DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1973/208

ALLIGATOR RIVERS REGION ENVIRONMENTAL FACT-FINDING STUDY

GEOLOGICAL AND GEOPHYSICAL REPORTS

by

R.S. Needham, P.G. Wilkes,
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by

R.S. Needham and P.G. Wilkes

SUMMARY

The Alligator Rivers Region is of particular economic importance because of the discovery of several major uranium deposits between 1969 and the present. Since 1971 the Bureau of Mineral Resources (BMR) has been particularly active in the area, carrying out geological and geophysical surveys. Geological work has included semi-detailed mapping to produce 1:100 000 scale geological maps of the Alligator Rivers Uranium Field. The main geophysical work has been an airborne magnetic and gamma-ray radiometric survey flown in 1971/2. This report also includes some results from airborne work done in 1957 in and around the South Alligator River valley.

The study area consists of ancient (Lower Proterozoic) sediments, deposited about 2000 million years ago, which were metamorphosed about 1800 million years ago to produce schist, migmatite, gneiss, and granitic rocks. The gneiss and granitic rocks have been mapped as 'migmatite complexes' (the Nanambu and Nimbuwah Complexes), which occupy most of the northern part of the study area. These Lower Proterozoic rocks are intruded by dolerite and phonolite (basic to intermediate igneous rocks), and are overlain by Carpentarian (1800-1400 m.y.) sandstone (Kombolgie Formation), which forms the Arnhem Land Plateau and covers most of the eastern and southeastern part of the study area. Mesozoic sandstone and siltstone, deposited about 100 million years ago, cover parts of the north and extreme east of the study area. Sand, alluvium, soil, and laterite were deposited between 60 million years ago and the present, and mantle almost all of the study area between the escarpment and the coast. This superficial material severely reduces the amount of outcrop available for geological mapping, and also considerably reduces the intensity of gamma radiation reaching detectors on or above the surface. One metre of cover is commonly sufficient to totally absorb radiation from below, and thus considerably reduces the effectiveness of radiometric surveys. Therefore, the relatively small number of anomalies over the Northern Plains do not accurately reflect its subsurface geology. The magnetic method, on the other hand, is little affected by overburden, and is thus particularly valuable in defining the extent of some of the underlying geological units.

The principal geophysical results are shown on the 1:250 000 scale interpretation map in the geophysical section of this report (Part 3). Interpretation of the magnetic data has been facilitated by dividing the the area into zones of different magnetic character, which have helped to determine the extent of different rock types. It has been particularly useful in mapping the Koolpin Formation and also its metamorphic

equivalents, which in places form the outer part of the Nanambu Complex. A second major use of the magnetic data has been to show that dolerites are considerably more widespread than originally mapped, and to enable numerous isolated outcrops to be interpreted as parts of large bodies clearly continuous in the subsurface.

The airborne radiometric results have identified areas of higher than average radioactivity, and have provided an indication of the predominant source of the radioactivity, i.e., whether it is due to uranium, thorium, or potassium. The survey detected a large number of anomalies, forty of which are predominantly due to uranium, and these are described in detail in the geophysical section of this report. They include known uranium deposits, known and possible prospects, and areas where the proportion of uranium is unusually high (relative to thorium and potassium), but probably not of economic importance. It is not possible from airborne data alone to assess the economic importance of radiometric anomalies.

The results of the geological mapping, together with the geophysical interpretation, have been used to outline the areas of greater uranium potential. The factors chosed to designate these areas depend partly on present ideas on the origin of the uranium mineralization.

Geological, aeromagnetic, and aeroradiometric information obtained during the last three years suggests that metamorphosed equivalents of the Koolpin Formation have had an important influence on the localization of uranium mineralization, and that parts of the formation - especially carbonaceous beds - may also have been host rocks for the deposition of uranium at the time of sedimentation.

In places, especially on the eastern side of the Nanambu Complex, rocks considered to be equivalents of the Koolpin Formation lie within or close to the marginal zone of the Complex, and contain the Ranger 1, Koongarra, and Jabiluka uranium deposits. Elsewhere, they have been completely engulfed in the Nimbuwah and Nanambu Complexes, and in this situation they are also regarded as haveing uranium potential (the Nabarlek deposit is thought to be an example of a lode emplaced in this environment). It is probable, also, that the outer and marginal zones of the Complexes which enclose metamorphosed equivalents of the Koolpin Formation are favourable places for uranium mineralization, for any uranium expelled from the Koolpin Formation during transformation of the sediments to schist, gneiss, migmatite, and granite may have migrated outwards and been concentrated there.

All deposits and prospects discovered to date lie within Lower Proterozoic metamorphic rocks, and mineralization appears to be predominantly within 300 m below the unconformity at the base of the Carpentarian rocks. The dolerites and plateau sandstone of the study area are considered to lack uranium potential, but Mesozoic and younger units do have a potential for relocated uranium deposits.

The 1971/2 airborne survey did, however, locate a series of uranium anomalies on top of the Arnhem Land Plateau. Ground inspection revealed that they were associated with laterite developed down-slope from volcanic members within the plateau sandstone, predominantly the Gilruth Volcanic Member. This unit is thin (less than 5 m), and rock material from it does not appear to be anomalously radioactive.

Gold and tin have been produced from time to time in small quantities, but the deposits appear to be insignificant, as are minor occurrences of copper noted in the area.

A demand for construction materials needed in the impending development of the area has led to examination of rock exposures for suitable sources of rock aggregate. Dolerite, phonolite, and quartzite (in that order) are the preferred rock types for crushing, and drilling of some dolerite exposures is under way. There are adequate reserves of sand and laterite gravel for construction purposes in the area.

Almost all of the study area, including the Lower Proterozoic rocks beneath the Kombolgie Formation, must be regarded as having considerable potential for further uranium discoveries.

PART 2 - GEOLOGY AND ECONOMIC POTENTIAL

by

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

INTRODUCTION

Survey Methods

Since 1971 a field party consisting of three geologists has spent five months each year conducting traverses by vehicle and on foot to examine and record all rock exposures in the survey area. A helicopter was used to reach otherwise inaccessible exposures on the Arnhem Land Plateau. Aerial photographs were used to locate likely areas of rock exposure, and also for navigation. An auger-drill rig capable of drilling to weathered bedrock was used to gather additional geological information where rock exposure is sparse.

Scout holes up to 70 m deep were drilled (using a rotary-percussion rig) in some areas of thick Cainozoic and Mesozoic cover to obtain fresh samples of the underlying rock for isotopic dating and other laboratory studies.

At the end of each field season, detailed interpretation of aerial photographs incorporating all field observations was carried out. 1:16 000 scale black and white photographs were generally used, but 1:25 000 scale colour photographs were used as they became available.

The detailed photo-interpretation was plotted onto 1:50 000 scale topographic bases redrawn from corrected RASC bases at the same scale. These maps, accompanied by a progress account of the work, have been or will be issued in the BMR Record series. Field checking of a small area in the southwest part of the study area will be carried out in 1974. Coloured geological maps at 1:100 000 scale will be prepared, and a report covering the area mapped to 1974 will be written soon after.

Previous Geological Investigations

The first reported geological observations of the study area were by Leichhardt (1847), who traversed the central part of the area in the final stages of his overland trek from Moreton Bay to Port Essington in 1844. He described the sandstone scarp known today as the Arnhem Land Escarpment, which is the dominant relief feature of the study area.

Brown (1908) was the first geologist to visit the area. He was aboard the steamship Federal conducting a coastal reconnaissance from Van Diemen Gulf to the McArthur River. He landed in the South Alligator River estuary in September 1907, and described rocks cropping out west of the river mouth; he correlated them with Precambrian rocks previously described in the Brocks Creek/Pine Creek area.

Gray (1915) made several traverses around Oenpelli in 1914-15. He divided the rocks into Precambrian, Permo-Carboniferous, and Cretaceous, and recorded some igneous rocks to which no age was assigned. He regarded the plateau sandstone as Permo-Carboniferous in age by analogy with information obtained elsewhere on the Arnhem Land Plateau, and reported by Brown (1908) and Jensen (1914). Gray discovered minor cassiterite-bearing quartz veins near Myra Falls; alluvial tin is still produced intermittently in small quantities from this locality.

In 1946, a CSIRO Land Research survey of the Katherine-Darwin region covered part of the study area. L.C. Noakes, of BMR, accompanied the survey team, and produced a reconnaissance geological map based mostly on photo-interpretation (Noakes, 1949).

The discovery of uranium at Rum Jungle in 1949 prompted regional investigations by BMR officers (financed jointly by BMR and the Australian Atomic Energy Commission) with the primary objectives of locating further uranium deposits and assessing the mineral potential of the Katherine-Darwin area. The investigations resulted in the discovery of the South Alligator uranium field and the ABC uranium prospect (both south of the study area discussed in this report). Detailed work by private companies (mainly United Uranium N.L.) followed in the South Alligator area, where exploration has continued spasmodically up to the present time.

BMR geologists completed regional mapping of the Katherine-Darwin region in 1958. Geological maps at 1:250 000 scale, accompanied by Explanatory Notes, were published for the whole region, and more detailed maps were produced of areas of special interest.

Geophysical surveys by BMR were conducted in parts of the Alligator River and Mount Evelyn Sheet areas between 1955 and 1957. The results of a gravimetric survey were reported by Langron & Stott (1959), and of an airborne radiometric survey by Livingstone (1958).

A BMR Bulletin on the Katherine-Darwin area was published in 1968 (Walpole, Crohn, Dunn & Randall); this gave a general appraisal of all the information gathered since 1950. The rocks occupying most of the study area were described as sediments deposited within a Lower Proterozoic geosyncline flanked by Archaean metamorphic rocks (the Myra Falls Metamorphics) east of the East Alligator River. The plateau sandstone (named the Kombolgie Formation) was considered to be of Adelaidean age.

In 1970, exploration for uranium by Queensland Mines Ltd led to the discovery of Nabarlek, a high-grade uranium deposit. Subsequent intensive exploration resulted in the discovery of the Ranger 1, Koongarra, and Jabiluka uranium deposits.

In 1971, BMR began a semi-detailed mapping program to cover the newly discovered 'Alligator Rivers Uranium Field', whose extent almost coincides with the study area covered by this report. Needham & Smart (1972) and Needham, Smart & Watchman (in prep. a, in prep. b) have described the first two years' work covering the Cahill, East Alligator, Wellington Range, and Junction Bay 1:100 000 Sheet areas and parts of the Goomadeer, Oenpelli, Jim Jim, and Mundogie 1:100 000 Sheet areas. Mesozoic strata mostly to the north of the study area were mapped by another BMR field party in 1972 (Hughes & Senior, 1973).

Complementary geophysical investigations have also been undertaken: airborne radiometric and magnetic surveys were made by BMR in 1971-72, and preliminary maps at 1:100 000 scale are available (Horsfall & Wilkes, in prep.); and a ground gravimetric traverse was made in 1972 (Wronski, in prep.)

Intensive investigations by mineral exploration companies are continuing, and their reports are lodged annually with the Mines Branch of the Department of the Northern Territory.

GENERAL GEOLOGY

The study area is occupied by a sequence of Lower Proterozoic rocks intruded by granite, dolerite, and phonolite, which are overlain by Carpentarian sandstone and interbedded volcanics (the Kombolgie Formation) in the east and south. Mesozoic sandstone (the Mullaman Beds) and Cainozoic sand and alluvium cover most of the Lower Proterozoic and Carpentarian rocks in the northern part of the study area, but are much less common in the south.

The geology of the study area is shown at 1:250 000 scale on Plate 1. The generalized geological map (Fig. 1) presented here is partly interpretative, for it depicts mainly the older rocks and does not show the full extent of the superficial cover of sand, soil, alluvium, and laterite.

Lower Proterozoic Rocks

The Lower Proterozoic rocks grade from unmetamorphosed sedimentary rocks in the west of the area to intensely metamorphosed rocks in the central and northeastern parts. The sedimentary rock units, which were deposited more than 2000 million years ago, are the Mount Partridge Formation, overlain by a probable equivalent of the Koolpin Formation, overlain by the Fisher Creek Siltstone.

Mount Partridge Formation: The Mount Partridge Formation, the oldest of the three units, forms the Mount Partridge Range and intermittent strike ridges and hills near Jim Jim Creek and Mount Cahill. Five subunits have been recognized: a basal sequence of sandstone (in places cross-bedded and ripple-marked) containing minor siltstone beds and a basal conglomerate (the Mundogie Sandstone Member); a sequence of siltstone, slate, and phyllite, together with minor arkose; a sequence of coarse conglomerate and feldspathic sandstone; a sequence of phyllite and minor schist; and a sequence of feldspathic sandstone and quartzite.

The Mount Partridge Formation is underlain by altered basaltic rocks at Mundogie Hill. Previous workers regarded these volcanics (the Stag Creek Volcanics) as Archaean in age, but they are more probably interbedded with the Lower Proterozoic sedimentary sequence, and lie in a stratigraphic position at the top of the Masson Formation (exposed south and west of the study area), which immediately underlies the Mount Partridge Formation.

The Mount Partridge Formation dips regionally to the east at

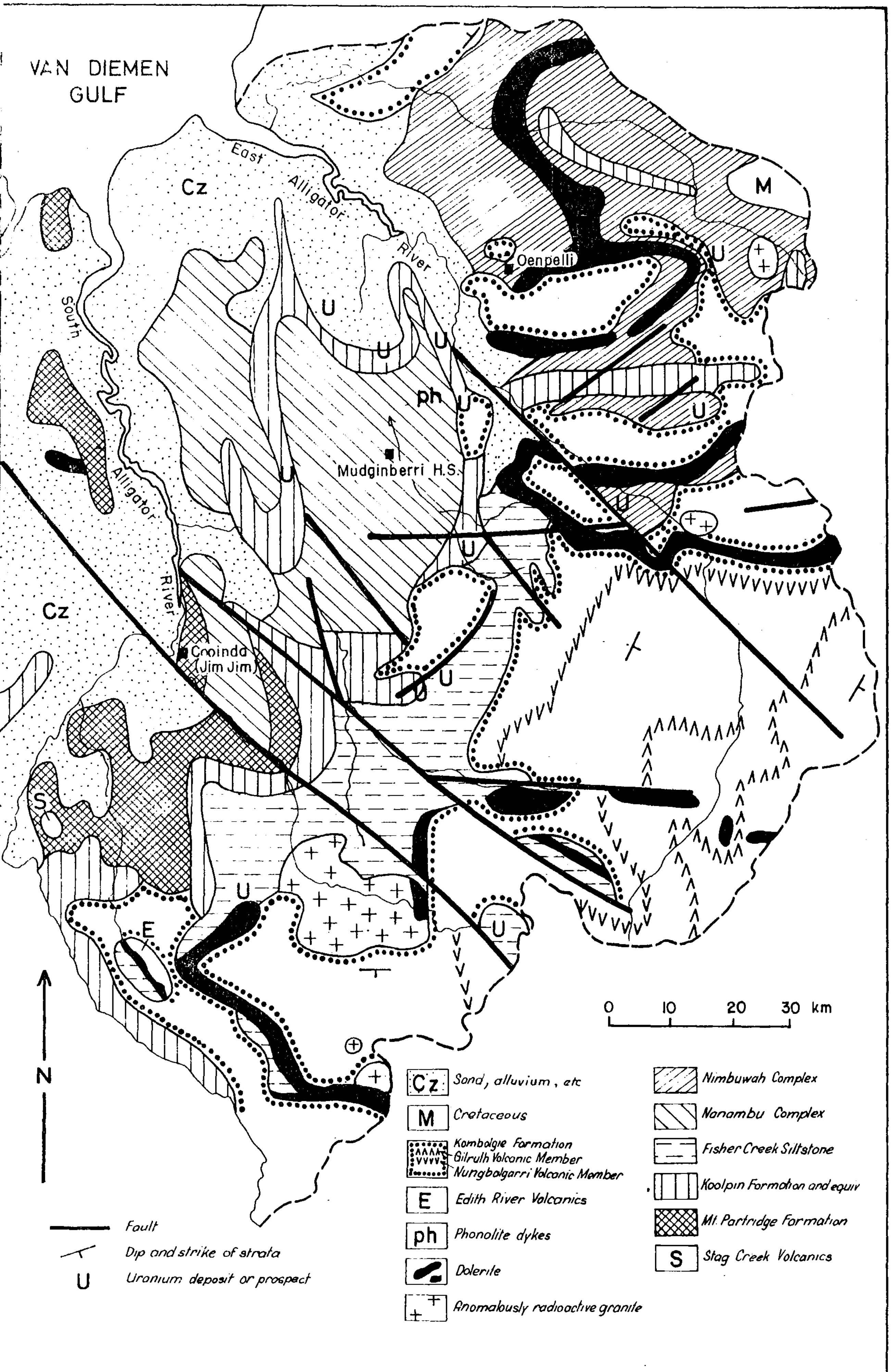

Figure 1. Generalized geological map of Alligator Rivers Region

To accompany Record 1973/208 D53/A1/10

about 40°. Arkose belonging to the formation crops out as far north as Mount Basedow, and near Patonga homestead. Feldspathic quartzite near Cooinda and Munmarlary, and west of the South Alligator River, are probably equivalents of the formation.

The formation was deposited in a shallow marine shelf or near-shore environment. Biotite schist bands within metamorphosed arkose and sandstone at Mount Basedow reflect middle greenschist facies metamorphism; recrystallized arkose at the same locality closely resembles granite, and crops out as rounded pavements and boulders in creeks.

Koolpin Formation: The Koolpin Formation crops out as a series of prominent strike ridges, up to 70 m high, southwest of the Mount Partridge Range, but elsewhere is poorly exposed. The rocks exposed southwest of the Mount Partridge Range are interbedded phyllite and chert which characteristically weather to a strong red-brown colour. Elsewhere, probable equivalents of the Koolpin Formation - schist, quartzite, and carbonate rock (dolomite and magnesite) - crop out as rare strike ridges up to 5 m high on the Northern Plains (Figure 2) and as low exposures adjacent to the Arnhem Land escarpment. Deep weathering and silicification have altered most of the exposures of carbonate rock to a yellow-brown cherty quartz-veined rock, termed 'silicified dolomite'; it is usually strongly ferruginized, and recognizable by the presence of a white fibrous talcose mineral. Fresh coarsely crystalline magnesite has been intersected by drilling 10 m below a silicified dolomite outcrop west of Nanambu Creek. Concentric laminar structures seen on some weathered surfaces of the silicified dolomite are probable algal stromatolites (Fig. 3).

Fisher Creek Siltstone: The Fisher Creek Siltstone is a fairly homogeneous succession of phyllite, quartz-chlorite-muscovite schist (Fig. 4), and minor quartzite, which crop out in and at the top of the footslope of the Arnhem Land scarp, and rarely as ferruginized schist rubble on the Northern Plains.

Regional metamorphism of the Lower Proterozoic sedimentary rocks: The degree to which the sedimentary formations have been metamorphosed by heat and pressure increases to the northeast, where they are represented by a series of lower to upper greenschist facies rocks. At higher grades of metamorphism, the leucocratic (lighter-coloured) minerals in the rocks have segregated from the melanocratic (darker) minerals, and form lighter pods or bands of quartz and feldspar in a darker matrix. This process is known as 'metamorphic differentiation', or 'migmatization', and is an early stage in the complete melting (or 'anatexis') of rock with increasing temperature and pressure. In some places, especially in the Nimbuwah Complex (see below), the transformation has been so intense that the rocks closely resemble granite.

Thus the first appearance of quartz-feldspar pods or bands in the metamorphosed rocks is an important feature, in that it delineates the outer margins of the most highly altered areas which have been named the Nanambu and Nimbuwah Complexes (Fig. 1). These Complexes are 'migmatite complexes', and were formed about 1800 million years ago.

The Complexes grade into the surrounding metamorphosed sedimentary rock units. The true thickness of the transitional zone is probably less than 5 km, but outcrop widths range up to 20 km, depending on whether the dip of the transitional zone is steep or shallow.

The quartzite and carbonate rocks of the Koolpin Formation equivalent are more stable mineralogically than the interbedded siltstone and the rocks of the Fisher Creek Siltstone. They are thus less susceptible to metamorphic differentiation, and can be traced continuously into the Complexes, where they reflect metamorphic grade in only their textures and coarser grainsizes; on the other hand, the siltstone has been completely changed to gneiss and migmatite. This observation proves that the Complexes were formed by migmatization and partial melting of Lower Proterozoic sedimentary rock units. The central more granitic parts of the Complexes are possibly Archaean, and formed basement highs upon which the sedimentary rocks were deposited unconformably. These granitic rocks were also migmatized and partially melted along with the Lower Proterozoic sediments, and thereby incorporated into the Complexes.

Nanambu and Nimbuwah Complexes: Rock exposure within the Complexes is generally very poor (less than 5%), and is mostly confined to the banks and beds of small incised creeks and isolated small rounded 'pavements' scattered through the countryside (Fig. 5). The deeply dissected hilly terrain of the Myra Falls and Caramal East Inliers within the Arnhem Land Plateau offers the only continuous fresh exposure of the Complexes anywhere in the study area.

Fig. 2. Lower Proterozoic quartzite (Koolpin Formation equivalent), 2 km west of Mount Cahill. Neg. GA5857

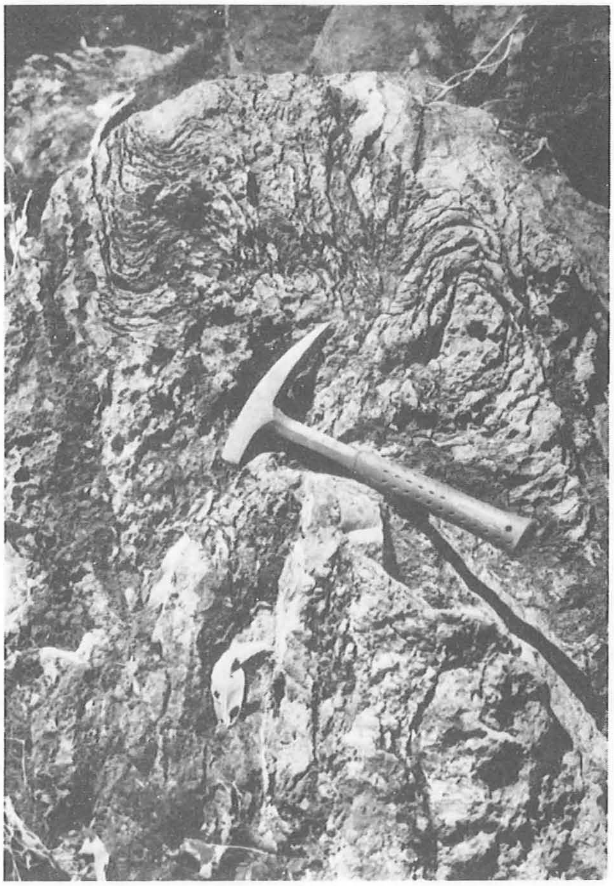

Fig. 3. Concentric laminar algal? structures in steeply dipping ferruginized and silicified dolomite, 22 km southeast of Munmarlary H.S. Neg. GA5863.

Fig. 4. Typical exposure of unconformity at the base of the Kombolgie Formation; sandstone of the Kombolgie Formation overlies isoclinally folded quartz-mica schist of Fisher Creek Siltstone, 9 km east of Mudginberri H.S. Neg GA5853

The Complexes form broad low topographic domes over which dendritic drainage patterns are developed. The Nanambu and Nimbuwah Complexes are similar in many respects, and may be united at depth. Aeromagnetic patterns suggest that there are several small subsurface bodies of migmatite between the two Complexes; these smaller bodies are represented by magnetic 'lows', as are the major parts of the Complexes.

The rocks of both Complexes are similar mineralogically: mostly medium to coarse-grained rocks of gneissic (banded) to granitic texture. They consist of feldspar, quartz, and biotite (black mica), with or without hornblende, and are commonly porphyritic (i.e., containing large feldspar crystals). Various configurations of the mineral grains give rise to a variety of rock structures, and on this basis the rocks of the Complexes are classified.

The cores of the two Complexes are composed of foliated and non-foliated rather homogeneous granitic rock - the Granitoid Core (Fig. 5) - which is surrounded by a belt of heterogeneous and structurally complex rocks (the Migmatite Zone - Figs. 6 and 7). The Migmatite Zone grades outwards into augen gneiss, which forms part of the Lit-par-lit Gneiss Zone (Fig. 8). Augen gneiss is characterized by large aggregates of quartz and feldspar around which the other minerals (mainly biotite) are aligned. Lit-par-lit gneiss consists of quartz-rich and feldspar-rich bands alternating with dark biotite-rich bands; with fewer and fewer quartz-feldspar bands it grades outwards into schist, phyllite, and arkose of the surrounding Lower Proterozoic sedimentary rock units. Where exposed the Nanambu Complex is composed predominantly of rocks typical of the Lit-par-lit Gneiss Zone, and is therefore regarded as a somewhat lower-grade and less deeply eroded equivalent of the Nimbuwah Complex, which consists mainly of rocks of the type here designated as Migmatite Zone and Granitoid Core.

Anomalously radioactive granites: A group of altered pink biotite granites typically having high radiometric backgrounds (see Table 1) crops out throughout the study area as bosses up to 25 km in diameter. The group includes the northern and southern extensions of the Jim Jim Granite, and granites 10 km east of Nabarlek, 7 km east of Myra Falls, and 5 km east of Caramal.

The granites are characteristically altered to quartz-clay-iron oxide rocks, but still retain granitic appearances. They are all transected by approximately north-trending quartz-breccia 'reefs', which stand out as positive relief features but are not anomalously radioactive.

The granites intrude the sedimentary units and the Nimbuwah Complex, and are thought to have been formed by complete melting of rocks deep within the Complex.

Basic and intermediate intrusive rocks: Dolerite of different ages intrudes the Lower Proterozoic rocks of the study area.

The so-called Zamu Complex consists of dolerite intruded into the Lower Proterozoic rocks before the migmatite complexes were formed. The Complex is best exposed near Graveside Gorge, where it forms prominent ridges up to 70 m high and is composed of homogeneous fine-grained, dark grey, altered dolerite. It crops out poorly within the migmatite complexes as isolated blocky 'pavements' or weathered exposures in incised creeks, or just as isolated cobbles lying on the surface. Zamu Complex rocks near the margins of the migmatite complexes commonly retain a doleritic texture, and are thus termed metadolerite; in those nearer the centre of the migmatite complexes, doleritic texture has been obliterated, and the mineralogy changed to that of an amphibolite. The amphibolite is everywhere strongly foliated; the foliation is similar to that of the surrounding gneiss and migmatite. Some outcrops are composed of interlayered metadolerite and amphibolite.

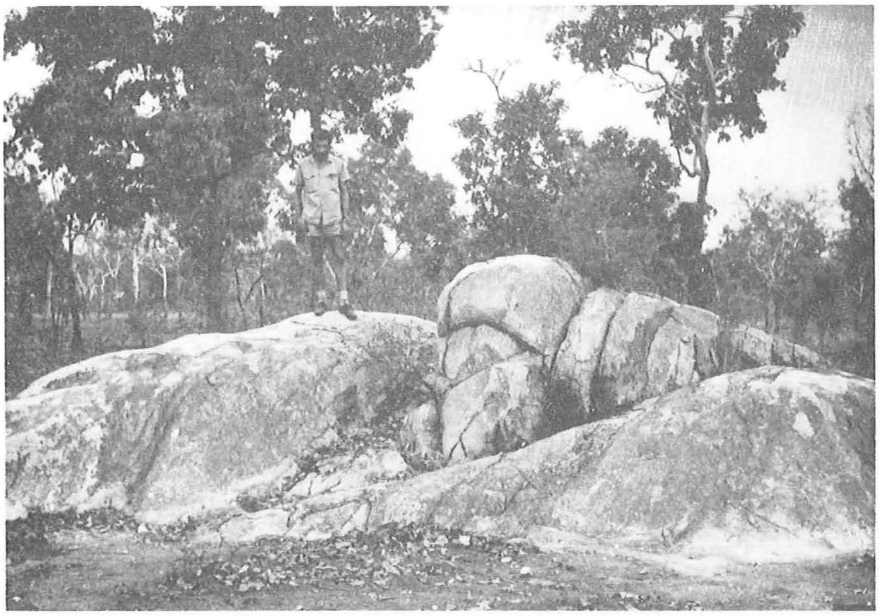

Fig. 5. Foliated homogeneous granitic rock, Nanambu Complex, 10 km southeast of Nourlangie Safari Camp. Neg. GA5850

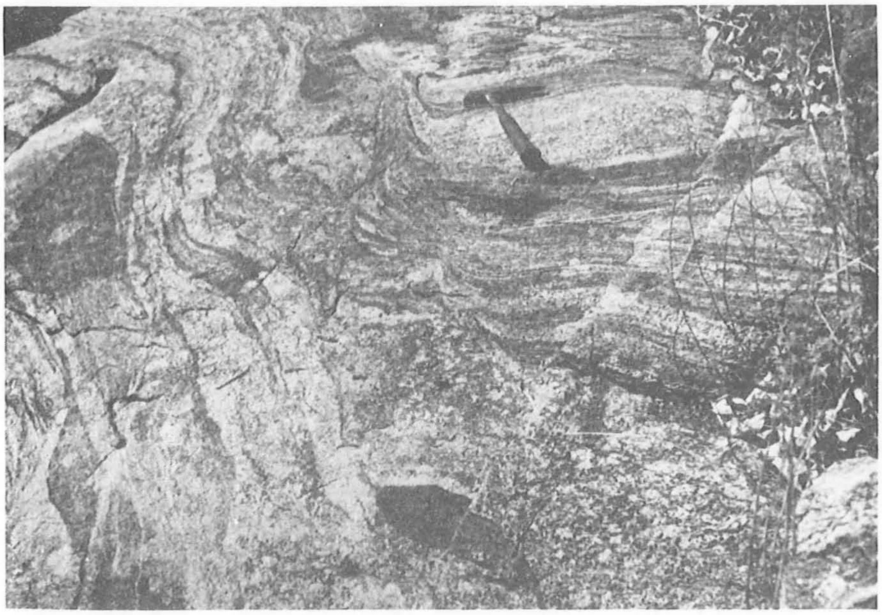

Fig. 6. Migmatite in the Migmatite Zone, Nimbuwah Complex, 30 km northeast of Nabarlek. Neg. GA8631

Fig. 7. Folded migmatite in the Migmatite Zone, Nanambu Complex, 5 km southeast of Munmarlary. Neg GA5856

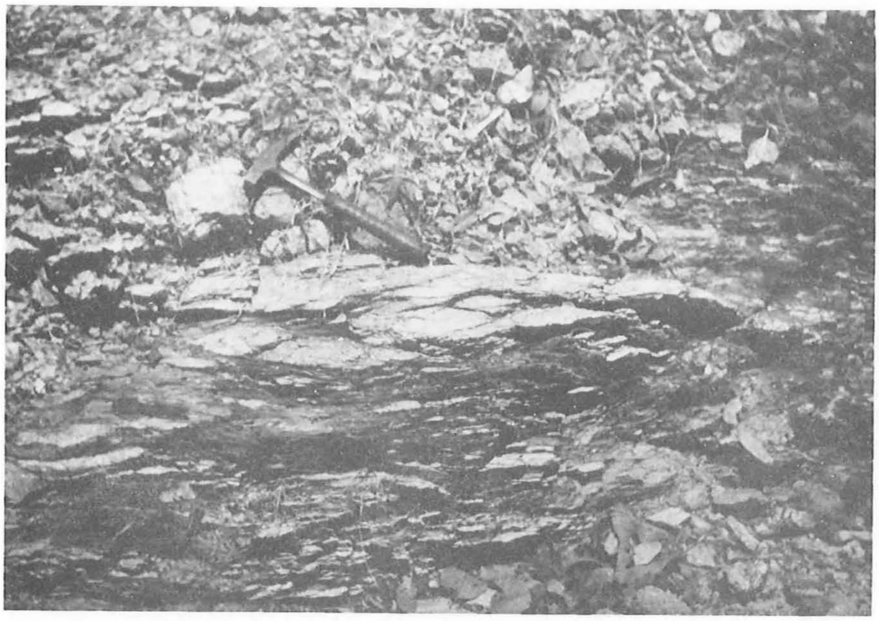

Fig. 8. Lit-par-lit gneiss and biotite schist, Nanambu Complex, 10 km south of Nourlangie Safari Camp. Neg. GA5851

Age	Unit		Radioactivity (counts/s)
	Black humic soil		3000
Cainozoic	Sand		20-30
(0-60 m.y.)	Laterite		40-100
Mesozoic	Mullaman Beds		20
(60-230m.y.)			
Adelaidean?	Mudginberri Phonolite		30
		(Gilruth Volcanic (Member	2000 (over laterite)
Carpentarian	Kombolgie Formation	(Nungbalgarri Volcanic (Member (	50
(1400-1800m.y.)		(Sandstone	30
	Anomalously radioactive granites		150-250
	Oenpelli Dolerite		20-40
Lower Proterozoic	Nanambu and Nimbuwah Complexes		40-80
	Zamu Complex		20
(1800-2300m.y.)			
	Fisher Creek Siltstone		50
	Koolpin Formation		100
	Mount Partridge Formation		50

TABLE 1: Radioactivity of the various rock units in the Alligator Rivers Uranium Field, Northern Territory, measured with hand-held Scintrex BGS1 total-count scintillometer.

The Oenpelli Dolerite* was intruded into the Lower Proterozoic rocks soon after the migmatite complexes were formed. In general the dolerite has hornfelsed (thermally metamorphosed) the surrounding country rock, but where the dolerite has intruded the central part of the Nimbuwah Complex, the country rocks have been metasomatized (chemically altered) by the dolerite, but have not been thermally metamorphosed. This suggests that there was a low thermal gradient during intrusion of the dolerite - that is, the core of the Complex was still at a high temperature.

The Oenpelli Dolerite is a differentiated intrusion which forms an extensive undulating subhorizontal sheet at least 250 m thick in places. The top of the intrusion is composed of porphyritic olivine dolerite, 5 to 50 m thick, which may have a chilled upper margin, and whose groundmass grainsize increases inwards. Rarely, gabbro pegmatite is developed near the chilled margin. The porphyritic olivine dolerite grades into ophitic dolerite, which forms the greater bulk of the intrusion - generally from 80 to 200 m thick. The centre of the ophitic dolerite commonly contains differentiates of granophyric dolerite, granophyre, and rarely syenite, which are up to 40 m thick. There are also rare ophitic gabbro differentiates within the ophitic dolerite. Porphyritic olivine dolerite again underlies the ophitic dolerite, but is characteristically thinner (up to 30 m) than that overlying the ophitic dolerite; it also has a narrow chilled margin.

Carpentarian Rocks

A marked regional unconformity separates Lower Proterozoic rocks from Carpentarian sandstone and volcanic rocks, which were deposited as subhorizontal sheets between 1800 and 1400 million years ago.

Edith River Volcanics: The oldest Carpentarian rocks of the study area are the Edith River Volcanics. This unit is composed of acid to intermediate volcanics - rhyolite and dacite - intercalated with lenses of 'valley fill' sediments (conglomerate, sandstone, and calcarenite breccia). It crops out sporadically below the Kombolgie Formation northwest of El Sherana (lat. 13°30'S, long. 132°32'E), and is represented in isolated rubbly exposures in valleys at Mount Basedow; it has not been seen farther north. The unit is unconformably overlain by the Kombolgie Formation.

*Name not yet approved.

Kombolgie Formation: This unit is by far the most prominent geological feature in the study area; it crops out as an extensive deeply dissected plateau, which slopes gently to the east, and is marked by a continuous prominent scarp (the Arnhem Land Escarpment) along its western margin.

The pre-Kombolgie erosion surface was much like the Northern Plains today: a gently undulating surface with occasional prominent hills, ranges, and ridges, such as Mount Cahill, the Mount Partridge Range, and discontinuous ridges of Zamu Complex and Oenpelli Dolerite rising above the general level. Similar 'basement highs' on the pre-Kombolgie erosion surface would have strongly influenced deposition of the Kombolgie Formation by forming the rims of a series of wide shallow depositional basins. Subsequent preferential erosion of the sandstone over basement highs has formed features such as the Oenpelli massif, a broad basinal massif of sandstone whose margins border a basement high of Oenpelli Dolerite.

The formation reaches a maximum thickness of about 400 m, and, as a whole, dips gently to the east, though several saucer-shaped sub-basins have been delineated within the area mapped. It consists mostly of coarse-grained quartz sandstone, pebbly quartz sandstone, conglomerate, and minor siltstone and tuffaceous bands. The Nungbalgarri Volcanic Member, a widespread series of basalt, amygdaloidal basalt containing agate, tuff, and intercalated sediments, divides the formation into upper and lower sandstone units (Fig. 9). The upper unit contains a narrow (up to 5 m) bed of tuff and tuffaceous siltstone, the Gilruth Volcanic Member*, which is continuous between the headwaters of the Goomadeer River (lat. 12°40'S, long. 133°40'E) and the South Alligator River. The erosion bench immediately below the member has a rectangular erosional pattern, which is prominent on aerial photographs and covers much of the central part of the Arnhem Land Plateau. The member is poorly exposed; it is mostly covered by lateritized talus containing fragments of the overlying sandstone.

Sandstone throughout the Kombolgie Formation is commonly cross-bedded (Fig. 10) and ripple-marked, and rare tool marks and intraformational breccias have been noted. The sandstone was deposited in a shallow lacustrine environment, and the predominant current of deposition was from the north. The formation is extensively jointed and faulted. Vertical displacements up to 100 m have been seen along major faults, but most displacements are no more than a few metres. Faulting determines the outline of the scarp in many places, e.g., east of the Goomadeer River.

* Name not yet approved.

Adelaidean? Rocks

An area within 10 km of Mudginberri H.S. is intruded by numerous straight steeply dipping dykes of what has been named the Mudginberri Phonolite*. The phonolite intrudes the Nanambu Complex, and is a dark green fine-grained to porphyritic peralkaline rock with chilled margins, and shows no contact effects on the country rock. The absence of field relations makes it difficult to place an age on the phonolite, but it probably lies between 1800 and 1200 m.y.

Mesozoic Rocks

Upper Cretaceous unconsolidated clayey quartz sand crops out extensively as low scarps north of Nabarlek and the East Alligator River estuary, and has been intersected by drilling in thickly timbered areas (of the Koolpinyah Surface) in the East Alligator 100 000 Sheet area, and in the north east of the Cahill 100 000 Sheet area. The Mesozoic sediments (Mullaman Beds) were deposited about 100 million years ago in a lacustrine environment, which graded northwards into marginal marine (Marligur Beds) and into deltaic environments (Moonkinu Beds) farther north (Hughes & Senior, 1973).

Cainozoic Rocks

Cainozoic sediments form a veneer over the Northern and Estuarine Plains, and talus slopes and colluvial sand cover occur over and adjacent to the Arnhem Land Plateau. Cainozoic deposits have been divided into laterite, late Teritary sand, talus, and Quaternary continental and marine sediments, which were deposited between 60 million years ago and the present.

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

The following laterite types have been recognized:

a) detrital laterite - blocks and 'pavements' over the Nanambu Complex and the outer zones of the Nimbuwah Complex.

* Name not yet approved

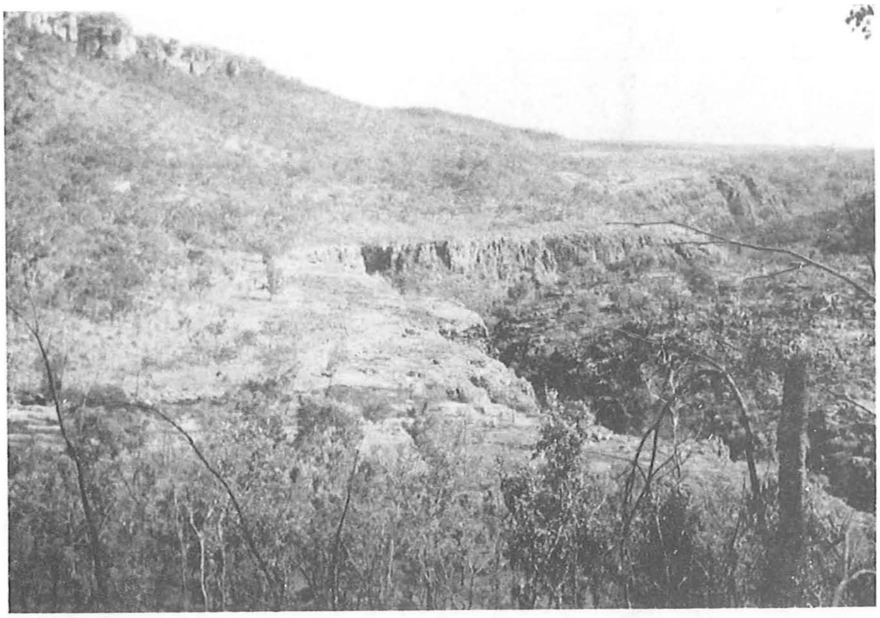

Fig. 9. The Nungbalgarri Volcanic Member forms a smooth slope between upper and lower sandstone units of the Kombolgie Formation, 35 km east-southeast of Jabiru. Neg. GA8632

Fig. 10. Cross-bedded coarse quartz sandstone and pebble conglomerate of the Kombolgie Formation, 4 km north of Koongarra. Neg. GA5858

b) pisolitic laterite (primary or detrital) - blocks or pavements at the edge of the Estuarine Plains, where the late Tertiary sands are being eroded.

c) mottled-zone laterite - over the Nanambu Complex and the outer zones of Nimbuwah Complex, in amphitheatres at creek headwaters.

d) concretionary (pedogenic) laterite - in poorly drained alluvial soils in or near major creek systems.

Late Tertiary sand is coarse unconsolidated clayey quartz sand, which forms the Koolpinyah Surface. Over most of the study area the Koolpinyah Surface is extensively dissected, and, where the sand has been almost completely removed, trends of the underlying Lower Proterozoic are visible. The sand was probably laid down as a fan deposit derived mainly from Mesozoic and Carpentarian units. Cainozoic sand on the Arnhem Land Plateau has developed in situ continuously since the Early Tertiary.

Large talus slopes are developed adjacent to the Arnhem Land escarpment where the base of the Kombolgie Formation is exposed. Scree may conceal the unconformity between the Kombolgie Formation and the underlying rocks, but commonly a bench is developed at the top of the talus slope, and the unconformity is exposed below an overhang of sandstone (Fig. 4) that formed by preferential erosion of the Lower Proterozoic rocks. The talus is composed mostly of large (up to 20 m) blocks of Kombolgie sandstone, but pebbles or slabs of the underlying rocks are also commonly present.

Laterite, quartz, quartzite, and dolerite rubble are widely scattered over low-lying areas, especially adjacent to strike ridges of Lower Proterozoic rocks and quartz veins. Much of the dolerite rubble has been transported by man, and is often found adjacent to exposures of quartzite, gneiss, or migmatite where grinding hollows show that the dolerite has been fashioned by Aboriginals into tools to grind seeds, etc.

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

Quaternary marine deposits comprise coastal deposits of silt and clay, clay pans, and beach ridges. Beach ridges are developed parallel to the present coast, and in a few places at the edge of the inner margin of the coastal plain adjacent to the higher-level Late Tertiary sand deposits.

ECONOMIC POTENTIAL

Uranium

Since 1970, four major uranium discoveries have been made in the study area; intensive exploration is continuing, and it is most likely that further discoveries will be made. The study area almost coincides with the extent of the 'Alligator Rivers Uranium Field'. Accordingly, almost all of the study area, including the Lower Proterozoic rocks beneath the Kombolgie Formation, must be regarded as having potential for further uranium discoveries. Exploration techniques in use today are restricted in that surface and airborne radiometric methods measure radioactivity from only the top metre of soil or rock. Thus exploration to date has been mostly restricted to areas of thin soil and sand cover adjacent to the Arnhem Land escarpment. All areas of thic sand and soil cover in the Northern and Estuarine Plains will eventually be prospected, however, either by radon gas detection techniques or by pattern drilling, or both.

Certain factors must be chosen to define the areas of greater potential, if a statistical approach to exploration (i.5, pattern drilling) is taken. These factors are deduced primarily from relationships between known mineralized areas and the regional geology, and current ideas on the genesis of the uranium mineralization. The genesis of the ore bodies is still a matter for discussion, and there are several possibilities, listed below in order of preference:

(a) Uranium derived from an Archaean basement was deposited within the Lower Proterozoic geosynclinal sequence, either distributed throughout the sedimentary pile or concentrated preferentially in reducing conditions in carbonaceous, carbonate, or carbonate-bearing beds (especially the Koolpin Formation). During migmatization of the geosynclinal sediments, uranium, many of whose compounds are volatile, was mobilized and concentrated within or adjacent to the Koolpin Formation or its metamorphosed equivalents. Various structures (shears, or collapse structures) provided sites for the deposition of uranium lodes, especially near the eastern margin of the Nanambu Complex.

(b) The anomalously radioactive granites or the acid Edith River Volcanics may have been a source of uranium which was later concentrated into its present positions. Neither of these units, however, appears to be extensive enough, nor do they have the correct spatial distribution in relation to the known deposits to be considered as a suitable source.

(c) Uranium may formerly have been distributed within the Kombolgie Formation, and may have been leached out by circulating waters, and concentrated below the base of the formation in Lower Proterozoic rocks. Background radioactivity is very low over the formation, however, and minor mineralization within it always overlies a strongly mineralized area in older rocks; this suggests that the insignificant mineralization within the Kombolgie Formation was introducd during weathering or other processes which affected the underlying lodes, and not concentrated from a source within the formation.

Dating of pitchblende from the Alligator Rivers Uranium Field has yielded ages between 1800 and about 450 million years ago; thus uranium mineralization existed - possibly in a less concentrated form - immediately after the migmatite Complexes (also dated at about 1800 m.y.) were formed, and before the Kombolgie Formation was deposited. For these reasons, genesis (a), above, is prefered. The younger dates (ranging between 850 and 450 m.y.) suggest, however, that there have been several periods of ore relocation since 1800 m.y. ago.

A strong association exists between mineralization and chlorite in the deposits; chloritized Kombolgie sandstone has been intersected at Ranger 1, suggesting that movement of uranium has taken place since deposition of the Kombolgie Formation (about 1600 m.y. ago).

Factors to be considered in future exploration for uranium in the study area are as follows:

(1) All known deposits lie adjacent to or within a heterogenous sequence of rocks, all of which are probably equivalent to the Koolpin Formation.

(2) Most of the known uranium deposits lie within the outer zones of the migmatite Complexes (i.e., the Lit-par-lit Gneiss Zone and Transitional Zone); the Caramal and Beatrice prospects lis within the Migmatite Zone of the Nimbuwah Complex.

(3) All deposits lie within or adjacent and parallel to structures transecting the Lower Proterozoic country rocks - either shear-zones (e.g., Nabarlek) or fault-bounded collapse structures (ee.g., Ranger 1).

(4) The country rock is retrogressively metamorphosed to chloritic schist along the structures, and chloritic schist is the major host rock for mineralization.

(5) All deposits so far discovered in the study area lie in Lower Proterozoic rocks within 300 m of the base of the Kombolgie Formation, but mineralization probably extends to still greater depths.

The simplified and generalized map (Fig. 11), which has been drawn up with the help of airborne magnetic results, takes as many as possible of the above factors into account, and as such illustrates the main locations of potential interest for uranium exploration.

The possibility of finding secondary uranium deposits in Mesozoic and younger sedimentary rocks must also not be overlooked. Deposits of this kind could have been formed through the weathering of uranium lodes and Lower Proterozoic radioactive granite.

Two clearly established points of interest in connexion with most of the known uranium deposits and prospects are:

(a) Their location fairly close to, or immediately adjacent to, the Arnhem Land Escarpment, where the cover of soil, laterite, and alluvium is relatively thin.

(b) The presence of dolerite near (or even within) the mineralized zone at several localities.

The first of these circumstances is entirely fortuitous as far as relevance to the origin of the deposits is concerned, and the second is probably so as well, though it is possible that heating during the intrusion of dolerite was responsible for the remobilization and further concentration of uranium in some places.

Published reserves of uranium oxide (U_3O_8) for the deposits in the Alligator Rivers Region as at December 1973 are:

Ranger 1	-	82 500 tonnes
Nabarlek	-	9 530 tonnes
Jabiluka	-	3 490 tonnes
Jabiluka East	-	19 585 tonnes

No figure has been announced for the Koongarra deposit.

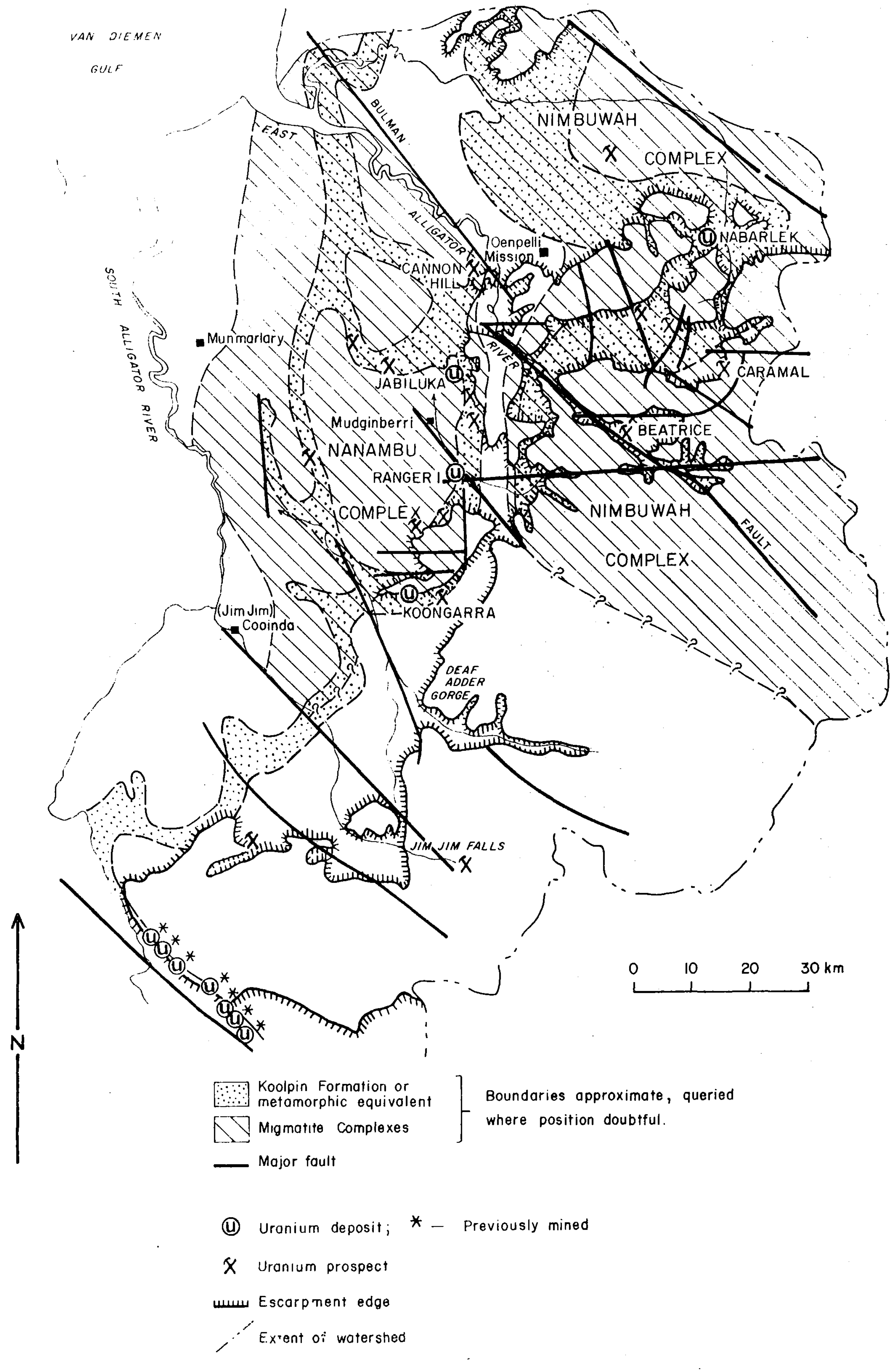

Figure II. Geological setting of the more prospective areas for uranium exploration

Other Minerals

Other minerals which have been found within the study area are gold, tin, and copper.

Gold, together with minor amounts of base metals, occurs as a minor accessory in the uranium deposits, but is of decidely marginal economic interest. Gold also occurs near Jabiluka in basal conglomerate in the Kombolgie Formation, which may be worth investigation.

At Yemelba, 8 km south of Mount Partridge, a group of auriferous quartz reefs was worked intermittently between 1933 and 1939. The reefs contain iron oxides, minor pyrite, and locally some copper minerals, and occur in north-northwesterly-trending shear-zones intersecting siltstone, sandstone, and conglomerate of the Mount Partridge Formation. Recorded production is about 7.8 kg of gold.

About 19 km northwest of Yemelba, some gold has been won from the Mundogie Hill area, mostly from small eluvial and alluvial deposits, but no records of production are available.

About 16 km northeast of Mundogie Hill, near Spring Peak, a number of small tin-bearing quartz reefs in sandstone of the Mount Partridge Formation were discovered in 1955. Costeaning and diamond drilling of the prospect did not locate occurrences of economic importance.

Alluvial tin is mined north of Myra Falls in small quantities. The tin is derived from minor cassiterite-bearing quartz veins nearby, but there appears to be little potential for finding further tin deposits.

A quartz-breccia reef 11 km southwest of Nourlangie Safari Camp contains subeconomic copper values. Other minor occurrences of base metals throughout the study area have been noted, but potential appears low.

Highly ferruginized exposures of schistose rock have been noted in the Cahill and Jim Jim Sheet areas, but they are far too small and low-grade to be economically siginficant as possible iron ore. Agate from the Nungbalgarri Volcanics within the study area is generally of poor quality in easily accessibly places, and its economic exploitation is unlikely, although it is of potential interest to tourists.

Construction Materials

Projected development in the Alligator Rivers region is creating a demand for construction materials, especially road metal. Exposures of rock potentially suitable for such purposes have been indicated by BMR to the Mines Branch, Department of the Northern Territory, and to other interested people on request. All outcrops of good potential are covered by applications for Mineral Leases which have been taken out over numerous exposures of metadolerite (Zamu Complex), phonolite (Mudginberri Phonolite), and quartzite (Nanambu Complex); of these, metadolerite is considered the most suitable for aggregate. The Mines Branch has drilled one exposure of metadolerite for Geopeko Ltd, and has calculated reserves of 150 000 to 200 000 cubic metres above the dry-season water-table (Lau, 1973). The Department of Works has estimated that 500 000 cubic metres of crushed rock may be required for building construction and road sealing for the proposed regional centre. Other material required in future will be sand (for cement) and laterite gravel, which will probably be used as a foundation for the proposed sealed airstrip. Sand is available in sufficient quantities in most of the major creeks of the study area; nodular laterite (generally less than 1 m thick) is widespread over the Nanambu Complex.

CONCLUSIONS

We believe that there is great potential for additional uranium discoveries in the study area. It is unlikely that economic mineralization will be found within the basic to intermediate intrusive rocks and the Kombolgie Formation, but all other geological units must be considered, especially where they are incorporated in, or occupy positions marginal to, the Nanambu and Nimbuwah Complexes.

It is also possible that economic deposits of base metals and other minerals will be found, but there is little indication so far that this will be so.

The economic impact of the proven uranium ore reserves alone is nationally important, and the effect on this area and the Top End generally will be profound. Recent opening up of the area, together with a great deal of concern for the environment, has been triggered off largely by the exploration successes of the last three years.

The economic importance of the area carries with it obvious implications for the survival of its scenic, ecological, and cultural attractions. The Kombolgie Formation offers scenery, fauna, and flora of note throughout much of the study area, and is bestowed with many features that would attract tourists who may be interested in rock formations and such phenomena as ripple marks, cross-bedding, rock stacks, and natural arches. However, the remainder of the geological units are poorly exposed, and would be quite uninteresting to the general public. The economic importance of the area, however, will ensure continuing interest amongst geologists for many years, and it is critical that access to rock exposures is not restricted, for a complete geological understanding of this uranium province may well prove to be important for the exploration of similar geological terrains elsewhere in Australia.

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PART 3 - RESULTS OF AIRBORNE GEOPHYSICAL SURVEYS CONDUCTED BY THE BUREAU OF MINERAL RESOURCES

by

P.G. Wilkes

1. INTRODUCTION

The Bureau of Mineral Resources (BMR) conducted airborne geophysical surveys of the Alligator River and Mount Evelyn areas in 1957 and 1971/2. The surveys cover the area now under study for the proposed National Park.

The 1957 survey covered part of the South Alligator valley from about 13°18'S to 13°42'S (straddling the South Alligator River along a strip about 2 km wide), and an area whose approximate extent was 12°58'S to 13°18'S and 132°25'E to 132°51'E (between Barramundie Creek and Nourlangie Creek). This survey provided scintillometer coverage showing the main areas of anomalous radioactivity, but did not distinguish the source of the radioactivity as uranium, thorium, or potassium; source information was derived later by laboratory analysis of rock samples. The survey was flown at about 60 m above ground level, and lines were spaced about 400 m apart. This work and its results were described by Livingstone (1958).

The 1971/2 work was a regional airborne magnetic and radiometric survey covering the 1:250 000-scale map sheets of Alligator River and the northern half of Mount Evelyn. This survey was flown on a regular grid pattern with east-west flight lines spaced at about 1.5 km. Flying height was about 150 m above the ground. The radiometric equipment used was a gamma-ray spectrometer, which, in addition to showing the main areas of anomalous radioactivity, provides an indication of whether the source of radioactivity is uranium, thorium, or potassium. The airborne work was done to assist in the uranium search that followed the initial discoveries in 1969 and 1970, and also to assist the current BMR semi-detailed geological mapping in the area.

Some brief follow-up work was done during August 1973 to investigate, on the ground, certain anomalies discovered by the 1971/2 survey; these were mainly on the Arnhem Land Plateau. A helicopter was used to provide access, and a small portable gamma-ray spectrometer was used to relocate the anomalies from the helicopter and also to make measurements on the ground.

Preliminary versions of 1:100 000 scale magnetic contour maps and total-count radiometric profiles have been produced and are available from the Australian Government Printer. An interpretation report is being prepared, (Horsfall & Wilkes, in prep.).

2. BACKGROUND INFORMATION ON AIRBORNE SURVEY TECHNIQUES

2.1 Magnetic method

The Earth's magnetic field varies with geographical position in both intensity and direction. There are broad regional magnetic variations on a global scale owing to the nature of the Earth's primary magnetic field, and superimposed on these are local variations which the primary field induces in certain minerals of the Earth's crust. These local variations, usually termed magnetic anomalies, reflect geological inhomogeneities or contrasts between the magnetic properties of adjacent rock units. After removal of the large-scale regional variations and the time variations, it is possible to study the residual magnetic anomalies and interpret these in geological terms. Magnetic surveys of large areas are usually carried out from the air, as this permits the magnetic data to be rapidly and economically obtained. The magnetic anomalies are usually displayed as profiles or contour maps, or both. Interpretation of aeromagnetic data, combined with careful correlation with known geology, can yield a wealth of additional information both on surface geological features and on those at depth. Examples include mapping the extent of various geological units, locating sedimentary basins, determining fault positions, and directly detecting magnetic ore deposits.

In this study of the Alligator Rivers area, the main part of the aeromagnetic interpretation has been directed at subdividing the area into zones of different magnetic character, and interpreting these in terms of the extent of different rock types.

2.2 Radiometric method

All rocks contain variable and usually minor amounts of the naturally occurring radioactive elements. About fifty naturally occurring radio-isotopes are known; of these the most important are potassium-40 and the members of the uranium-235, uranium-238, and thorium-232 series. Each series comprises a 'parent' radio-isotope, 'daughter' radio-isotopes, and a stable (non-radioactive) end-product. The contribution of the uranium-235 series to gamma-ray emission of rocks is relatively small (compared with the potassium-40, the uranium-238, and the thorium-232 series), and can usually be disregarded in airborne work.

The decay processes between the various radio-isotopes are characterized by gamma radiation of specific energies, which are seen to be peaks superimposed on a continuous gamma radiation spectrum. The spectra from uranium-238, thorium-232, and potassium-40 are sufficiently different to make source diagnosis possible from measurements made on the energy-distribution of the gamma radiation (see Fig. 12). Characteristic spectral peaks from each series are resolvable with sensitive detectors at flying heights up to about 250 m above ground level.

A gamma-ray spectrometer is designed to measure the gamma radiation intensity within preselected energy 'windows' (sometimes called 'channels'). One channel is usually set to monitor the 2.62 Mev peak from the thorium series. A second channel is set for the 1.76 Mev peak from the uranium series, and a third for the 1.46 Mev peak of potassium-40. In addition, it is usual to have a channel set to make a broad-band measurement across the energy spectrum in order to study the overall distribution of radioactivity in an area. This channel is often referred to as the 'total-count' channel. The data from this channel are used to locate areas of higher radioactivity, and those from the other three channels to determine the contributions from uranium, thorium, and potassium. It is thus possible to detect uranium deposits directly if gamma radiation from them reaches a suitable detector. In addition, gamma-ray spectrometer data are useful in geological mapping because different rocks have different concentrations and proportions of the radioactive elements.

The 1.76 Mev peak from the uranium-238 series is due to gamma-ray emission from bismuth-214. Monitoring this peak as an indicator of uranium assumes equilibrium within the series. Equilibrium is the condition achieved when the rate of formation of daughter radioisotopes is balanced by their rate of decay. This requires that none of the daughters are physically removed. The solubility of uranium-234 and radium-226 and the mobility of the gas radon-222 (all of which precede bismuth-214 in the series) can frequently lead to disequilibrium conditions which greatly complicate the interpretation of gamma-ray data for uranium. Disequilibrium is relatively rare in the thorium series. It is not possible from the airborne data alone to know whether or not equilibrium has been achieved. In the area under study for the proposed National Park, it appears, from work done by the Australian Atomic Energy Commission (AAEC), that disequilibrium in the uranium series occurs quite widely, and may mean that near-surface uranium deposits may exist either with no associated uranium anomaly above them on the surface or with the anomaly displaced a short distance.

Before the late 1960s most airborne radiometric surveys were made with scintillometers. These were capable of measuring the distribution of radioactivity, but were not able to determine the composition of the source. The airborne gamma-ray spectrometer is a development of the airborne scintillometer. The 1957 work referred to in this report was done with a scintillometer, and the recent (1971/2) work with a spectrometer.

It is very important to note that, as a result of ground absorption of gamma radiation, detectors on or above the ground receive radiation from only about the top metre of the ground. Thus, to detect a radioactive zone in this way one of the following conditions must apply:

(a) The zone must either outcrop or approach close to the surface.

(b) If the zone is deeper than about one metrsit will be detectable only if radioactive gases or solutions from the zone are able to reach the surface, or if the overburden is derived from the radioactive rocks and thus has similar radiometric characteristics.

For the purposes of this study, a radiometric anomaly is defined as an area of above average radioactivity, or an area where the distribution of radioactivity in the spectrometer channels (channels 2, 3, and 4 of Fig. 12) is significantly different from that of the surrounding area.

3. GEOPHYSICAL RESULTS

3.1 Magnetic Results

3.1.1 Nanambu and Nimbuwah Complexes

The magnetic results (Plate 2) show that the areas occupied by the Nanambu Complex are characterized by magnetically 'flat' (or weakly disturbed) response. Their extents are thus difficult to map directly from the magnetic data. However, by mapping formations marginal to the Nanambu Complex their extents can be inferred. For example, the eastern side of the Magela Mass (Zone A) is bounded by a magnetically disturbed area interpreted as Koolpin Formation equivalent (Zone G). In a similar way we have interpreted the boundaries of the Munmarlary (Zone B) and Jim Jim (Zone C) Masses. These are also part of the Nanambu Complex, and from the magnetic data appear to be joined beneath Woolwonga Swamp. To the north of the Magela Mass are two zones, D and E, which have been interpreted as Nanambu Complex, and initial drilling results confirm this. Definition of areas of Nanambu Complex rocks is important because a number of the important uranium deposits and prospects are located close to the margins of the Complex (e.g., Ranger 1 and Jabiluka).

It does not appear to be possible to define the margins of the Nimbuwah Complex from the magnetic data.

3.1.2 Dolerites

Dolerites appear to be much more widespread than originally mapped. Areas marked as H zones on the map are interpreted as areas of dolerite. In many places these fit well with the observations of outcrop.

3.1.3 Other Zones

Zones labelled J (in the southwestern part of the study area) have been correlated with rocks of the Koolpin Formation.

Zone K is attributed to rocks of the following groups: Koolpin Formation, Koolpin Formation equivalent, Mount Partridge Formation, and dolerite. Possibly more detailed interpretation will further subdivide this zone, and clarify which rock type or types are producing the anomalies observed in it.

Zones labelled L (in the northwestern part of the area) are attributed to the Mount Partridge Formation. Geological information obtained during the 1973 fieldwork indicates that some of these zones may correlate with areas of Koolpin Formation equivalent, in some places overlain by Fisher Creek Siltstone.

Zone M (in the South Alligator valley) reflects the complex geology in the South Alligator fault zone.

Zone N correlates well with the mapped extent of the Plum Tree Creek Volcanic Member of the Katherine River Group of rocks.

Two areas in the northeastern corner are labelled Zone O; they appear to be magnetic units within the Nimbuwah complex.

Zone P (southeastern corner of the area) appears to correspond to ferruginous sandstone and conglomerate of the Mullaman Beds.

The linear magnetic features in the southeast of the area are attributed to fractures within the Kombolgie Formation filled with some magnetic material, possibly near-vertical dolerite dykes.

3.2 Radiometric Results

3.2.1 1957 Survey

Within the area under study for this report, the 1957 Survey located fifteen radiometric anomalies. These can be divided into four groups according to locality:

a. Spring Peak

Four anomalies were detected near Spring Peak. One of these was in an area where thorium-bearing arkoses (of the Mount Partridge Formation) had previously been found, and from this it was inferred that all four anomalies were due to thorium. Interpretation of the 1971/2 work suggested, however, that most of the radioactivity of the Spring Peak area was due to potassium.

b. Mount Basedow

Nine anomalies were detected on the Mount Basedow range; these were mainly of small areal extent and were located in quartz schist and quartz-mica schist. Radiometric assays of rock samples taken from several of these anomalies gave up to 0.03% U_3O_8. It was generally concluded that both uranium and thorium were present in this region. The 1971/2 work showed that the uranium content was lower than the thorium content, particularly on the southern end of the range. On the northern end, the ratio of uranium to thorium is higher, but here the radioactivity is predominantly due to potassium.

c. One anomaly was detected in the headwaters of the Barrumundie Creek, close to the northern edge of the Kombolgie Formation outcrop. It was not checked on the ground, and no conclusion about its source was reached. The more recent work did not locate this anomaly, because it was either of low intensity or located too far from the flight lines to be detectable.

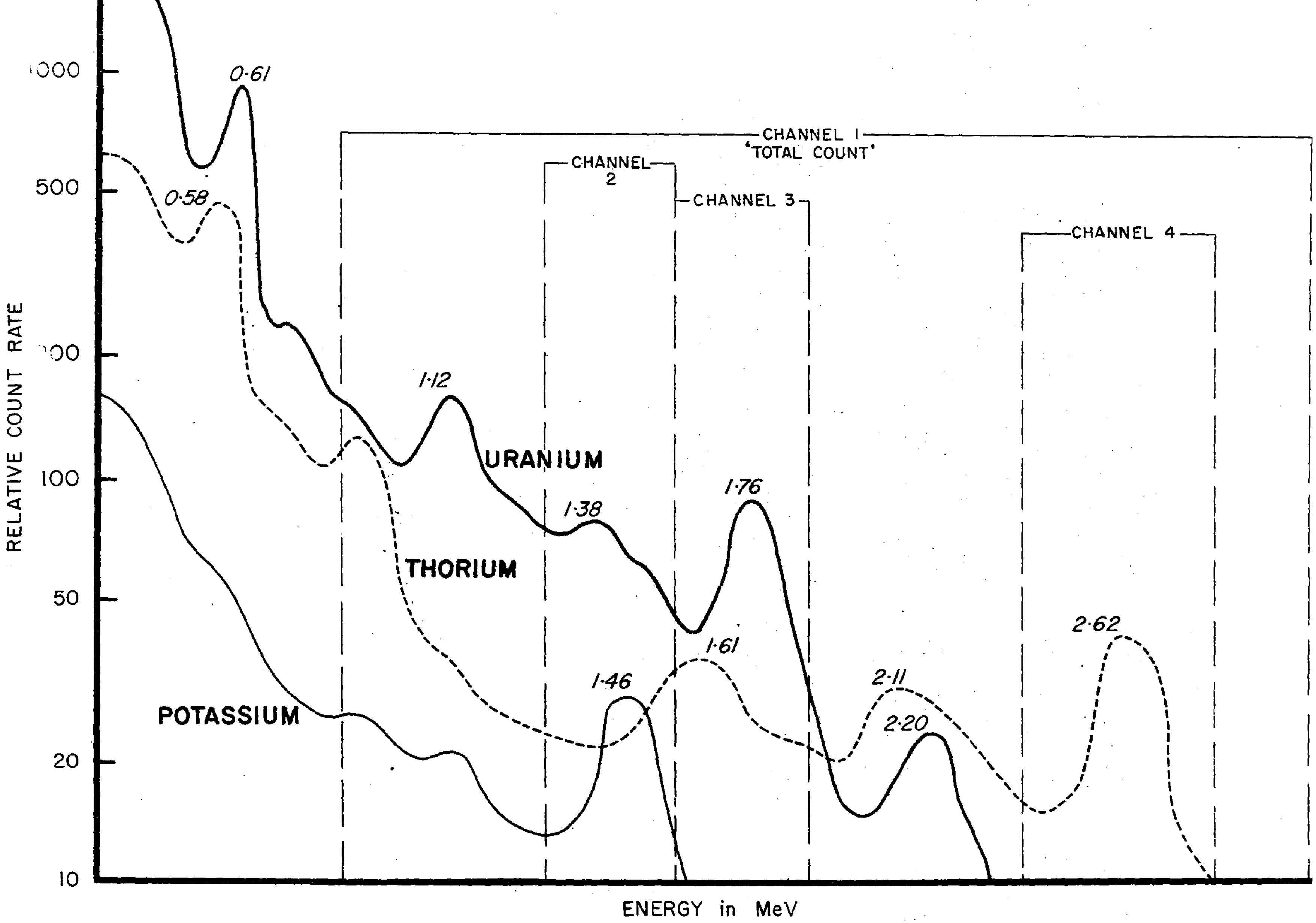
d. Rockhole (lat. 13°28'30"S, long. 132°27'40"E)

The 1957 survey located an anomaly over the Rockhole uranium deposit. This deposit was mined by South Alligator Uranium NL.

TO ACCOMPANY RECORD NO. 1973/208

TYPICAL GAMMA-RAY SPECTROGRAMS FOR POTASSIUM, URANIUM, AND THORIUM

SLOPING NUMBERS INDICATE GAMMA-RAY SPECTRAL PEAKS IN MeV



G43-513A

Figure 12

3.2.2 1971/2 Survey

From a study of the total-count radiometric profiles, original records, and the most recent BMR geological mapping, radiometric interpretation maps have been prepared at a scale of 1:250 000. The interpretation map (Plate 2) included with this report shows a simplified version of these.

It is important to note that the flight-line spacing of 1.5 km does not provide complete radiometric coverage of the survey area, as the airborne spectrometer flown at 150 m above the ground records radioactivity from a strip of ground about 600 m wide (i.e., 300 m either side of the flight path). This results in 40 percent coverage of the ground, and means that there is a high probability of not detecting anomalies located farther than 300 m from a flight line.

The interpretation map shows the radiometric anomalies divided into four groups based on their predominant source types:-

a. Anomalies predominantly due to potassium

b. Anomalies predominantly due to uranium

c. Anomalies predominantly due to thorium

d. Anomalies of mixed source where none of the source types predominates.

Each of these groups is denoted by a different symbol on the map. As only those with significant uranium content are likely to be of importance to the National Park study, this discussion of results concentrates mainly on that group of anomalies. It should be noted that it is not possible, from the airborne data alone, to make any deductions about concentrations, areal extent, or ore grades of anomalies.

The Appendix lists all the anomalies detected in the BMR survey which have been interpreted as uranium anomalies; the column labelled ch3/ch4 means the following:-

ch3 = the count-rate in channel 3 ('uranium channel') after subtracting the non-geological contribution (e.g., cosmic radiation, artificial sources in the aircraft).

ch4 = the count-rate in channel 4 ('thorium-channel') after subtracting the non-geological contribution.

ch3/ch4 is the ratio of these two corrected count-rates, and is an indicator of the relative uranium to thorium content. The higher the count-rate ratio, the greater is the uranium to thorium ratio, and, hence in general, the more significant is the anomaly.

The anomaly reference numbers in the Appendix are the same as those on the map.

Anomaly 1

This is a high-intensity anomaly over the Nabarlek uranium deposit of Queensland Mines Ltd. It has a characteristically high ch3/ch4 ratio of 14. The anomaly was detected on only one flight line, as would be expected from the known strike length of the deposit.

Anomaly 2

This anomaly is located close to the southwestern corner of Cannon Hill. It has a ch3/ch4 ratio of 4, and probably indicates a small relative increase in the uranium to thorium ratio with respect to the surrounding area. This anomaly is probably of little or no importance.

Anomaly 3

This low-intensity anomaly is located just west of some low hills of Mount Partridge Formation. It has a relatively low ch3/ch4 ratio of 5. Like anomaly 2, it appears to represent a small local increase in uranium to thorium ratio, rather than uranium mineralization.

Anomaly 4

This low-intensity anomaly is located within the Munmarlary Mass of the Nanambu Complex. It is probably not of high significance, but warrants ground checking.

Anomaly 5

This anomaly is located close to the northern margin of the Magela Mass of the Nanambu Complex. It appears to be close to the Ranger 4 prospect of Peko-EZ. The ch3/ch4 ratio is only 6, but the position of this anomaly close to the margin of the Nanambu Complex makes it worth further investigation.

Anomaly 6

This anomaly is of very low intensity (40 counts/s) but has a high ch3/ch4 ratio of 11. This is probably due to unusually low thorium content rather than high uranium content. The anomaly appears to be located within Kombolgie Formation close to the margin of a large area of dolerite.

Anomaly 7

This anomaly coincides with Queensland Mines' 'Beatrice' uranium prospect. Drilling at this prospect failed to locate significant uranium mineralization at depth (de Ferranti, 1973).

Anomalies 8, 9, 10, and 11

These four anomalies are all located over the Ranger 1 uranium deposit of Peko-EZ. The Ranger 1 deposit was crossed by four flight lines between Mount Brockman and Magela Creek, and one anomaly was recorded on each line. Anomalies 8 and 9 are particularly intense.

Anomalies 12 and 13

Both these anomalies appear to be located in the headwaters of the Baroalba Creek, on the western side of Mount Brockman. Anomaly 12 is known to occur in black soil some distance from the Kombolgie Formation. It is a moderately intense anomaly, and has a high ch3/ch4 ratio of 15. It seems probable that the source of uranium in this anomaly is farther upstream, back towards the edge of sandstone. Anomaly 13 is not as intense but was probably farther below the aircraft, as the aircraft would have had to climb to clear Mount Brockman. Both these anomalies warrant further attention.

Anomalies 14 and 15

Anomaly 15 is located over Noranda's Koongarra uranium deposit. Anomaly 14 was detected on the next line north of Koongarra, and indicates that there may be more uranium close to the eastern margin of Mount Brockman (Kombolgie Formation).

Anomalies 16, 17, 18, and 19

These four anomalies are located close to an area of Nungbalgarri Volcanics in the Kombolgie Formation. The anomalies are all of low intensity, but stand out quite distinctly above the very low background of the Kombolgie Sandstone. Anomalies 16, 17, and 19 were visited briefly in August 1973. Anomaly 16 is located within a black soil area, and the others within laterite. It is believed that the laterite is developed at the base of the Nungbalgarri Volcanics. From rock samples collected at these anomalies, the uranium content appears not to exceed 20 ppm.

Anomaly 20

This is a very low-intensity anomaly (50 counts/s in total-count channel), which would not be significant except for its channel 3 ('uranium') response. It appears to be located close to or within an exposure of Koolpin Formation. The ch3/ch4 ratio is low, and it appears that this anomaly is probably of little importance.

Anomaly 21

This anomaly is located about 1.5 km east of Cooinda airstrip, close to the margin of the Jim Jim Mass of the Nanambu Complex. The ch3/ch4 ratio is low (4), but the position of the anomaly relative to the Complex increases its significance.

Anomaly 22

This anomaly was briefly examined in the August 1973 fieldwork, and found to be due to radioactivity in laterite probably associated with Nungbalgarri Volcanics within the Kombolgie Formation.

Anomalies 23-38 inclusive

This group of anomalies is situated high up on the Arnhem Land Platau within the Kombolgie Formation. Eleven of these anomalies were visited during the August 1973 fieldwork, and found to be associated with laterite. The anomalies visited were 23-25, 29, and 31-37. The radioactive laterite is developed down-slope from the base of a thin volcanic member within the upper part of the Kombolgie Formation. The volcanic member was discovered during 1973 fieldwork, and it is currently being referred to as the Gilruth Volcanic Member (see Part 2 of this report). Photogeology indicates that all the anomalies in this group are located within (or close to) the laterite associated with this volcanic member. The average radioactivity measured on the ground over these laterites is moderately high and similar to the radioactivity measured on the Jim Jim

Granite. Anomaly 33 is particularly intense - up to about seven times as strong as the average over the Jim Jim Granite. The thorium content of the anomalies visited appears to be low, and this is partly responsible for the quite high uranium to thorium ratios. Initial results from rock samples collected at these anomalies indicate that the uranium content does not appear to exceed 45 ppm except at anomaly 33, where up to 280 ppm is present. (All these measurements refer to surface material).

Anomaly 39

This anomaly is located in the southeastern corner of the Five Sisters Window. This is a window of Fisher Creek Siltstone surrounded by Kombolgie Formation. The anomaly is located in phyllite, and is moderately intense on the ground - about 2.5 times that of the Jim Jim Granite. Surface uranium content appears to be of the order of 40 ppm.

Anomaly 40

This is a high-amplitude anomaly over, or close to, the treatment plant at Teagues' uranium deposit in the South Alligator River valley.

4. CONCLUSIONS

The 1971/2 survey detected all the known major uranium deposits except Jabiluka. In addition, it indicated a number of other prospects, most of which (if not all) are already known to the companies holding the relevant exploration licences.

The uranium in laterite on the Arnhem Land Plateau is probably a surface feature only, and not of economic importance.

It seems likely that more uranium deposits will be discovered in this area, but exploration for them will not be easy. Gamma-ray spectrometry is of limited application because of the overburden problem which can either mask or significantly attenuate gamma radiation originating beneath the overburden. It is further complicated by the disequilibrium problem which can result in a geophysical response some distance away from the uranium source.

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LIVINGSTONE, D.F., 1958 - Airborne radiometric survey of the South Alligator River region, Nothern Territory. Bur. Miner. Resour. Aust. Rec. 1958/70 (unpubl.).

APPENDIX

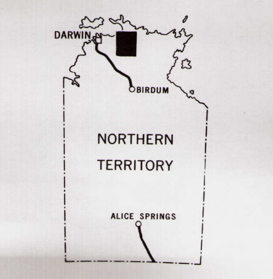
URANIUM ANOMALIES

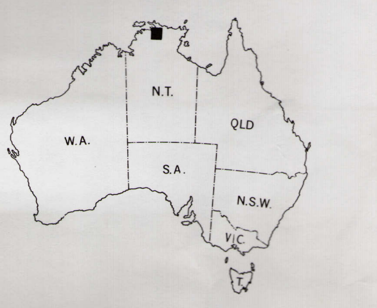
DETECTED BY BMR AIRBORNE SURVEY, 1971/2

Anomaly Reference no.	Total-count intensity above background (counts per second)	ch3/ch4	Geology	Comments
1	700	14	Nimbuwah Complex	Nabarlek uranium deposit
2	120	4	Probably Koolpin Formation equivalent	
3	90	5	Probably Mount Partridge Formation	
4	90	4	Nanambu Complex	
5	90	6	Nanambu Complex	
6	40	11	Kombolgie Formation	
7	130	5	Nimbuwah Complex	Beatrice prospect
8	790	14	Koolpin Formation equiv. marginal to Nanambu Complex	Ranger 1 uranium deposit
9	1460	15	"	Ranger 1 uranium deposit
10	100	6	"	Ranger 1 uranium deposit
11	310	9	"	Ranger 1 uranium deposit
12	200	15	Nanambu Complex	Noranda prospect
13	100	6	Probably Koolpin Formation equivalent	" "
14	120	8	Probably Koolpin Formation equivalent	" "
15	345	11	Probably Koolpin Formation equivalent	Koongarra uranium deposit
16	55	5	Kombolgie Formation	
17	40	5	" "	
18	70	4	" "	
19	40	4	" "	

Anomaly Reference no.	Total-count intensity above background (counts per second)	ch3/ch4	Geology	Comments
20	50	4	Koolpin Formation	
21	100	4	Marginal to Nanambu Complex	
22	40	4	Kombolgie Formation	
23	120	4	" "	Close to Gilruth Volcanic Member
24	170	4	Kombolgie Formation	Close to Gilruth Volcanic Member
25	70	4	" "	Close to Gilruth Volcanic Member
26	90	4	" "	
27	80	5	" "	
28	100	4	" "	
29	150	5	" "	Close to Gilruth Volcanic Member
30	130	4	" "	
31	130	8	" "	Close to Gilruth Volcanic Member
32	100	4	" "	" "
33	50	8	" "	" "
34	110	8	" "	" "
35	90	5	" "	" "
36	150	10	" "	" "
37	100	4	" "	" "
38	90	6	" "	
39	150	6	Fisher Creek Siltstone	
40	More than 600	not recorded		Teagues' treatment plant

GEOLOGY OF THE ALLIGATOR RIVERS REGION NORTHERN TERRITORY





Scale 1:250,000

5 0 5 10 15 20 25 KILOMETRES

5 0 5 10 MILES

BROWN NUMBERED LINES ARE 20,000 METRE INTERVALS OF THE AUSTRALIAN MAP GRID ZONE 53
TRANSVERSE MERCATOR PROJECTION

Geology 1971–1974 by R.S. Needham, P.G. Smart, A.L. Watchman
Compiled 1973 by R.S. Needham, P.G. Smart, A.L. Watchman, P. Fuchs, D.J. Callaghan
Drawn 1973-1974 by D.J. Callaghan

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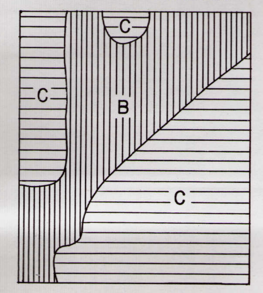
Base map compiled by the Division of National Mapping from aerial photography at 1:50,000 Scale

CAINOZOIC	QUATERNARY		Qca	Silt, mud; coastal alluvium
			Qcr	Sand, shelly sand, coastal sand ridges
			Qa	Silt, clay, sand, soil; terrestrial alluvium
			(stippled)	Thin soil cover
			Czs	Unconsolidated sand, clayey sand
			Czl	Laterite; ferricrete, mottled zone
MESOZOIC	LOWER TO UPPER CRETACEOUS		K	Fossiliferous, poorly sorted quartzose sandstone, mudstone, siltstone and conglomerate
PROTEROZOIC	ADELAIDEAN	Mudginberri Phonolite *	ph	Phonolite dykes
	CARPENTARIAN	Katherine River Group, Kombolgie Formation: Gilruth Volcanic Member *	Ɋhg	Tuffaceous siltstone, siltstone, minor amygdaloidal basalt, jasperite
		Katherine River Group, Kombolgie Formation	Ɋhk2	Quartz sandstone, minor conglomerate and siltstone; cross-bedded, ripple marked
		Katherine River Group, Kombolgie Formation: Nungbalgarri Volcanic Member *	Ɋhn	Basalt, amygdaloidal in places, interrelated siltstone and tuffaceous sediments
		Katherine River Group, Kombolgie Formation	Ɋhk1	Quartz sandstone, conglomerate, minor siltstone; cross-bedded, ripple marked
		Katherine River Group: Edith River Volcanics	Ɋhe	Rhyolite, dacite, pyroclastic breccio-conglomerate
	LOWER PROTEROZOIC		Ɋlg	Pink biotite granite, altered; anomalously radioactive
		Jim Jim Granite	Ɋgj	
		Oenpelli Dolerite *	Ɋdo	Porphyritic, ophitic and granophyric dolerite; syenite differentiates
		Nanambu Complex	Ɋlx	Schist, gneiss, minor granitoid migmatite
		Nimbuwah Complex: Granitoid Core	Ɋlz1	Homogeneous, foliated to non-foliated, hornblende-biotite granitoid migmatite
		Nimbuwah Complex: Migmatite Zone	Ɋlz2	Hornblende-biotite granitoid migmatite; complex interpenetration fabrics
		Nimbuwah Complex: Lit-par-Lit Gneiss Zone	Ɋlz3	Lit-par-lit gneiss, banded gneiss, augen gneiss
		Nimbuwah Complex: Transitional Zone	Ɋlz4	Isoclinally folded, schist, gneiss, feldspathic, some leucosome bands
		Zamu Complex	Ɋdi	Dolerite, metadolerite, amphibolite
		Goodparla Group, Sth. Alligator Group	Ɋl	Undivided sediments
		Sth. Alligator Group: Fisher Creek Siltstone	Ɋlf	Siltstone, phyllite, minor quartzite
		Sth. Alligator Group: Koolpin Formation and equivalent	Ɋlk	Siltstone, phyllite, quartzite, carbonate rock, chert bands
		Goodparla Group: Mount Partridge Formation	Ɋlp4	Feldspathic quartzite, micaceous quartzite, quartzite
		Goodparla Group: Mount Partridge Formation	Ɋlp3	Phyllite, minor schist
		Goodparla Group: Mount Partridge Formation	Ɋlp2	Conglomerate, feldspathic sandstone, arkose, minor slate
		Goodparla Group: Mount Partridge Formation	Ɋlp1	Slate, phyllite, minor meta-arkose
		Goodparla Group: Mount Partridge Formation: Mundogie Sandstone Member	Ɋlu	Sandstone, conglomerate, minor slate and siltstone
		Goodparla Group: Stag Creek Volcanics	Ɋlv	Altered basalt and basalt-agglomerate

* Name not yet approved

RELIABILITY DIAGRAM



B Detailed reconnaissance and airphoto interpretation
C General reconnaissance: few traverses, mainly airphoto interpretation

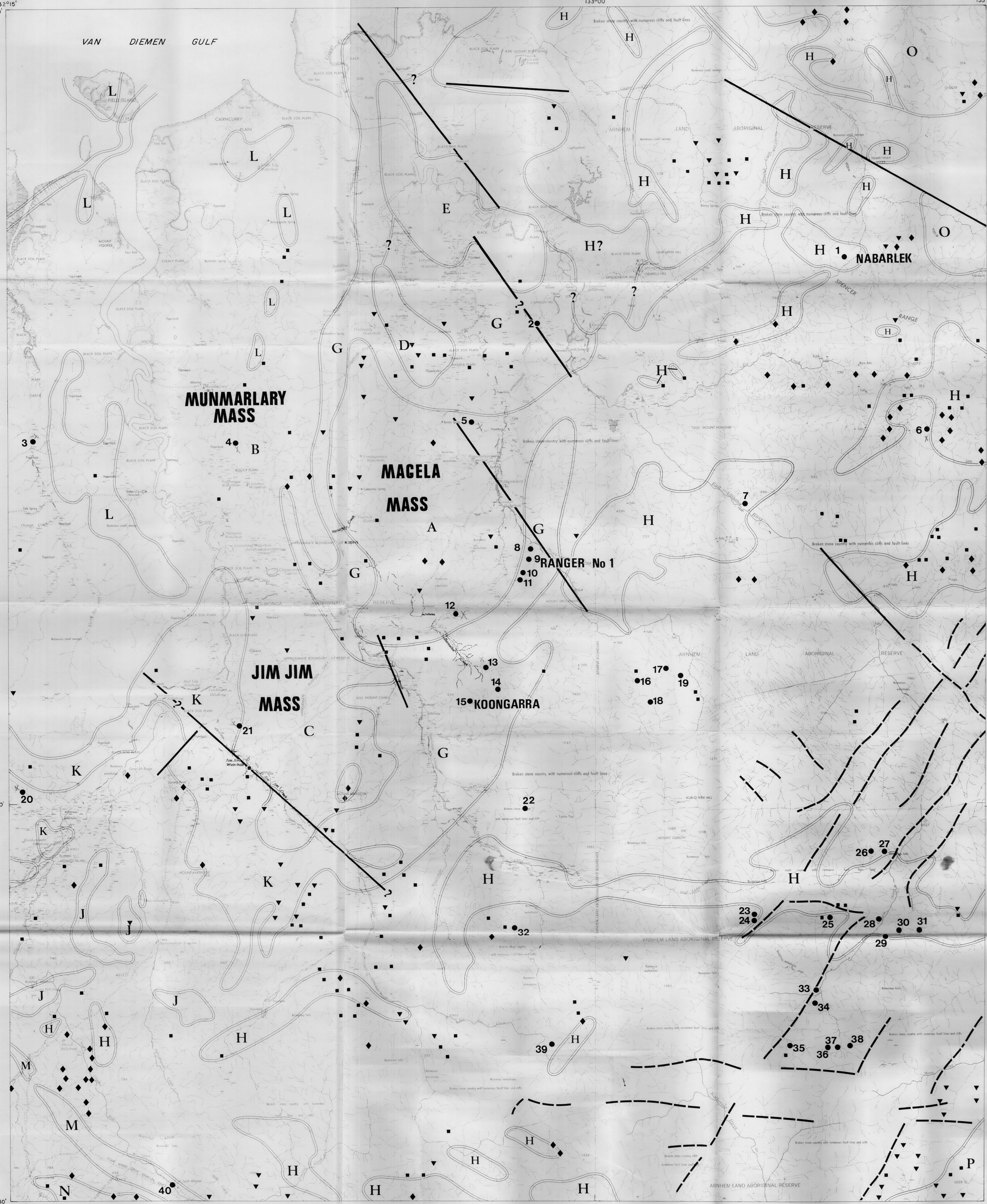
- Geological boundary
- Anticline
- Syncline, showing plunge
- Fault, (D,U indicates relative movement down, up)
- Fault; high angle reverse, triangle indicates direction of dip
- Fault, inclined (80)
- Fault, showing relative horizontal movement
- Fault, with slickensides

Where location of boundaries, folds and faults is approximate line is broken; where inferred, queried; where concealed boundaries and folds are dotted, faults are shown by short dashes

- Plunge of minor anticline
- Plunge of minor syncline
- Plunge of fold axis
- Plunge added to trend line
- Dome
- Strike and dip of strata (60)
- Prevailing strike and dip of strata
- Vertical strata
- Horizontal strata
- Overturned strata (25)
- Curving dip (40, 70)
- Dip < 5° — airphoto interpretation
- Dip 5°–15° — airphoto interpretation
- Dip 15°–45° — airphoto interpretation
- Trend lines — airphoto interpretation
- Joint pattern — airphoto interpretation
- Lineament — airphoto interpretation
- Dip slope — airphoto interpretation
- Prevailing dip of strongly deformed strata
- Strike and dip of joints (40)
- Strike and dip of joints, unmeasured
- Strike and dip of joints, vertical
- Strike and dip of foliation (20)
- Strike and dip of foliation, unmeasured
- Vertical foliation
- Strike and dip of cleavage (60)
- Strike and dip of cleavage, unmeasured
- Vertical cleavage
- Apparent dip of cleavage on bedding plane (10, 50)
- Strike of bedding and cleavage coincident (80, 25)
- Strike and dip of bedding with vertical cleavage (50)
- Lineation on bedding (35, 50)
- Foliation with plunge of lineation (20, 35)
- Platy flow, inclined
- Platy flow, vertical
- Platy flow, horizontal
- Direction of sedimentation x-cross stratification
- Direction of sedimentation, sense unknown
- Macrofossil locality
- Dyke or vein, q-quartz ph-phonolite d-dolerite peg-pegmatite
- •u Minor mineral occurrence
- (U) Unworked deposit
- Prospect
- Mine, minor
- Au Gold
- Cu Copper
- Pb Lead
- Sn Tin
- U Uranium
- Zn Zinc
- Waterhole
- Spring
- Small lake or lagoon
- Intermittent lake or lagoon
- Ground subject to inundation
- Swamp
- Mangroves
- Falls
- Highway
- Vehicle track
- Landing ground
- "Koongarra" Homestead
- Building
- Trigonometrical station
- Astronomical station
- .14 Elevation in metres

To accompany Record 1973/208: A geological report for the Alligator Rivers Region Environmental Fact-Finding Study

PLATE 2



DEPARTMENT OF MINERALS AND ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS
COMPILED AND DRAWN IN THE GEOPHYSICAL BRANCH

ALLIGATOR RIVERS REGION
INTERPRETATION OF AIRBORNE GEOPHYSICAL RESULTS

SCALE 1 : 250 000

KILOMETRES 5 0 5 10 15 20 25 30 KILOMETRES

MILES 5 0 5 10 15 MILES

INDEX TO 1:250 000 MAP SERIES

MELVILLE ISLAND	COBOURG PENINSULA	JUNCTION BAY
DARWIN	ALLIGATOR RIVER	MILINGIMBI
PINE CREEK	MT EVELYN	MT MURUMBA

11°00' 14°00' 130°30' 135°00'

LEGEND

RADIOMETRIC

Anomaly predominantly due to potassium ◆
" " " " uranium ●
" " " " thorium ▼
Anomaly of mixed source ■
Anomaly reference number 23

MAGNETIC

Magnetic zone boundary
Magnetic zone reference label A
Interpreted fault
Linear magnetic feature

KEY TO MAGNETIC ZONES

LABEL	PROBABLE GEOLOGICAL CORRELATION
A B C D E	Nanambu Complex
G	Koolpin Formation equivalent
H	Dolerite
J	Koolpin Formation
K	Koolpin Formation and/or Koolpin Formation equivalent, Mt Partridge Formation and dolerite
L	Mt Partridge Formation
M	South Alligator fault zone
N	Plum Tree Creek Volcanic Member
O	Nimbuwah Complex
P	Mullaman Beds

TOPOGRAPHIC

TO ACCOMPANY RECORD NO.1973/208

BMR. RECORD 1973/208

D53/B1-26