert, which includes the so-called 'Mine Series' at Ranger 1 and Jabiluka and the host rocks of the Koongarra and Nabarlek orebodies. It has been tentatively correlated with the Koolpin Formation, as mapped by Walpole et al. (1968) because its distinctive lithology is similar (Table 1) and its stratigraphic position apparently equivalent.

TABLE 1

Lithological comparison: Koolpin Formation in South Alligator River valley and apparent metamorphosed equivalent*

Koolpin Formation (after Walpole et al., 1968)	Koolpin Formation? (as described in this paper)
Massive algal dolomite and reef breccias near base.	Discontinuous lenses (250 m thick) of recrystallized dolomite and magnesite near base.
Carbonaceous siltstone.	Graphite schist and graphitic mica schist.
Pyritic siltstone.	Quartz-mica and quartz-chlorite schists, some with accessory pyrite.
Chert bands, lenses, and nodules	Chert lenses and bands.
Diagenetically altered dolomitic sediments.	Actinolite-talc-tremolite schist, tremolite quartzite, and quartz amphibolite.

* No stratigraphic succession is implied in this table.

The Koolpin Formation is 1500 m thick in the South Alligator River Valley, according to Walpole et al. (1968); it appears to thicken to the northeast, and reach a maximum thickness in the Alligator Rivers region of more than 3000 m.

Low strike ridges or bioherms of 'silicified dolomite', chert, and quartzite constitute the most common outcrops. In some places amphibolite crops out as foliated slabs. Schist and phyllite are exposed only in incised drainage channels. Most carbonate rock exposures are strongly silicified, and many are ferruginized, and form a characteristic yellow-brown vuggy brecciated cherty rock. Crystalline magnesite-dolomite has been intersected in a BMR drill hole 10 m below an outcrop of silicified dolomite, but unaltered carbonate rocks rarely crop out. Radiating crystals of tremolite and white fibrous talc are usually the only indications that the parent rock is a carbonate, and even these are absent from some silicified dolomite outcrops. Occasional concentric lamellar algal structures are found on weathered surfaces of the silicified dolomite, suggesting that the dolomite may be stromatolitic.

North of Koongarra, metamorphic differentiation, into felsic and mafic bands, of pelitic horizons in the Koolpin Formation? is considered to be an incipient stage of migmatization. Such rocks have therefore been included in the outer zones of the migmatite complexes. In some places the Koolpin Formation? gives rise to a strong positive magnetic feature; where this feature has been drilled, the Formation consists of feldspar-quartz-biotite schist with porphyroblasts of magnetite, garnet, and, more rarely, staurolite and kyanite, interlayered with basic amphibolite, and up to 250 m of massive carbonate rock at the base of the sequence. Magnetite porphyroblasts measuring up to 0 5 cm form as much as 20 percent of some of the schist. The presence of staurolite and kyanite in these rocks east and north of Ranger 1 indicates that low to middle amphibolite facies was reached. Retrogressive metamorphism accounts for the anomalously low metamorphic grade of the chlorite and graphite schist in the so-called

'Mine Series'. In the orebodies biotite, garnet and amphibole have been completely converted to chlorite but in the adjacent country rocks there is a gradual reduction in the intensity of retrogressive metamorphism. The 'Mine Series' rocks have also been subjected to Mg-metasomatism, as chlorite replaces potash feldspar in gneiss and pegmatite at Ranger 1 and Koongarra.

The gradational boundaries between schist and amphibolite within the Koolpin Formation? suggest that the amphibolites are of sedimentary origin. Where orthoamphibolite is recognized elsewhere in the region it has sharp contacts. The distinctive lithology and, in places, the magnetic expression of the Koolpin Formation? enable it to be traced through most of the area.

Fisher Creek Siltstone

The Fisher Creek Siltstone appears to overlie the Koolpin Formation? conformably but may also interfinger with it. The Siltstone consists of a thick sequence of lutites, very poorly exposed except in the footslope of the Arnhem Land scarp. Little more is known, as subsurface information is restricted to cuttings taken from a few auger holes. The formation is metamorphosed to slate in the extreme south of the region; farther north, toward Deaf Adder Gorge, phyllite and quartz phyllite are found except where obscurred by hornfels due to dolerite. Below the Arnhem Land scarp, 15 km northeast of Ranger 1, quartz-mica schist and mica schist with minor quartzite bands crop out. Many of the schists in the north that have been assigned to the Fisher Siltstone may equally well be part of the Koolpin Formation?, as the contact has not been clearly defined. Block faulting may account for the absence of most, if not all, of the Fisher Creek Siltstone in the north.

The thickness of the Fisher Creek Siltstone has not been established, but Walpole et al. (1968) suggested a thickness exceeding 5000 m in the South Alligator River valley.

Migmatite Complexes

Two migmatite complexes in the region, the Nanambu Complex (Needham & Smart, 1972) and the Nimbuwah Complex (Needham, Smart & Watchman, 1974), have been described using a nomenclature based on Mehnert (1968). These complexes are almost certainly connected at depth, and represent local highs or 'domes' in an irregular undulating surface of migmatization within the Lower Proterozoic sedimentary pile. Similarly the Gunbatgari Complex* in the Milingimbi 1:250 000 Sheet area may be continuous with the Nimbuwah Complex at depth.

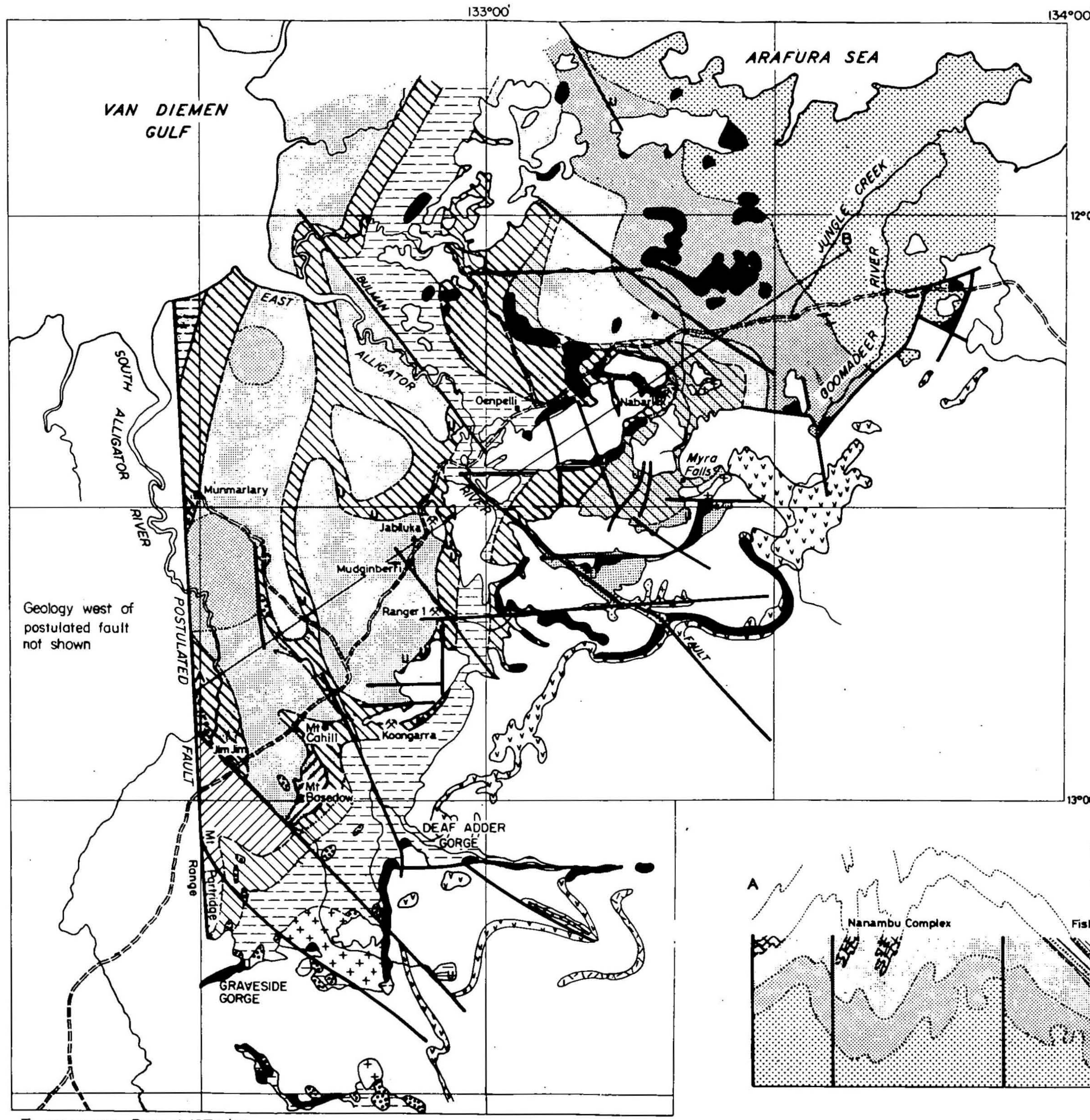
Airborne magnetic data (Horsfall & Wilkes, 1974) suggest that several migmatite 'domes', concealed by Cainozoic and Mesozoic cover, exist within the region: one, 10 km northwest of Jabiluka, has since been verified by drilling.

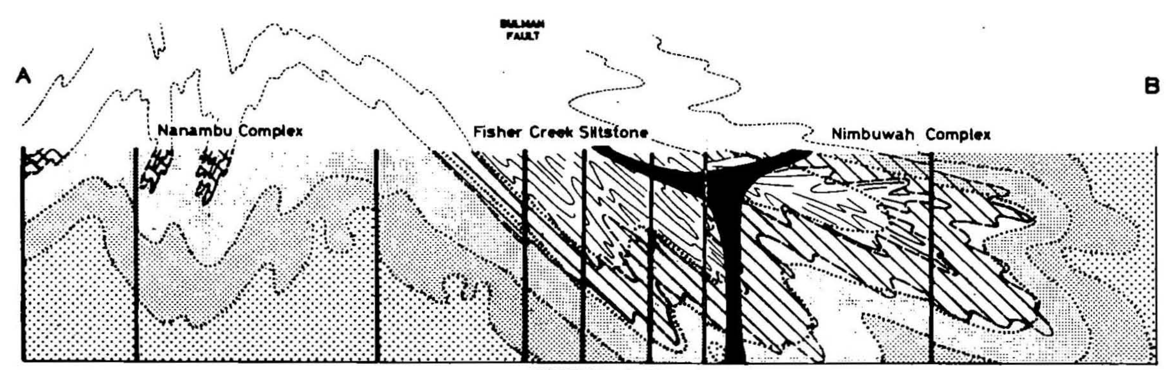
Preliminary geochronological results based on samples from both the Nanambu and Nimbuwah Complexes suggest an age of 1800 m.y. for migmatization (R. Page, pers. comm.).

* Name not yet approved.

Fig. 3

INTERPRETATIVE PROTEROZOIC GEOLOGY





SECTION A-B

To accompany Record 1974/17

NT/A/397

Some Archaean basement rocks may be incorporated in the cores of these Complexes, but the intensity of the regional metamorphism at 1800 m.y. would have obliterated the contact with Lower Proterozoic rocks.

The internal structure of the Nanambu Complex is not clear, as it is not deeply eroded, and only poorly exposed. The Nimbuwah Complex, which is better exposed, is divided into a granitoid core, migmatite zone, lit-par-lit gneiss zone, and transitional zone (see Fig. 3); each is gradational, into the next. The outer limits of the complexes are defined by the onset of metamorphic differentiation - the incipient development of compositional banding and minor pegmatoid leucosome* layers or boudins in the Lower Proterozoic sequence.

The metamorphic grade increases subtly from staurolite-almandine amphibolite in the transitional zone to sillimanite-almandine-orthoclase amphibolite or possibly hornblende granulite facies towards the granitoid core, where anatectic melting has occurred.

Exposure of both complexes is generally confined to weathered outcrop in incised creeks and isolated pavements and boulders. Deeply dissected hilly terrain, in 'windows' within the Arnhem Land Plateau south of Nabarlek, offers the most continuous fresh exposure of the complexes.

*Leucosome = leucocratic part of a migmatite, generally rich in quartz and feldspar.

Granitoid Core

Within the granitoid core of the Nimbuwah Complex, in the northeast, two distinct phases of foliated to homogeneous diatexites* displaying sharp contacts are recognized - a medium to coarse-grained pink granitoid diatexite and a porphyroblastic diatexite with euhedral feldspar laths up to 5 cm long. The composition of these rocks ranges from granite to granodiorite.

The granuloblastic texture and presence of orthoclase in many of these rocks suggest that the sillimanite-almandine-orthoclase amphibolite metamorphic sub-facies of Winkler (1965) has been reached.

Diatexites of another similar granitoid core are exposed in a 'window' in the Arnhem Land Plateau 40 km south of Nabarlek. The presumed granitoid core of the Nanambu Complex is not exposed.

Migmatite Zone

A zone of structurally complex migmatites, up to 30 km wide, surrounds the granitoid core of the Nimbuwah Complex. At its inner margin, porphyroblastic diatexite has invaded the rocks of the migmatite zone. Xenoliths several metres within the diatexite retain parallelism of their foliation with that of the parent migmatite, and suggest passive replacement rather than active displacement.

*Diatexite = rock formed by complete anatexis, i.e., melting of both mafic and leucocratic minerals of the rock.

Most of the migmatite structures described by Mehnert, (1968, pp 7-40), have been observed within this zone. Augen gneiss is largely confined to the outer margin of this zone, and appears to mark the transition to the lit-par-lit gneiss zone. The metamorphic grade of the migmatite ranges from middle to upper amphibolite facies. In the Nanambu Complex rocks of the migmatite zone are only patchily exposed.

Lit-par-lit Gneiss Zone

The lit-par-lit gneiss zone is composed mainly of biotite, muscovite-biotite and biotite-hornblende granitic gneiss, leucogneiss, basic amphibolite, feldspar-quartz-biotite schist, quartzite, and pegmatoid leucosome. These rocks also form the bulk of the exposed Nanambu Complex, which is therefore regarded as a less deeply eroded equivalent of the Nimbuwah Complex.

Characteristically, pegmatoid leucosome layers, 2-20 cm wide lie sub-parallel to the foliation of gneiss and minor schist, and to quartzite and amphibolite layers. Basic amphibolite appears to be confined to the lit-par-lit gneiss and transitional zones. The best exposure of amphibolite is found beneath the Arnhem Land excarpment 14 km east of Oenpelli Mission, where a continuous band 10 m thick can be traced for a kilometre. The granuloblastic texture and presence of relict ortho-pyroxene and garnet porphyroblasts in some of these rocks are indicative of retrogressive metamorphism. A few basic amphibolites display relict ophitic texture, indicating that at least some were pre-migmatization dolerite intrusives.

Steeply dipping recrystallized, quartzites (feldspathic and micaceous quartzite, and minor garnet quartzite) form discontinuous strike ridges and hills within the lit-par-lit gneiss and transitional zones. They are interlayered with schist and gneiss which rarely crop out. The quartzites are commonly veined by pegmatoid leucosome whose modal mineralogy closely resembles that of the host quartzite: 90% quartz, 5% muscovite, 5% feldspar, 1% tourmaline. Cross-bedding is preserved in some of the quartzites.

Foliated granitoid rocks are rare in lit-par-lit gneiss zone.

Transitional Zone

The metamorphic grade of the transitional zone is similar to that of the lit-par-lit gneiss zone, low to middle amphibolite facies.

Gneiss and pegmatoid leucosome boudins and veins make up the bulk of the lit-par-lit gneiss zone, whereas the transitional zone is composed predominantly of banded feldspar-quartz-muscovite-biotite schist, some with garnet porphyroblasts. Basic amphibolite, gneiss, quartzite, and pegmatoid leucosome are less common constituents. The fine felsic and mafic banding of the schist represents the start of metamorphic differentiation. The rocks in this zone have been only incipiently migmatized.

Intrusive Pink Granites

Pink biotite granite, typically with a high radiometric background, forms stocks up to 25 km in diameter. They include the Jim Jim Granite, the granite 7 km east of Nabarlek (intersected at Nabarlek 400 m below the ore zone), and the granite bodies 8 km southeast of

Myra Falls and 40 km east of Ranger 1. They intrude the Lower Proterozoic sequence and the migmatite complexes, and appear to represent the later stages of Wegmann's 'Granite Series' (Turner & Verhoogen, 1960, pp 386-388). Numerous other pink granites which intrude Lower Proterozoic sediments in the Pine Creek Geosyncline south and west of the region are probably of similar origin. Compston has dated these granites at 1800 m.y. (see Walpole et al., 1968).

Many of the granites are strongly altered to a quartz-clay rock containing some brown iron oxides. Aplite dykes are altered to quartz-sericite-clay rocks. The granites are all transected by approximately north-trending quartz breccias which in places form ridges.

The Jim Jim Granite is an example of a post-tectonic or late-syntectonic magma which has been squeezed from the deep zone of melting, and intruded into lightly metamorphosed rocks. The absence of a thermal aureole and the presence of quartz breccias at the margins of the Jim Jim Granite indicate that the contacts of the granite are faulted.

Other Intrusive Rocks

Intrusive rocks in the province, other than the pink granites, have been divided into two groups: (1) those intruded into Lower Proterozoic sediments before regional metamorphism and migmatization - the Zamu Complex; and (2) those intruded after migmatization - the Oenpelli Dolerite and the phonolite dykes.

21

Zamu Complex

The pre-deformation intrusives are best exposed near Graveside Gorge, where a fine-grained massive metadolerite forms a prominent ridge up to 70 m high. Elsewhere the Complex crops out as low hills of rounded in situ boulders or is indicated by red-brown soil. Some of the metadolerites have chilled margins, but none are apparently layered. The Zamu Complex generally appears to be conformable with the Lower Proterozoic strata it intrudes. Therefore the intrusions were predominantly flat-lying sill-like bodies which have been folded into their present steeply-dipping attitudes. This is broadly in agreement with the findings of Stewart (1959) in the Zamu Creek area. The petrography of the dolerites and their differentiates is described by Bryan (1962).

Where almandine amphibolite facies has been reached, the dolerites of the Zamu Complex are altered to basic amphibolite, and their contact aureoles have been obliterated. In some of the thicker amphibolite bodies, ophitic and porphyritic textures are preserved. In the south where only low to upper greenschist facies was attained, hornfelsing at the margins of metadolerites is still recognizable.

The Zamu Complex metadolerites and basic amphibolites are easily distinguishable in the field from un-metamorphosed, strongly layered post-deformation dolerite - the Oenpelli Dolerite.

Oenpelli Dolerite

The Oenpelli Dolerite extends (mostly subsurface) over an area of 20 000 km^2 in the east of the region. It is best exposed as prominent ridges up to 150 m high adjacent to the Arnhem Land scarp, and in the scree slope below the scarp. East of Oenpelli Mission and north to the coast the Dolerite crops out as low hills (some of which are capped by Lower Proterozoic metamorphics), as boulders, and as weathered rock in incised creeks. It is also exposed as prominent ridges and low hills at the bottom of deep fault-controlled gorges in the Kombolgie Formation. Generally where the Dolerite is poorly exposed its presence is indicated by distinctive red-brown soil, characteristic vegetation, and dark photo pattern. Airborne magnetic data provide further evidence of the presence of the Dolerite at depth (see Geophysics - Magnetic Interpretation).

The Oenpelli Dolerite is a sheet-like intrusion which forms a series of largely discordant ellipsoidal basins some of which are interconnected. Most of these basins have a major axis of 30-35 km and a minor axis of 10-15 km, and are believed to be lopoliths. According to Grout (1926), this would suggest that they are 500-1500 m thick. At Nabarlek, near the eastern edge of one of the basins, the Dolerite is 250 m thick. The dip of the Dolerite, rarely exceeds 20°, and normally ranges from 5° to 15°.

The intrusions are almost symmetrically layered (see Fig. 4). Igneous lamination is common in the ophitic dolerite and ophitic gabbro, but compositional banding is rare.

The following differentiation sequence is recognized for the Oenpelli Dolerite: olivine basalt porphyritic olivine dolerite → ophitic dolerite → ophitic gabbro → granophyric dolerite → sodic syenite → sodic granophyre. This series indicates an alkali basalt parent magma.

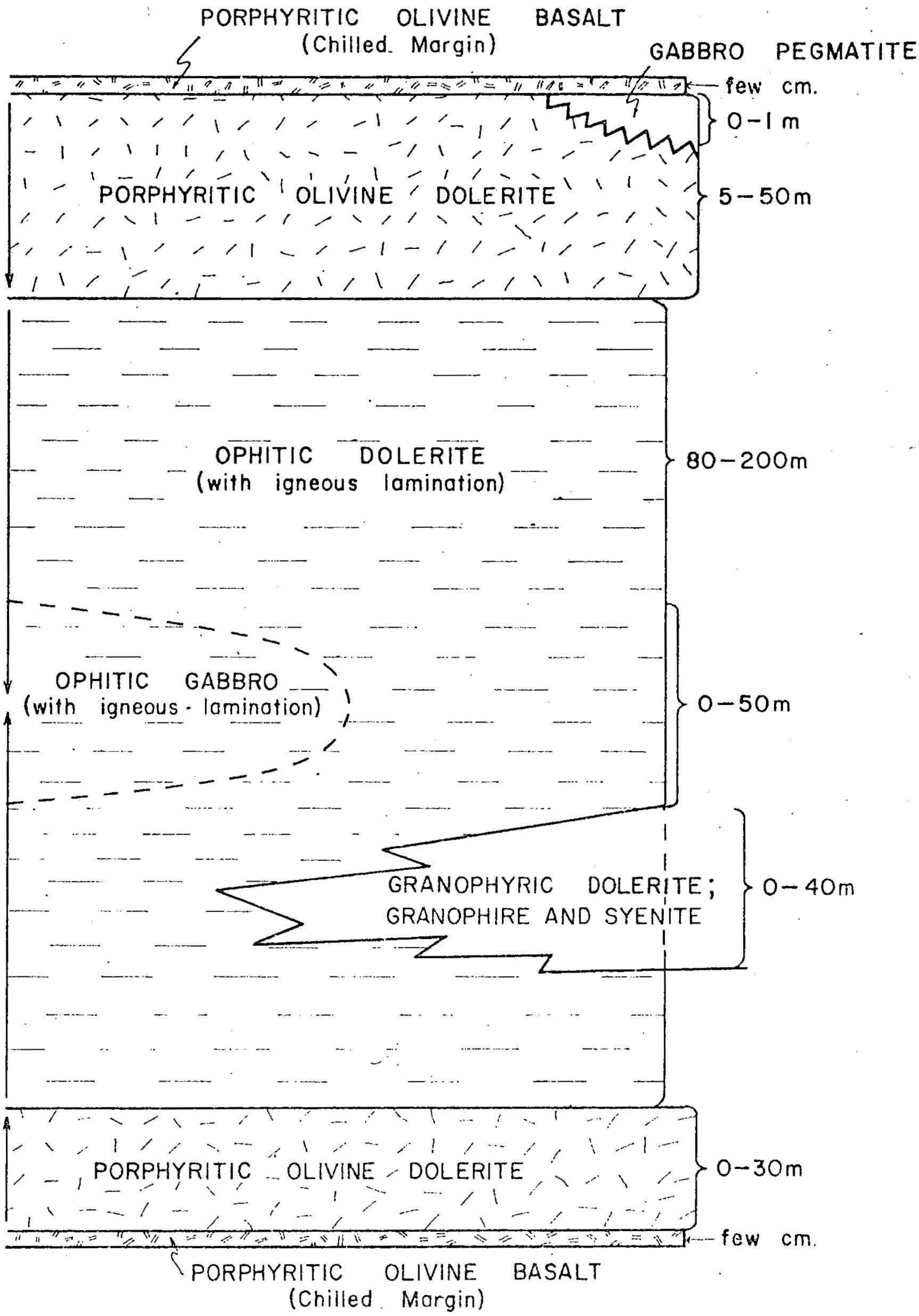


Fig. 4 Schematic diagram showing the internal structure of the Oenpelli Dolerite. Arrows indicate direction of increase in grain size of groundmass

To accompany Record 1974/17 M(S)195

In places a high-temperature contact aureole surrounds the Dolerite, and its margins contain pyrometamorphosed xenoliths of the country rock. Generally, however, the aureole reaches only the albite-epidote-hornfels facies, probably as a result of high prevailing PH_2O in the host rocks. Where the Dolerite intrudes the central zones of the migmatite complexes, the result is Fe, Mg - metasomatism rather than thermal metamorphism, suggesting that the temperature of the host rocks was still high, and they were relatively mobile. Where the dolerite intrudes the Jim Jim Granite a similar effect is observed.

A slickensided chloritic serpentinite commonly occurs at the upper margin of the Dolerite.

Phonolite Dykes

Steeply dipping phonolite dykes near the headwaters of Jungle Creek (Maningkorrirr Phonolite*) and near Mudginberri homestead (Mudginberri Phonolite*) rarely exceed 1 m in width and 1 km in length. They have narrow chilled margins, but no thermal aureoles.

The phonolites are dark greenish-grey, commonly porphyritic, fine-grained rocks. Phenocrysts include large euhedral sanidine and anorthoclase laths, small hexagonal nepheline prisns, and dark green acicular prisms of aegirine. The sodic peralkaline character of these rocks suggests that they may have been derived (by magma segregation and differentiation) from the alkali basalt parent magma of the Oenpelli Dolerite. Edwards (1938) has reported two distinct series in the evolution of an alkali basalt magma on the Kerguelen archipelago, which yield both

* Name not yet approved.

saturated (sodic rhyolite) and undersaturated (phonolite) differentiation products.

CARPENTARIAN (MIDDLE PROTEROZOIC)

Kombolgie Formation

The Kombolgie Formation forms an extensive, deeply dissected, sandstone plateau, (whose western edge is the Arnhem Land excarpment.

The region was virtually peneplaned after the Lower Proterozoic to form a gently undulating land surface with some prominent hills, ranges, and ridges such as Mount Cahill, the Mount Partridge Range, and discontinuous ridges of Zamu Complex and Oenpelli Dolerite. The Kombolgie Formation was deposited in a series of wide shallow depositional basins between such prominences, many or all of which, were ultimately completely covered by sandstone. Erosion has now exposed a number of these hills and ridges within the Arnhem Land Plateau itself, and away from the main escarpment, where more of the sandstone has been removed, wide corridors of Lower Proterozoic rocks separate outliers of sandstone from the main plateau (e.g., the Oenpelli and Mount Brockman massifs).

The Formation mostly consists of flat-lying to gently dipping coarse-grained porous quartz sandstone, pebbly quartz sandstone, conglomerate, and minor siltstone, quartz greywacke, and tuffaceous bands. The Nungbalgarri Volcanic Member, a continuous horizon of basalt, amygdaloidal basalt, andesite, tuff, and intercalated cherty sediments up to 80 m thick, divides the formation into lower (Phk_1, up to 300 m thick) and upper (Phk_2, up to 200 m thick) sandstone members. Narrow vertical basalt dykes in the volcanic member are the only rocks known to intrude the Kombolgie Formation. The Gilruth Volcanic Member* a thin (5m) intercalation in Phk_2, consists of lateritized tuff and tuffaceous siltstone. The laterite displays anomalous radioactivity apparently due to uranium. Outcrop of the member is continuous between the headwaters of the Goomadeer River and the South Alligator River.

Sandstone throughout the Kombolgie Formation is commonly cross-bedded and ripple-marked, and was probably deposited in a shallow lacustrine environment. Few measurements of cross-bedding directions have been made, but the main current appears to have been from the north.

Sandstone of the Kombolgie Formation is metamorphosed only locally: thermally at the top of Phk_1 by the basalt flows, and in fault planes where it is closely jointed, and has been converted to quartzite.

MESOZOIC

Upper Cretaceous fossiliferous clayey and poorly consolidated quartz sandstone and siltstone crop out extensively as low lateritized scarps north of Nabarlek and near the East Alligator River estuary. The sequence thickens northwards, and consists of a deltaic facies (Marligur Member) which grades into a marginal marine facies (Moonkinu Member) farther north (Hughes & Senior, 1973). Lower Cretaceous lacustrine sediments (Mullaman Beds, up to 50 m thick) have been intersected by drilling below thickly timbered areas of the Koolpinyah Surface (Story et al., 1969) in the north, between the East and South Alligator Rivers.

* Name not yet approved.

27

CAINOZOIC

Cainozoic sediments form a veneer over the plains between the Arnhem Land escarpment and the coast; talus slopes and colluvial sand lie on and adjacent to the Arnhem Land Plateau. Cainozoic deposits have been divided into laterite, late Tertiary sand, talus, and Quaternary continental and marine sediments.

Laterite is commonly developed on low lying exposures of pre-Cainozoic rocks of the province, apart from the Kombolgie Formation. The laterites are generally either truncated remnants of the standard laterite profile described by Whitehouse (1940) or detrital in origin.

Late Tertiary sand is coarse unconsolidated clayey quartz sand, which forms the Koolpinyah Surface. It was probably deposited as a fan and derived mainly from Mesozoic and Carpentarian units. Cainozoic sand on the Arnhem Land Plateau has been deposited continuously since the Early Tertiary. Large talus slopes are developed against the Arnhem Land escarpment, where the base of the Kombolgie Formation is exposed. Scree mostly conceals the unconformity below the Kombolgie Formation but quite commonly small cliff-like exposures are found at the top of the talus slope, below an overhang formed by preferential erosion of the Lower Proterozoic rocks. The talus is composed mostly of large blocks of Kombolgie sandstone up to 20 m across but pebbles or shards of the underlying rocks are commonly present.

Quaternary continental sediments include alluvial silt, sand, and clay deposited along rivers and creeks, and in abandoned river channels; silty levee deposits along the banks of major rivers; and black humic soils deposited in poorly drained depressions within drainage systems.

Quaternary marine sediments include coastal deposits of silt and clay, clay pans, and beach ridges. Beach ridges have developed parallel to the present coast, and less commonly at the edge of the inner margin of the coastal plain adjacent to the higher-level Late Tertiary sand deposits.

GEOPHYSICS

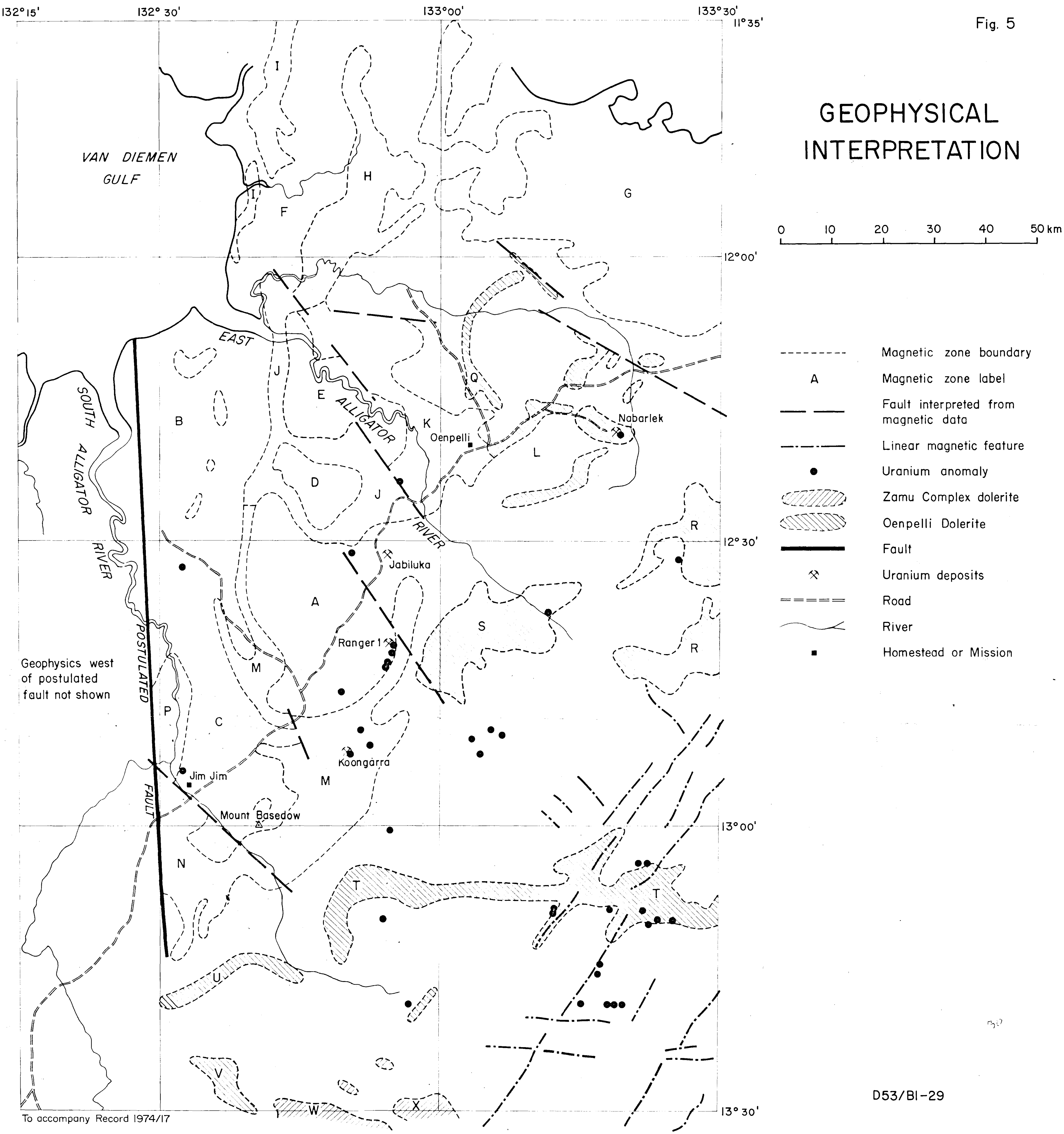
Magnetic Interpretation

The aeromagnetic data acquired during the BMR 1971/2 airborne survey have been interpreted by Horsfall & Wilkes (1974); a simplified interpretation is given here. The area has been divided into zones of different magnetic character which are interpreted in terms of different rock types. Many of the anomalies are of shallow or surface origin, and their correlation with geological units has helped considerably in tracing these units beneath the extensive overburden that covers much of the area to the north and west of the Arnhem Land excarpment. Some of the correlations between magnetic zones and geological units will doubtless be modified as further work is done. Those quoted here represent the ideas at the time of writing. The main magnetic zones are shown in Figure 5.

29

Fig. 5

GEOPHYSICAL INTERPRETATION



Zones A, B, C, D, E, and F

These six zones are all characterized by low-amplitude anomalies (generally less than 30 gammas). Zones A, B, and C correlate well with lit-par-lit gneiss and migmatite zones of Nanambu Complex, known respectively as the Magela Mass, Munmarlary Mass, and Jim Jim Mass. It appears likely from the magnetic data that the two latter masses are continuous beneath swampy ground. The low magnetic relief makes it difficult to determine directly the boundaries of zones A, B, and C, but some may be inferred by mapping the more magnetic formations marginal to the areas of Nanambu Complex. It does not appear possible to define the western boundary of the Munmarlary Mass (zone B) or the northeastern boundary of the Magela Mass (zone A) in this way. Zones D and E are of similar magnetic character to A, B, and C, and are interpreted as further areas of Nanambu Complex. This is supported by results from shallow drilling. Zone F, on the northern side of the East Alligator River, appears to be a continuation of zone B.

Zone G

Zone G is a highly complex magnetic zone comprising many individual anomalies whose amplitudes range from about 50 to 200 gammas. The area covered by the zone corresponds to parts of the migmatite zone and granitoid core of the Nimbuwah Complex; a number of exposures of Oenpelli Dolerite mapped within this zone, especially in the southern part, coincide with magnetic anomalies. The magnetic interpretation suggests that the Dolerite is considerably more extensive than mapped, and is probably the main source of many of the anomalies in this zone. A smaller contribution is possibly due to granitic rocks within the Complex.

Zones H and I

Zones H and I are moderately magnetic with anomalies up to about 200 gammas. The eastern boundary of zone H is quite sharp, and very close to the western edge of the Kombolgie Formation. There is very little outcrop within these zones, and geological correlation is therefore difficult. The most likely causes of the anomalies are amphibolites and magnetite schists of the Koolpin Formation?, with possibly some contribution from the Oenpelli Dolerite.

Zone J

Zone J consists of a narrow north-south linear section, and an area which surrounds Zone D. Anomaly amplitude ranges from about 350 gammas in the north to about 100 gammas in the south. Drilling in the northern part of the zone has intersected up to 200 m vertical thickness of Oenpelli Dolerite. A shallow drill hole farther south intersected no dolerite, but about 40 m of magnetite schist. Zone J is attributed to Oenpelli Dolerite together with amphibolite and magnetite schist of the Koolpin Formation?

Zone K

Zone K consists of a number of anomalies with amplitudes up to about 100 gammas. Throughout the zone there are a number of outcrops of Oenpelli Dolerite. Oenpelli Dolerite has also been found in auger holes together with Fisher Creek Siltstone. The Dolerite is probably more extensive than mapped from surface outcrop, and is likely to be the main source of magnetic anomalies in this zone.

Zone L

Zone L consists of a magnetically flat area almost completely ringed by linear magnetic anomalies (the three shaded areas which surround the label 'L' on Figure 5). These anomalies correlate very well with exposures of Oenpelli Dolerite which are geologically interpreted as forming the outer parts of a lopolith mostly covered by Kombolgie Formation sandstone, and extending from near Oenpelli Mission to just east of Nabarlek. This is consistent with interpretation of the magnetic data, which show pronounced negative anomalies close to the northern edge of the intrusion, and pronounced positive anomalies close to the southern edge. From the form of these anomalies it appears that the lopolith is remanently magnetized in a direction approximately opposite to the earth's present magnetic field direction.

Zones M, N, and P

The magnetic character of zones M, N, and P appears to be mainly attributable to the presence of Koolpin Formation? and Zamu Complex dolerite. In Zone N there is probably an additional effect from the Mount Partridge Formation.

Zone M corresponds to part of the transitional zone of the Nanambu Complex. The Ranger 1 uranium deposit lies close to the edge of this zone, and the Koongarra deposit well within it. Individual anomalies within the zone have amplitudes up to about 300 gammas.

Zone N is separated from Zones M and P by a fault along Jim Jim Creek. Anomalies range up to about 150 gammas, and trend approximately north-south. This probably reflects the orientation of the dolerite rather than the trends in the Koolpin Formation?

Zone P is elliptical, and its long axis trends north-south. It consists mainly of two strong positive anomalies (up to 500 gammas) aligned in that direction, and converging at either end of the zone.

Zones Q, R, S, T, U, and V

Oenpelli Dolerite appears to be the principal source of the magnetic anomalies in these six zones. The maximum anomaly amplitude is 150 gammas for zones S, U, and V, and 100 gammas for Zones Q, R, and T. The form of some of the anomalies indicates that some of the Dolerite is likely to be remanently magnetized.

Zones W and X

Zones W and X, and two small unlabelled zones immediately to the north, appear to correlate with Zamu Complex dolerite. Anomaly amplitudes range up to 200 gammas in Zone W, and 130 gammas in Zone X.

Linear Magnetic Features

In the southeastern corner of the area there are a number of linear magnetic anomalies, most of which are aligned approximately southwest. A smaller number of anomalies are aligned west and northwest. The magnetic data indicate that the linear magnetic features, which in many places coincide with fractures in the Kombolgie Formation, are probably due either to basement ridges of dolerite beneath this Formation or infilling of the fracture system by younger dolerite. They appear to extend close to the surface, and may crop out, but as yet none has been observed.

Faults

Only faults interpreted from the magnetic data are shown in Figure 5, except for the postulated fault that has been taken as the western boundary of the area under discussion, and is not apparent from the magnetic data.

Radiometric Interpretation

Airborne gamma-ray spectrometry has been used very successfully in the area, and led to the direct discovery of the uranium deposits of Nabarlek, Ranger 1, and Koongarra. It has also indicated other prospective areas for ground work, and provided information on the radiometric characteristics of the various rock types exposed in the area.

The radiometric data produced by the BMR 1971/2 survey are of a regional nature and of low sensitivity. The combination of 1.5 km flight-line spacing with 150 m ground clearance produced no more than 40 percent ground coverage. The spectrometer was calibrated against a Radium-226 source, and has a sensitivity of 58 counts per second per micro-roentgen per hour. (This applies to the 'total count' channel, which was set to record in the energy range 0.84 to 3.00 Mev.) Use of this sensitivity figure makes possible comparison of results with other such calibrated systems.

The main radiometric results are:-

(1) Many radiometric anomalies have been located and analysed. Considering the extensive overburden (particularly away from the escarpment) the number detected is possibly surprising.

(2) 37 anomalies have been classified as 'uranium anomalies', and are shown on Figure 5. These include anomalies over Nabarlek, Ranger 1, and Koongarra, over various prospects, and over areas with anomalously high uranium to thorium ratios, but with probably no economic importance. Jabiluka was not detected by the BMR survey.

(3) Anomalously high radioactivity has been detected over Mount Basedow and over the pink biotite granites.

(4) Four major groups of thorium anomalies have been delineated.

(5) Certain formations are only very weakly radioactive. These include the non-volcanic members of the Kombolgie Formation and the Zamu and Oenpelli dolerites.

Uranium anomalies

Anomalies have been classified as uranium anomalies if:

1. Potassium is not the major contributor to the radioactivity; and
2. The ratio of the count rate in the 'uranium channel' (1.60-1.90 Mev) to that in the 'thorium channel' (2.40-2.80 Mev) is four or greater.

Non-geological contributions to these count rates were subtracted before computing this ratio. The ratio of four corresponds to a uranium to thorium compositional ratio of about 1.5, provided that equilibrium is achieved within the uranium and thorium series.

Data obtained over the major uranium deposits are summarized in the following table.

Deposit	Maximum Total-Count Intensity (Counts per second)	Maximum Ratio of Count Rates in 'Uranium' and 'Thorium' Channels	Ground Clearanc (Metres)
Nabarlek	700	14	110
Ranger 1	1460	15	110
Koongarra	345	11	90

Ranger 1 was detected on four flight lines. Nabarlek and Koongarra were each detected on only one flight line.

In the southeast there is a group of uranium anomalies high up on the Arnhem Land plateau, close to the eastern end of magnetic Zone T. Ground checking showed that most of these anomalies are in laterite down-slope from the Gilruth Volcanic Member of the Kombolgie Formation. Measurements made on the ground show radioactivity up to about 25 μR/h (microroentgen per hour), except for one anomaly where radioactivity up to 170 μR/h was recorded. Ground radiometric measurements indicated high uranium to thorium ratios, but these are probably due to low thorium rather than high uranium content. These anomalies are likely to be surface features only, and not of economic importance.

Other uranium anomalies located on the plateau occur in laterites developed from the Nungbalgarri Volcanics (Kombolgie Formation) and in an inlier of Fisher Creek Siltstone

Mount Basedow is a prominent radiometric feature, with count rates up to 770 counts/s recorded in the airborne data. Radioactivity is due to potassium and thorium in arkoses and conglomerates of the Mount Partridge Formation.

Figure 3 shows five areas where pink biotite granites are exposed. They are all radioactive, and produced anomalies up to 300 counts/s. Their radioactivity is due mainly to potassium and thorium.

Four major groups of thorium anomalies were delineated:

(1) About 20 km northeast of Oenpelli. This group is probably associated with laterites;

(2) In and adjacent to the northwest corner of magnetic zone A. These are within the Nanambu Complex;

(3) About 15 km southwest of Mount Basedow in Lower Proterozoic sediments;

(4) In the extreme southeast in sandstone and conglomerate of the Lower Cretaceous Mullaman Beds.

STRUCTURE

Within the region the poorly exposed Lower Proterozoic sediments are regionally metamorphosed, intensely folded, and commonly faulted. The intensity of folding increases broadly from southwest to northeast - i.e., with increase in regional metamorphism (see Fig. 6). In the extreme south, bedding is still recognizable in the slightly metamorphosed Lower Proterozoic sediments, which are openly folded about northwest-trending axes. Elsewhere, where beds are isoclinally folded, bedding appears to be almost parallel to the foliation. Lithological differences within the metamorphic sequence provide evidence of bedding direction in areas of high-grade regional metamorphism, and so Lower Proterozoic bedding trends

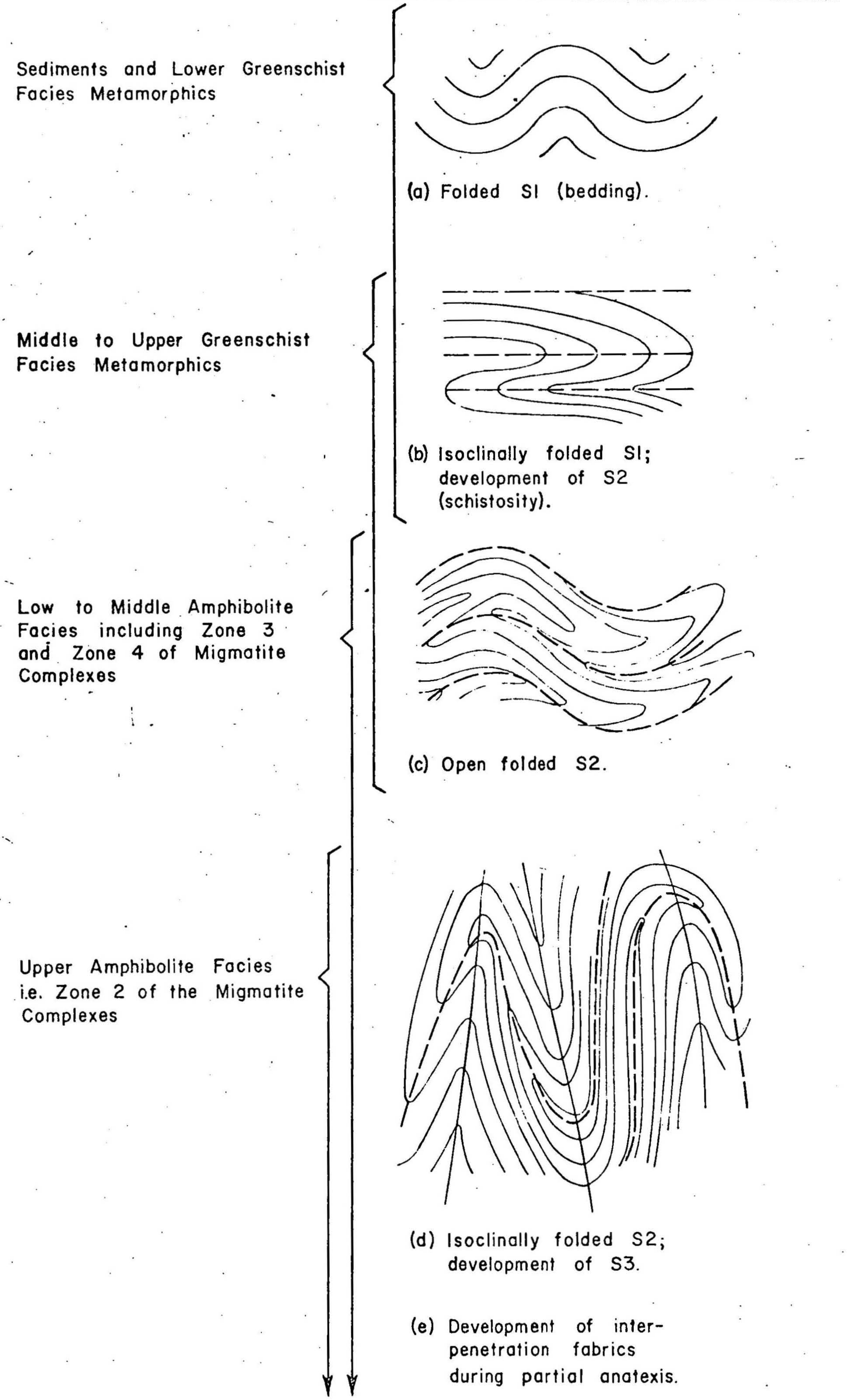


Fig. 6 Progressive fold styles with increasing regional metamorphism of the Lower Proterozoic sediments

can be traced into the transitional zone and parts of the lit-par-lit gneiss zone of the migmatite complexes. In these zones relict cross-bedding in quartzite indicates that some beds are overturned. The Lower Proterozoic sedimentary units cannot be traced within the migmatite zone or granitoid core because new rock fabrics have developed through partial and complete anatexis.

Walpole et al. (1968) considered that the region occupies the subsidiary eastern trough of an intracratonic basin, the Pine Creek Geosyncline. Our work suggests that it lies within the major trough of Lower Proterozoic deposition. The regional metamorphic grade of the Lower Proterozoic formations suggests increased depth of burial toward the northeast. Thicknesses of sediment calculated from drilling or outcrop width, together with measured dips, indicate that the sequence is thickening toward the east; though beds may be repeated in isoclinally folded sequences.

The distribution of the Koolpin Formation?, determined largely from airborne magnetics and drilling, indicates that the Lower Proterozoic sediments have been updomed at numerous centres, intensely folded, and anatectically melted at depth to produce the migmatite complexes.

Alternatively the complexes may have formed mantled gneiss domes, similar to those in Finland (Eskola, 1948), rejuvenated about 1800 m.y. ago: and sediments which abutted or were draped over them were migmatized to such an extent that the Archaean/Lower Proterozoic unconformity is no longer recognizable. The degree of regional metamorphism of Lower Proterozoic sediments provides the best evidence against such a theory. In the north, Koolpin Formation? rocks are metamorphosed to kyanite-almandine amphibolite grade. This indicates considerable depth of burial, and cannot be explained entirely by thermal metamorphism of a reactivated dome.

Haller (1956, vide Mehnert, 1968, p. 279-280) recognizes four genetic stages of progressive mechanical mobility of migmatite complexes: dome→diapir→nappe→mushroom. The Nanambu Complex is considered to be a 'migmatite dome', and the Nimbuwah Complex a more advanced stage, probably a 'migmatite nappe' (see cross section, Fig. 3). Overturning and recumbent folding of Koolpin Formation? rocks in the transitional and lit-par-lit gneiss zones on the western side of the Nimbuwah Complex provide evidence for this structure.

The pink granites represent the latest stages in the tectonic cycle after formation of the migmatite complexes. Distribution of these high-level stock-like intrusions, however, appears to be random, i.e., unrelated to the centres of migmatization.

Before the migmatite complexes or the granites cooled, the Oenpelli Dolerite was intruded. Interpretation of airborne magnetic data suggests that the Dolerite forms several basins rather than a continuous undulating sheet intruded from a single igneous centre. At the margins of some of these basins the Dolerite thins and even divides to form numerous narrow stringers (a few cm wide), providing further evidence that each basin is a separate intrusion. Marked petrological and structural similarities between the dolerites in the basins suggest that they were all derived from the same magma by multiple phases of injection. The sub-horizontal attitude of the Dolerite probably indicates that the magma was intruded to a certain level before spreading laterally, being controlled largely by load pressure and the hydrostatic pressure of the magma. Sagging of the floor-rocks under the load of the horizontal sheets produced lopoliths.

Phonolite dyke swarms which intrude both Nanambu and Nimbuwah Complexes were probably also intruded at this time. Their distribution is not understood.

Folding

In addition to the major folding, a phase of broad open folding and possible updoming after deposition of the Mount Partridge Formation may have influenced subsequent Lower Proterozoic deposition. Since the Lower Proterozoic era, the region has been tectonically stable and the generally flat-lying Kombolgie Formation has been subjected to only gentle very broad folding mostly about northeast axes. Cretaceous sediments have not been folded, but the region has since been epeirogenically uplifted and possibly tilted.

Jointing

Jointing is common in all Precambrian rock-types in the region, but is most obvious in the Kombolgie Formation. Erosion along joint planes in this Formation produces steep gorges and abrupt escarpments, and gives rise to a distinctive photo-pattern. The most prominent sets of joints in the Kombolgie Formation trend east, northeast, north, and northwest.

Faulting

Faults are numerous. Many are recognized only as photolinear features, disruption or truncation of airborne magnetic patterns, and mylonite zones, or may be represented at the surface by ridges of quartz breccia. Displacements are seldom measurable, but wrench, reverse, and normal faults have been identified. Their relative importance is unknown, but some northwest-trending wrench faults could have displacements of several kilometres. Vertical displacements in the Kombolgie Formation of up to 200 m have been measured.

The most prominent fault directions are similar to the major joint directions in the Kombolgie Formation (northwest, northeast, east, and north). Faulting appears to have been a slow discontinuous process, old faults being reactivated possibly several times. Some major faults such as the Bulman Fault (which can be traced for 400 km from the Gulf of Carpentaria to the Van Diemen Gulf) appear to do little more than fracture the Kombolgie Formation. The development of fault-breccia and sympathetic close jointing in the Kombolgie Formation adjacent to the structure provide the only evidence that it is a reactivated fault.

A postulated north-trending hinge fault bounds the western side of the region. This structure is inferred to account for the abrupt drop in the regional metamorphic grade to the west of the region. At the northern end of the fault the grade drops from middle or upper amphibolite facies in the east to lower greenschist facies to the west; southwards the change in grade becomes less pronounced.

Although no change in the magnetic pattern across the structure is indicated on the airborne magnetic maps of Horsfall & Wilkes (1974), a regional gravity survey by Whitworth (1970) revealed a marked change in the intensity of Bouguer anomaly features across the postulated fault. East of the fault, in the 'Oenpelli Gravity Complex', he noted a gradual increase in the average Bouguer anomaly northwards. The region, therefore, probably represents an up-faulted block with maximum uplift in the north. The South Alligator Fault Zone probably defines the southern edge of this block; its northern and eastern extents are not known.

ECONOMIC GEOLOGY

Uranium

Four major uranium deposits and numerous partly tested prospects have been found in the region since the beginning of 1970 (see Fig. 3). Most of these were first detected as airborne radiometric anomalies in areas of Lower Proterozoic outcrop or subcrop, generally close to the Arnhem Land escarpment. Other airborne anomalies detected are due to concentration of uranium in laterite or black soil. On the plains north and west of the Arnhem Land escarpment, prospecting is hampered by thick Cainozoic and Mesozoic cover.

Ore genesis is still a matter of contention. Although a simple syngenetic origin is not favoured for these deposits, it is most probable that the ultimate source of the uranium was an Archaean basement, and that uranium was deposited in sediments of the Pine Creek Geosyncline. The uranium may have originally been concentrated and precipitated in a reducing environment, and deposited in carbonaceous or carbonate sediments, or both. Processes likely to have concentrated uranium further to form ore deposits are listed below in order of preference.

(a) Uranium was mobilized by migmatization of Lower Proterozoic sediments, and deposited where a heterogeneous sequence of rocks provided suitable chemical and physical interfaces for its precipitation. Parts of the Koolpin Formation? are considered to have been a suitable host rock. Subsequent development of dilatant zones (e.g., fault-breccia zones and collapse structures in carbonate rocks) are likely to have provided further suitable environments for uranium deposition. The presence of several phases of chlorite in the uranium deposits is considered to be an indication of the influence of hydrothermal solutions, or circulating groundwater, or both.

(b) The anomalously radioactive pink intrusive granites and comagmatic acid volcanics such as the Edith River Volcanics exposed southwest and south of the region are alternative or, more probably, additional sources of uranium. Neither unit, however, appears extensive enough, nor are they close enough to known deposits of the region to be considered the major sources of uranium.

(c) Another hypothesis which has been considered involves the leaching of uranium from a massive overlying source rock such as the Kombolgie Formation, a sequence composed of sandstone, conglomerate, and two interbedded volcanic layers. With prolonged interstratal migration, sufficient mineralizing solution might have penetrated permeable zones below the unconformity to form ore deposits under suitable conditions. No evidence for such a process has been found, and some facts that cast doubt on this genesis are:

(i) The uranium content of the Kombolgie Formation is very low; (ii) the volcanics are not a suitable source, as they are basic rather than acidic; and (iii) in the major deposits, minerals not normally found in supergene deposits (e.g., gold, pyrite, galena, and chalcopyrite) are present.

45

Boulders of sandstone from the Kombolgie Formation containing secondary uranium minerals are found at the Jabiluka and Nabarlek deposits, but these minor occurrences are attributed to secondary migration of uranium from the strongly mineralized rocks beneath. Similarly, chloritization of the Kombolgie Formation at the Ranger 1, Koongarra, and Jabiluka deposits is believed to be merely an indication that vadose solutions have at times risen above the unconformity.

Dating of pitchblende and galena from the ore deposits of the province by Hills (pers. comm., 1972) has yielded ages ranging from 1800 to 450 m.y. This suggests that the mineralization dates back at least to the formation of the migmatite complexes. The younger dates suggest that there have been several periods of ore concentration and mobilization since 1800 m.y.

All major uranium deposits and most of the prospects lie within the same heterogeneous sequence of rocks considered to be equivalents of the Koolpin Formation. At least two horizons of the unit appear to contain anomalous concentrations of uranium, and in places contain ore-grade concentrations. The lower one, at the base of the Formation, includes Ranger 1 and a few minor prospects. The other is believed to be about 2000 m higher in the section, and includes the Jabiluka and Koongarra deposits and several prospects. Nabarlek may also be in this horizon. The deposits and most prospects also have other important factors in common:

they lie within the transitional zone of migmatite complexes;
they lie within or adjacent to post-migmatization structures - brecciated fault-zones, shear-zones, or faulted collapse structures;
their host rocks show pronounced retrograde metamorphism - e.g., basic amphibolite → chlorite schist. Quartz-chlorite schist,

massive haematite-chlorite rock, and less commonly, graphitic schist are the major host rocks.

Other common characteristics of the deposits which are probably coincidental include the presence of the Oenpelli Dolerite in or near most deposits, and the spatial distribution of the deposits adjacent to the Arnhem Land escarpment. The dolerite forms an extensive sheet in the eastern part of the region; it is inevitable that it will be found near all prospects in that area. The dolerite is not considered as a possible source of uranium, but may have provided structural traps to mineralizing solutions at some of the deposits (e.g. Nabarlek), or caused mobilization of uranium.

Other Minerals

As yet uranium is the only metal discovered in significant quantities in the region. Minor base metal sulphides and gold occur in the uranium ore lodes. Gold has also been found in the basal conglomerate of the Kombolgie Formation near Jabiluka, but its distribution within this unit is erratic. Quartz-breccia reefs 11 km southwest of Nourlangie Safari Camp contain lead-zinc-copper sulphide mineralization, and other minor occurrences of base metals have been noted throughout the province. Small quantities of alluvial tin derived from minor cassiterite-bearing pegmatite veins are still mined north of Myra Falls.

REFERENCES

BERKMAN, D.A., 1968 - The geology of the Rum Jungle uranium deposits. In Symposium: Uranium in Australia. Melbourne, Aust.Inst.Min.Metall. 12-31.

BRYAN, R., 1962 - Lower Proterozoic basic intrusive rocks of the Kathernie - Darwin area, Northern Territory. Bur.Miner.Resour.Aust. Rec. 1962/7 (unpubl.).

EDWARDS, A.B., 1938 - No. 2 Tertiary lavas from the Kerguelen Archipelago. B.A.N.Z. Antarctic Expedition 1929-1931, Rep., Ser.A, pt 5, 72-100.

? Grout on p. 16

GRANT, F.F., 1926 - Internal structures of igneous rocks, with special reference to the Duluth gabbro. J.Geol, 26, 439-58.

HALLER, J., 1956 - Probleme der Tiefentektonik. Bauformen im Migmatit-Stockwerk der ostgronlandischen Kalidoniden. Geol.Rdsch., 45, 159-67.

HATCH, F.H., WELLS, A.K., & WELLS, M.K., 1965 - Petrology of the Igneous Rocks. London, Murby, 12th edn.

HORSFALL, K.R., & WILKES, P.G., 1974 - Aeromagnetic and radiometric survey of Cobourg Peninsula, Alligator River and Mt. Evelyn (part) 1:250,000 Sheet areas N.T., 1971/72. Bur.Miner.Resour.Aust.Rec. (unpubl in prep.).

HUGHES, R.J., & SENIOR, B.R., 1973 - Progress report on the geology of the Bathurst Island, Melville Island, Cobourg Peninsula and Fog Bay 1:250 000 Sheet areas, N.T. Bur.Miner.Resour.Aust.Rec. 1973/52 (unpubl.).

MEHNERT, K.R., 1968 - MIGMATITES AND THE ORIGIN OF GRANITIC ROCKS. Amsterdam, Elsevier.

NEEDHAM, R.S., & SMART, P.G., 1972 - Progress report Alligator River Party N.T., 1971. Bur.Miner.Resour.Aust.Rec. 1972/1 (unpubl.).

NEEDHAM, R.S., SMART, P.G., & WATCHMAN, A.L., 1974 - Alligator River Party N.T., Progress report, 1972 - Oenpelli Region. Bur.Miner. Resour.Aust.Rec. (unpubl., in prep).

STEWART, J.R., 1959 - Proterozoic igneous rocks of the Katherine - Darwin region, Northern Territory. M.Sc.Thesis, Univ.of New England.

STORY, R., WILLIAMS, M.A.J., HOOPER, A.D.L., O'FERRAL, R.E., & McALPINE, J.R., 1969 - Summary description of the Adelaide-Alligator area; in Lands of the Adelaide-Alligator area, N.T., C.S.I.R.O. Land Res. Ser. 25.

TAYLOR, J., 1968 - Origin and controls of uranium mineralization in the South Alligator Valley. In Symposium : Uranium in Australia Melbourne, Aust. Inst.Min.Metall., 32-44.

TREMBLAY, L.P., 1972 - Geology of the Beaverlodge Mining Area, Saskatchewan. Geological Survey of Canada Mem. 367.

TURNER, F.J., & VERHOOGEN, J., 1960 - Igneous and Metamorphic Petrology. New York, McGraw-Hill, 2nd Edn.

WALPOLE, B.P., CROHN, P.W., & RANDAL, M.A., 1968 - Geology of the Katherine-Darwin Region, Northern Territory. Bur.Miner.Resour.Aust. Bull 82.

WHITEHOUSE, F.W., 1940 - Studies in the late geological history of Queensland. Pap.Dep.Geol.Uni.Qld, 2(1).

WHITWORTH, R., 1970 - Reconnaissance of Gravity of parts of Northern Territory and Western Australia, 1967. Bur.Miner.Resour.Aust.Rec. 70/15 (unpubl.).

WINKLER, H.G.F., 1965 - PETROGENESIS OF METAMORPHIC ROCKS. Berlin, Springer-Verlag.