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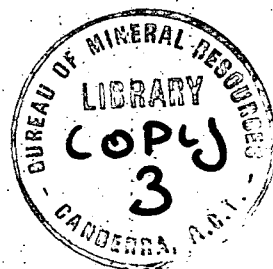
DEPARTMENT OF
MINERALS AND ENERGY



BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/37

URANIUM MINERALIZATION IN THE RUM JUNGLE- ALLIGATOR RIVERS PROVINCE, NORTHERN TERRITORY, AUSTRALIA



by

R.G. Dodson, R.S. Needham, P.G. Wilkes, R.W. Page, P.G. Smart,
and A.L. Watchman

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Geology and Geophysics, Canberra, Australia.

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SYNOPSIS

Renewed interest in uranium exploration in northern Australia in the late 1960s led to the discovery of one of the most important uranium fields in the world. To obtain an understanding of the geological setting of the uranium deposits, and to provide guidelines for future exploration, the Bureau of Mineral Resources (BMR) undertook an investigation which included semi-detailed mapping, aided by geophysical surveys, isotopic dating, and stratigraphic drilling. From the results so far obtained, and from the important data made available by mining companies engaged in exploration in the region, a pattern of uranium mineralization can be recognised, particularly in relation to the Lower Proterozoic sedimentation of the region.

INTRODUCTION

In a review of the more important environments of Australian uranium deposits, Dodson¹ pointed out that 'Future exploration of the Alligator Rivers area will be greatly assisted if the genesis of uranium ore is established.' Since delivery²⁻⁴ of the paper (September 1970), semi-detailed geological mapping⁵ and geophysical surveys by the Bureau of Mineral Resources (BMR), and investigations by mining companies, have added considerably to our knowledge of the geological setting of these deposits. Although certain assumptions cannot be fully substantiated at present, we believe that we are close to understanding the origin of the ore. Conversely, certain hypotheses put forward in the past appear less likely as new data are obtained.

Following the discovery of uranium at Rum Jungle in 1949, the Katherine-Darwin region was mapped at reconnaissance scale by BMR⁶. The survey established the main outlines of the regional geology, and identified the most favourable environments for uranium. The resulting 1:250 000 geological maps formed the basis for more detailed mapping and the planning of exploration when interest in uranium was revived at the close of the 1960s. In 1970, following the discovery of high-grade uranium ore in the Alligator Rivers area about 250 km east-northeast of Rum Jungle, a start was made on semi-detailed geological mapping aided by geophysical surveys, isotopic dating, and stratigraphic drilling. The area being mapped consists of the whole of the Alligator River 1:250 000 Sheet area and parts of the Cobourg Peninsula, Junction Bay, Milingimbi, and Mount Evelyn Sheet⁷ areas (Fig. 1.) A similar but more restricted program at Rum Jungle commenced in 1972. The aim of the current program is to determine the geological setting of the newly discovered uranium deposits, to correlate the geology of the uraniferous areas with each other, and to establish the origin of the mineralization.

GEOLOGY OF THE URANIUM DEPOSITS

With the exception of a few minor prospects, all known uranium deposits of the province occur in Lower Proterozoic sediments of the Pine Creek geosyncline. The deposits are concentrated in three areas: Rum Jungle, South Alligator River valley, and an area between the South Alligator River and Cooper Creek, known for convenience as the Alligator Rivers area. Perhaps the most important clue to the origin of uranium in this province that has resulted from the present

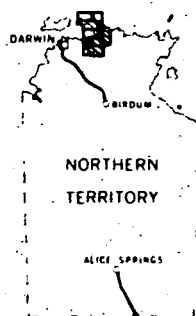
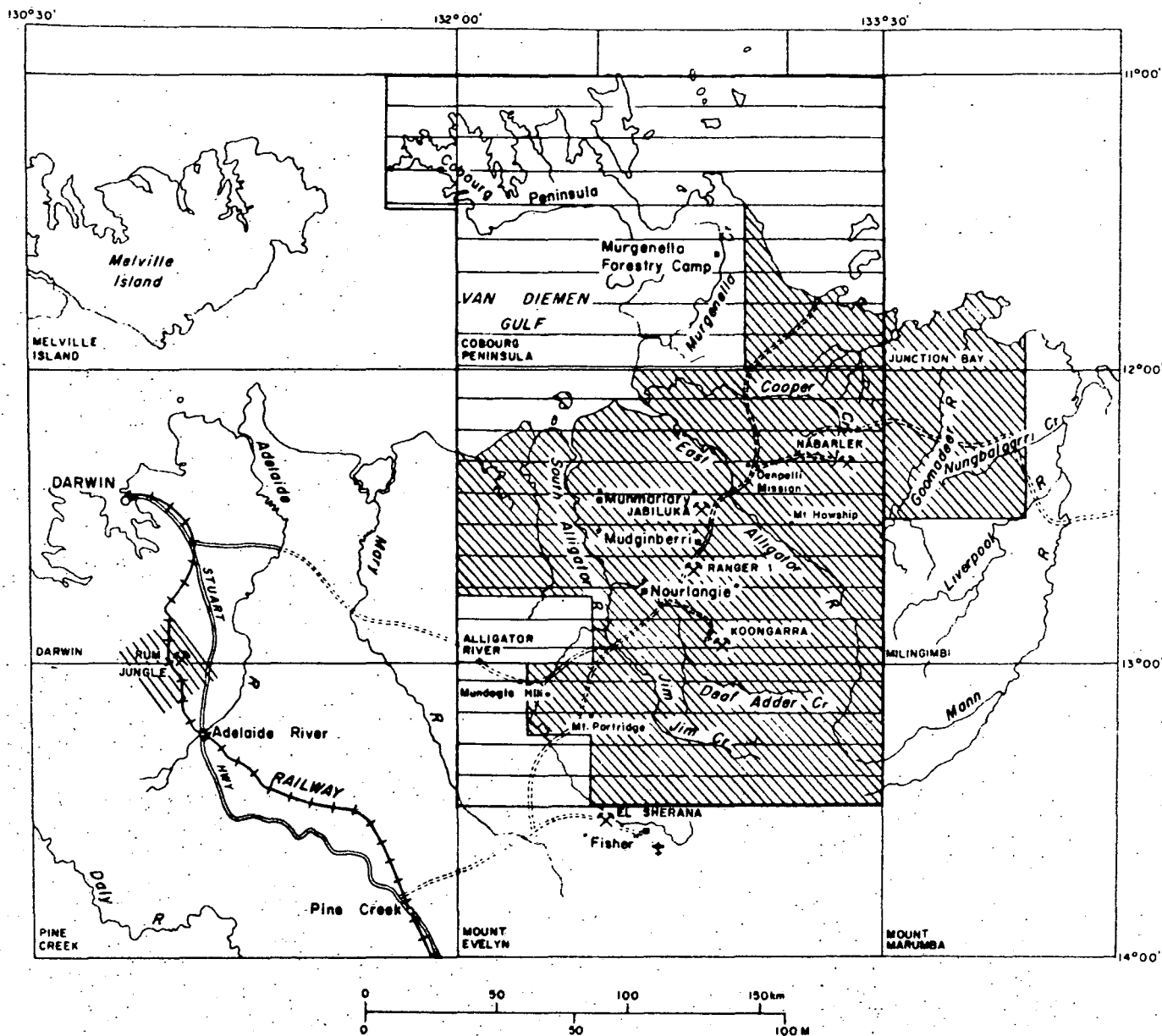
investigation is the recognition of a stratigraphic control on the distribution of uranium. In the Alligator Rivers area, both the uranium deposits and untested uranium prospects lie in the same sequence, and there are sound reasons for correlating the succession at the Alligator Rivers area with those of the South Alligator River valley and Rum Jungle. Both the Rum Jungle⁸ and South Alligator River valley^{9,10} deposits have been described in detail, and are therefore only briefly outlined in this paper. The more recently discovered deposits of the Alligator Rivers area are less well known; details of their environment are only now becoming available as geological and geophysical investigations in the area progress.

Rum Jungle

Lower Proterozoic sediments are draped around a core of the Pine Creek Geophysical basement, the late Archaean Rum Jungle Complex. The sediments dip steeply away from the complex, indicating post-Archaean updoming of the complex at the close of sedimentation in the Pine Creek Geosyncline. Further evidence of this updoming has been provided by the discovery of a sheared contact between the Rum Jungle Complex and the Lower Proterozoic sediments (K. Johnson, pers. comm., 1974).

Rhodes¹¹ distinguished six major units in the southern part of the Rum Jungle Complex, in order of decreasing age: Schists and gneisses, granite gneiss, metadiorite, coarse granite, large feldspar granite, and leucocratic granite. Banded ironstone and quartzite have also been recorded in the complex. The uranium contents of these rocks range from a low 2.8-4.5 ppm in the metadiorite to 10-28 ppm in the leucocratic granite¹². Rb-Sr dating of the leucocratic granite has yielded a whole-rock isochron of about 2400 m.y., and three zircons from different parts of the complex yielded an extrapolated U-Pb age of around 2550¹³ m.y. Evidence of post-Archaean activity in the complex is provided by the presence of quartz-tourmaline veins radiating from centres in the complex and invading the overlying Lower Proterozoic rocks (K. Johnson, pers. comm., 1974).

The complex is cut by the Giant's Reef Fault, which strikes northeast and has a horizontal displacement of about 6 km.



DARWIN 1:250 000 sheet area



Area covered by current
geophysical surveys



Area covered by current
detailed mapping programme

Regional Gravity coverage
exists for 1 250,000 sheets
Cobourg Peninsula, Alligator River,
Mount Evelyn (Not published)

✕ Uranium mine or prospect

Fig 1 Locality map Rum Jungle Alligator Rivers Uranium Province
To accompany Record 1974/37

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During the Lower Proterozoic, sediments of the Batchelor Group (Beestons Formation, Celia Dolomite, Crater Formation, and Coomalie Dolomite; see Fig. 2) were deposited against and around the Rum Jungle Complex. The Batchelor Group sediments were in turn overlain by sediments of the Goodparla Group, represented at Rum Jungle by the Golden Dyke Formation and the Acacia Gap tongue, which underlies and interfingers with the Golden Dyke Formation. The Batchelor Group sediments were deposited in littoral to neritic conditions; the overlying Goodparla Group sediments were deposited in a shallow marine, partly euxinic environment. Both the Batchelor Group and the Goodparla Group sediments were overlain by the Finnis River Group, represented in the Rum Jungle area by the Noltenius Formation. The Burrell Creek Formation is a lateral facies variation of the Noltenius Formation.

The five small uranium deposits were in Lower Proterozoic schist, siltstone, and shale of the Golden Dyke Formation of the Goodparla Group. The lodes were located in shears, faults, and, at Rum Jungle Creek South, in a tight fold, the host rock being carbonaceous sediments or chloritic slate, near the contact with the underlying Coomalie Dolomite.

South Alligator River valley

The Lower Proterozoic sediments of the South Alligator River valley area are lithologically similar to and are stratigraphically relatable to the Lower Proterozoic sediments of the Rum Jungle area.

Basement rocks of the Pine Creek Geosyncline are not exposed in the valley. The Stag Creek Volcanics, tentatively assigned to the Archaean by Walpole et al. ⁶, are considered in the light of recent field work to be Lower Proterozoic; the unit occurs in sequence with Lower Proterozoic sediments at the top of the Masson Formation, underlying the Mount Partridge Formation, both of the Goodparla Group. In the South Alligator River valley the Mount Partridge Formation is overlain by the South Alligator Group, consisting of the Koolpin Formation and its facies variant, the Gerowie Chert, and the overlying Fisher Creek Siltstone.

Allowing for lateral facies changes, the Lower Proterozoic

successions at Rum Jungle and the South Alligator River valley are similar. K. Johnson (pers.comm., 1974) believes that sediments of the Batchelor Group lens out within a short distance of the Rum Jungle Complex, and are interbedded with sediments of the Masson Formation and Golden Dyke Formation, as shown in Figure 2. In the vicinity of Mundogie Hill north of the South Alligator valley, the Masson Formation is overlain by the Stag Creek Volcanics and The Mount Partridge Formation, which is overlain by the Koolpin Formation, a unit similar lithologically to the Golden Dyke Formation.

The uranium deposits of the valley consisted of thirteen small but mostly high-grade deposits distributed along a 19km section of a fault zone along the South Alligator River valley. Almost all the uranium ore in the Lower Proterozoic rocks is in steeply dipping Koolpin Formation black carbonaceous shale. Uranium is also contained in volcanics and sandstone of the Carpentarian Edith River Volcanics at Coronation Hill and Saddle Ridge, and in sandstone of the Carpentarian Kombolgie Formation at Palette. Where pitchblende occurs in the sandstone the host rock is mostly in contact with carbonaceous shale of the Koolpin Formation. The lodes are in the form of veins, stringers, or pods located in shears and cross-fractures along the main fault zone, which strikes north-northwest.

Alligator Rivers area

The geology of the Alligator Rivers area is dominated by two large complexes - the Nanambu and Nimbuwah Complexes - surrounded by Lower Proterozoic metamorphic rocks which grade into unmetamorphosed sedimentary units of the Goodparla and South Alligator Groups. Rb-Sr geochronological studies have demonstrated that the geological histories of the two complexes are different. The Nanambu Complex (Fig. 3) extends over about 3500 sq km in the centre of the area and consists of a core of granitoid rocks, leucogneiss, and migmatite, mantled by Lower Proterozoic sediments. It is surrounded by metamorphosed Lower Proterozoic sediments. Metamorphic grade decreases away from the complex, and arkose, sandstone, and siltstone are exposed southwest of Jim Jim Creek. Isotopic dating has revealed that the granitoid core of the complex is Archaean, suggesting that the Lower Proterozoic rocks that now form the outer mantle of the complex were draped around a

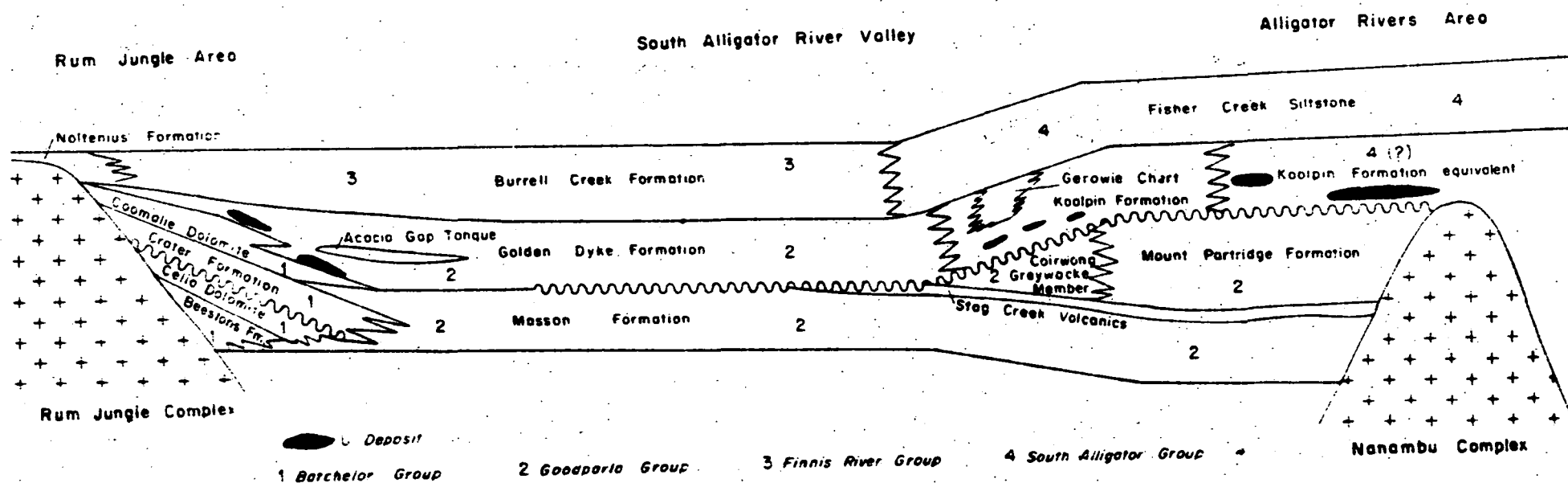


Fig.2 Relationship of the Lower Proterozoic rock units Rum Jungle, Alligator Rivers Uranium Province

THE DISTRIBUTION OF GROUPS SHOWN HERE WAS PROPOSED BY WALPOLE ET AL 1966, AND IS SUBJECT TO AMENDMENT PENDING COMPLETION OF FIELD MAPPING NOW IN PROGRESS. THE FORMATION CORRELATIONS SHOWN ARE BASED ON THE RECENT MAPPING

NT/A/405

CAINOZOIC AND MESOZOIC

Superficial Deposits

CARPENTARIAN

Komboyne Formation

LOWER PROTEROZOIC

Undifferentiated

Golden Dyke Formation

Koolpin Formation

Koolpin Formation
Equivalent

LOWER PROTEROZOIC TO
ARCHAEOAN

Granites and Granitic
Complexes

Uranium Deposits

Settlement

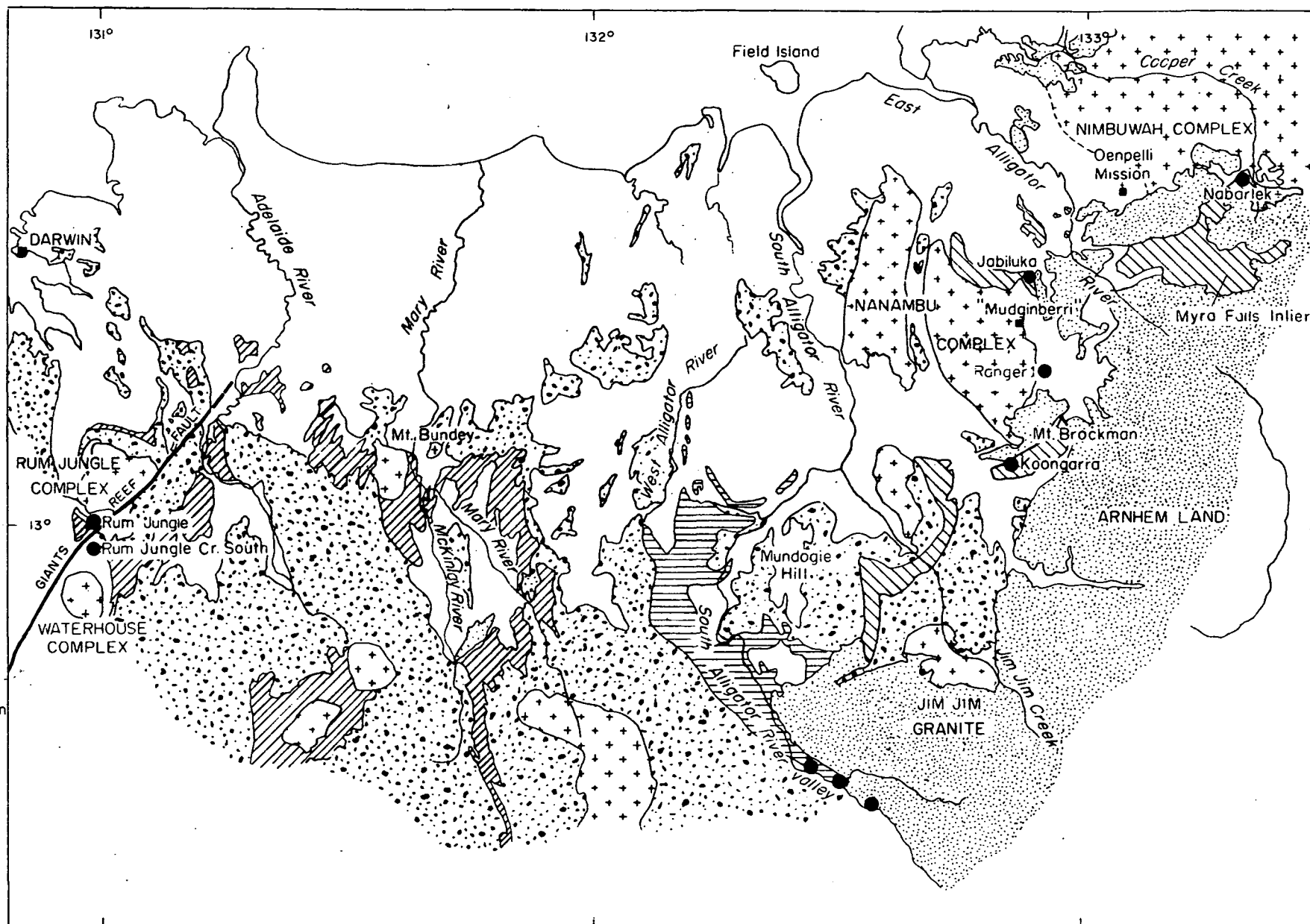


Fig. 3 Distribution of Golden Dyke Formation, Koolpin Formation, and Koolpin Formation equivalent rocks.

basement high. The antiquity of part of the granitoid core of the Nanambu Complex has been established by Rb-Sr total-rock isochrons, the oldest of which is 2520^{+30} m.y. (initial Sr 87/Sr 86 = $0.704^{+0.001}$). Other parts of the complex yield isochron ages of around 1800 and 2000 m.y., but with rather high initial Sr 87/Sr 86 ratios (up to 0.78). The Lower Proterozoic ages represent partial or complete resetting of the total rocks at the time of the 1800 m.y. metamorphism. Mica ages, obtained by K-Ar and Rb-Sr methods, also reflect the 1800 m.y. event.

The Nimbuwah Complex to the northeast extends over about 10 000 sq km. Its northeastern and southern extents are masked by Carpentarian and younger sediments; its true extent may exceed 20 000 sq km. Walpole et al.⁶ ascribed an Archaean age to schist and quartzite (Myra Falls Metamorphics)¹⁴ which crop out mainly east of the East Alligator River. Needham et al.¹⁴, however, have shown these rocks to be metamorphosed and mylonitized equivalents of the Lower Proterozoic South Alligator Group, and that in migmatized form they constitute the outer zones of the Nimbuwah Complex. The complex has been divided into zones which represent increasing degrees of migmatization and/or mobility towards the centre. The zonation represents a classical gradation of migmatite types from incipiently migmatized schists to completely homogenized and mobilized granitoid anatectites in the centre. All of the migmatite types described by Mehnert¹⁵ have been recognized. South Alligator Group sediments have been fully incorporated into the outer zones of the Nimbuwah Complex, and in the Myra Falls Inlier cross-bedded quartzite, carbonaceous schist, dolomitic marble, and amphibolite within banded and lit-par-lit gneiss masses are considered to be metamorphic equivalents of the Koolpin Formation. The inner zones of the complex may also have been formed by migmatization of Lower Proterozoic units which have been highly migmatized. Field evidence is not conclusive, however; the Nimbuwah Complex could have an Archaean core like the Nanambu Complex. An 1840 m.y. Rb-Sr total rock isochron age obtained for the Nimbuwah Complex represents the time at which Rb and Sr became fixed in the rocks shortly after the peak of the migmatization and metamorphism.

Altered pink biotite granites, all anomalously radioactive, are thought to be anatectic and produced by mobilization of migma developed in the centre of the Nimbuwah Complex during migmatization. They are probably comagmatic with the Edith River Volcanics, a series of acid

volcanics best exposed in the South Alligator valley where they unconformably overlie folded South Alligator Group sediments. The acid igneous rocks mark the last Lower Proterozoic event.

Lower Proterozoic sediments of the Alligator Rivers area comprise the Masson and Mount Partridge Formations of the Goodparla Group and the Koolpin Formation equivalent and Fisher Creek Siltstone of the South Alligator Group (Fig. 2).

Masson Formation rocks are the oldest sediments in the Pine Creek Geosyncline, and crop out between the South Alligator River and McKinlay River and Mount Bunday. The formation is predominantly quartz greywacke, carbonaceous siltstone, calcareous siltstone, and conglomerate about 3000 m thick.

Arkosic sandstone, siltstone, and conglomerate of the Mount Partridge Formation conformably overlie the Masson Formation. The Mount Partridge Formation appears to be wedge-shaped, and has a maximum thickness of about 3000 m; deposition was probably confined to the west and southwest flanks of the Archaean core of the Nanambu Complex. The formation thins out westwards, and west of the South Alligator River valley is continuous with the Coirwong Greywacke.

The South Alligator Group unconformably overlies the Goodparla Group and appears to onlap the Archaean core, although this relation is not clearly observable in the field. The Koolpin Formation metamorphic equivalent of the Alligator Rivers area also differs lithologically from the Koolpin Formation type section of the South Alligator Valley; it is composed of chlorite-muscovite schist, carbonaceous schist, amphibolite, quartzite and gneiss with lenses of massive carbonate rock near the base of the sequence.

The Fisher Creek Siltstone gradationally overlies Koolpin Formation and its equivalent. It is a homogeneous sequence of siltstone and arenaceous siltstone, metamorphosed to phyllite and schist north of Jim Jim Creek. The Fisher Creek Siltstone is the youngest Lower Proterozoic unit to be deposited in the Alligator Rivers and South Alligator River valley areas, and is believed to be the lateral equivalent of the Burrell Creek Siltstone and Noltenius Formation farther west.

Two series of basic igneous rocks intrude Lower Proterozoic rocks: the Zamu Complex diorite, dolerite, and differentiates which were emplaced as numerous sills prior to migmatization, and subsequently altered in places to amphibolite, and the Oenpelli Dolerite*, emplaced as a large undulating flat lying discordant sheet soon after metamorphism and migmatization. The absence of hornfelsing adjacent to the dolerite where it intrudes the inner zones of the Nimbuwah Complex suggests that the Oenpelli Dolerite was emplaced before the migmatite complex had cooled.

Phonolitic and sodic trachyte dyke swarms intrude one small area, near Mudginberri homestead in the Nanambu Complex (Mudginberri Phonolite*).

The Carpentarian Kombolgie Formation sediments unconformably overlie Lower Proterozoic rocks, and form the most prominent feature in the region, the Arnhem Land Plateau. The Kombolgie Formation consists of lower (about 300 m) and upper (about 150 m) medium to coarse sandstone units separated by the basic Nungbalgarri Volcanic Member which consists of one or more flows with minor intercalated sediments. The volcanic member ranges from 0-70 m in thickness. The upper sandstone unit includes a thin (up to 3 m) volcanic layer comprising tuff, tuffaceous siltstone, and basalt known as the Gilruth Volcanic Member*. The Carpentarian plateau sandstone covers most of the north-east, east, and southeast of the region mapped.

Post-Carpentarian rocks in the region cover extensive areas. They include terrestrial Mesozoic sediments which form low plateaux in the northern part and underlie Cainozoic sand plains in the centre. A recent coastal submergence has resulted in extensive alluvial accumulation along major rivers; the flood plains are seasonally inundated by brackish water up to 100 km inland during the wet season.

During parts of 1971 and 1972, BMR made an airborne magnetic and gamma-ray spectrometric survey of the Alligator Rivers area¹⁵. The airborne geophysics was designed to assist the semidetalled

(* Informal name)

geological mapping and the uranium search in the area particularly where the surface geology is covered by superficial deposits (see Figs 1, 3). It was hoped that the radiometric and magnetic characteristics of individual rock units would prove sufficiently distinctive to allow recognition of hidden rock units. The survey was of a regional nature; east-west lines were flown 150 metres above the ground with a spacing of 1.5 km.

Many of the magnetic anomalies are of shallow or surface origin, and their correlation with geological units has been helpful in tracing these units beneath the extensive overburden which covers much of the area to the west and north of the Arnhem Land Plateau escarpment. The more magnetic of the geological units appear to be the Stag Creek Volcanics, Koolpin Formation, Koolpin Formation equivalent, Zamu Complex dolerite, and Oenpelli Dolerite.

The magnetic data show that the Nanambu Complex is only weakly magnetic (anomalies generally less than 30 gammas). This complex is surrounded by rocks of Koolpin Formation equivalent, and locally by Oenpelli Dolerite. Both of these exhibit stronger magnetic expression (anomalies up to 300 gammas). Mapping these magnetic features permits indirect interpretation of parts of the margin of the complex. Magnetic interpretation has also indicated the likelihood of two further areas of Nanambu Complex to the north of the main mass, and this has been confirmed by shallow drilling. The Nimbuwah Complex, however, has a very variable and complex magnetic expression, and its extent seems impossible to determine from the magnetic and radiometric data.

The Koolpin Formation equivalent exhibits very variable magnetic expression, with anomaly amplitudes ranging from less than 10 gammas (in the Myra Falls Inlier) to possibly as high as 300 gammas (to the west of Koongarra.) This makes it difficult to trace its full extent, and also to see whether it is continuous with the Koolpin Formation.

Dolerites appear to be much more widespread than originally mapped. Magnetic anomalies are associated with both the Zamu Complex dolerite and the Oenpelli Dolerite. Interpretation of the magnetic data indicates that many of the surface exposures are parts of larger continuous dolerite bodies in the subsurface.

The airborne radiometric results have identified areas of higher than average radioactivity, and provided an indication of the predominant sources of the radioactivity - i.e., whether due to uranium, thorium, or potassium.

The radiometric anomalies of highest amplitude were recorded over three of the major uranium deposits (Ranger 1, Nabarlek, and Koongarra), various uranium prospects, granite masses, and a large hill of Mount Partridge Formation (Mount Basedow). The BMR survey did not fly directly over the Jabiluka uranium deposit, which appears to have been too far from the nearest lines to be detectable.

Forty anomalies were classified as 'uranium anomalies'. For this purpose a uranium anomaly was defined as one where potassium was not the major source and the uranium-to-thorium ratio was roughly two or greater (assuming equilibrium to be achieved in both the uranium and thorium decay series). The host rocks for these 'uranium anomalies' are Nanambu Complex, Nimbuwah Complex, Koolpin Formation equivalent, Mount Partridge Formation, and laterites associated with the volcanic members of the Kombolgie Formation.

All the granite masses are anomalously radioactive, potassium and thorium being the major sources. Similarly, the anomalous radioactivity of the large hill of Mount Partridge Formation, referred to earlier, is due to potassium and thorium.

The sandstone of the Kombolgie Formation is very low in radioactivity. However, certain laterites that developed down slope from the Nungbargarri Volcanics and the Gilruth Volcanic Member are somewhat radioactive, with moderately high uranium-to-thorium ratios. It is considered that these are only surface features, and that the laterite is a concentrating agent for the uranium.

¹ The Alligator Rivers uranium deposits were briefly described by Dodson¹ in 1971. Since then exploration has proved extensions of known lodes, and much has been learnt about the geology of the deposits through drilling and trenching. From north to south the deposits are: Nabarlek (Queensland mines Ltd), Jabiluka (Pancontinental Mining Ltd), Ranger 1 (Peko-Wallsend - E.Z. Industries Ltd), and Koongarra (Noranda Ltd).

Nabarlek^{16,17} consists of two high-grade lensoid lodes composed of ore richer than 10 percent U_3O_8 , surrounded by a zone of lower-grade ore 230 m long and up to 20 m wide. Massive pitchblende coated with secondary minerals was intersected at 1.5 m below the surface, and the ore extends to a depth of about 70 m, lensing out above a thick flat-lying dyke of Oenpelli Dolerite. Disseminated uranium minerals occur along strike for a total of about 270 m. The lode strikes north-northwest, parallel to the schistosity of the host rock (quartz-chlorite-muscovite schist of the Koolpin Formation equivalent), and dips to the east at 30-45°.

In two deep drill-holes at Nabarlek, granite was intersected about 500 m below the surface.

Nabarlek has estimated reserves of 9540 tonnes U_3O_8 (402 000 tonnes of ore of an average grade of 2.37 percent U_3O_8).

Jabiluka¹⁷ is situated about 50 km southwest of Nabarlek, close to the Arnhem Land Plateau. Pancontinental Mining Ltd announced the discovery of Jabiluka 1 in January 1973. The lode trends west-southwest away from the Arnhem Land Plateau and dips south at about 45°. The ore zone is up to 30 m thick and about 150 m long, and extends to a depth of about 105 m. Primary ore is pitchblende in quartz-chlorite carbonaceous schist of the Koolpin Formation equivalent. Pyrite and chalcopyrite are minor constituents in the lode, and gold is locally present. Secondary uranium ore is disseminated through a narrow zone in the Kombolgie Formation sediments, possibly deposited by hypogene enrichment.

In September 1973 Pancontinental Mining Ltd announced the discovery of Jabiluka 2, about 480 m to the east of Jabiluka 1 and beneath the Kombolgie Formation sediments of the Arnhem Land Plateau. Jabiluka 2 is similar in geological setting to Jabiluka 1 but it is much larger: the ore zone is up to 49 m thick, and at depths of between 61 m and 192 m below the surface. The length of Jabiluka 2 has not been fully tested.

Ore reserves announced by Pancontinental Mining Ltd on 20 December 1973 were: Jabiluka 1-3490 tonnes U_3O_8 ; Jabiluka 2-19 580 tonnes U_3O_8 .

An anomalous zone in the same exploration licence area known as Prospect 7J is as yet not fully tested. Secondary uranium minerals are present at the surface and gold values as high as 23 g/tonne were recorded in the ore.

Ranger 1^{18,17} consists of six radiometric anomalies grouped in a roughly north-trending arc-like zone about 6.5 km long and up to 1 km wide, approximately 25 km south of Jabiluka. Of the six anomalies, Nos. 1 and 2 have been fully tested; ore grade uranium has been intersected at anomalies 2, 4, and 5. The host rocks at Ranger 1 are known to the company geologists as the 'Mine Series' or 'Mine Sequence' - a sequence readily divisible into upper and lower units. The Mine Series is considered by BMR geologists to be part of the Koolpin Formation equivalent. The Lower Mine Series consists of biotite-feldspar-quartz schist overlain by a discontinuous band of dolomite and biotite-quartz schist. In the mineralized part, the schist is chloritized. Carbonaceous schist is locally present in the sequence. The Mine Series is intruded by pegmatite and dolerite, both of which are heavily altered in the mineralized parts.

The uranium is present mostly as primary pitchblende-rich chloritic veinlets infilling cracks and fissures, mainly in the Lower Mine Series but also in the Upper Mine Series. In the Upper Mine Series, uraniferous veinlets tend to be concentrated around fragments of brecciated chlorite schist. Pitchblende is also present as fine grains disseminated through veins and in mineralized zones in chloritic host rocks. Copper, lead, and gold are erratically distributed through the ore. Ore reserves for anomalies 1 and 3 announced by Peko Wallsend Ltd (1972-73 Annual Report) confirmed an earlier estimated figure (1972) of 82 500 tonnes U_3O_8 .

The Koongarra^{19,17} deposit is located about 20 km south-south-west of Ranger 1. The deposit lies close to the southern side of the Mount Brockman massif, an outlier of Kombolgie Formation sandstone. The mineralized zones are roughly conformable with the schistosity of the host rock and parallel to a major reverse fault dipping at about 60° to the southeast. The fault plane coincides with the southeastern margin of the Mount Brockman massif, and has brought the Lower Proterozoic host rock into contact with unmineralized Kombolgie Formation sandstone. The faulted contact is intensely brecciated and marks the footwall of

the mineralized zone; the hangingwall is a carbonaceous horizon, some 70 m above and nearly parallel to the fault. The orebodies consist of a series of en echelon zones of disseminated uranium minerals. The zones enclose cores of higher-grade ore. Host rock to the ore is Lower Proterozoic quartz-chlorite-muscovite schist of the Koolpin Formation equivalent. Graphite and garnet are accessory minerals. In the primary ore the uranium mineral is pitchblende; minor pyrite, chalcopyrite, galena, and a trace of gold are associated with the ore.

To date no announcement has been made on the ore reserves of Koongarra.

GENESIS OF THE ORE

The current BMR program has shown that metasediments originally considered to be Archaean are the metamorphosed equivalent of Lower Proterozoic sediments (South Alligator Group) exposed in the South Alligator River valley. Field investigations have provided evidence for the correlation of the Koolpin Formation, host rock to most of the uranium deposits in the South Alligator River valley, with the Koolpin Formation equivalent, which is the host rock to the uranium deposits at Nabarlek, Jabiluka, Ranger, and Koongarra (See Fig. 3.) and also, we believe with the Golden Dyke Formation, host rock to the uranium deposits at Rum Jungle. The concentration of uranium in the Koolpin Formation and its correlatives suggests a syngenetic enrichment of uranium during sedimentation. The source of uranium is not known, but it is assumed that the provenance was sufficiently enriched in uranium to make uranium available during sedimentation. (Archaean rocks at Rum Jungle, from which some of the sediment was derived, have anomalously high uranium content, ranging from 2.8 to 28 ppm U_3O_8). The high carbonaceous content of the Koolpin Formation and equivalents (up to 5 percent) would provide a reducing environment, during sedimentation, capable of precipitating uranium.

Assuming syngenetic enrichment of uranium in favourable units in the Lower Proterozoic sequence, there remains an important consideration: the mechanism responsible for the concentration of uranium into ore deposits.

The orebodies occupy faults, shears, and breccias or, as at Rum

Jungle Creek South deposit, are contained in a fold. This relation may be due to the squeezing-out of mineralized solutions from a sedimentary pile into²⁰ centres of low stress during a tectonic event as suggested by Roberts²⁰. However, the proximity of the major deposits to the mantled gneiss domes suggest that mineralization was also related to orogenic activity responsible for the rejuvenation of Archaean igneous masses, and the intrusion of other igneous masses at about 1800 m.y. Extensive zones of alteration, mostly chloritization and sericitization, around the deposits of the Alligator Rivers area in particular indicate a mesothermal mineralization temperature range. Uranium-lead ages and lead isotopic compositions of ore from the Alligator Rivers area point to at least four pitchblende ages: 1880, 1700, 900, and 500 m.y. The ages support the suggestion of syngenetic deposition of uranium in the Lower Proterozoic sediments before 1880 m.y. and uranium concentration at 1700 m.y., perhaps by remobilization of pre-existing uranium accumulations, followed by periods of lead loss at 900 m.y. and 500 m.y. - ages which cannot be related to an igneous or tectonic event. (Hills & Richards, pers. comm., 1974)

The spatial distribution of uranium deposits and prospects around the Nanambu, and Rum Jungle complexes suggests a relation between the mineralization and a major igneous phase (1700-1800 m.y.) responsible for the renewal of activity in the pre-existing Archaean masses and for the emplacement of large granitic masses in the province and elsewhere in northern Australia. The nature of this relation is not known, but judging from the comparatively low grade of hydrothermal alteration in ore zones throughout the province, we consider that the mineralizing solutions did not originate from the granitic masses. More probably the mineralizing solutions were fluids isolated by lithification of the Lower Proterozoic sediments and mobilized during the igneous and contemporaneous tectonic phases.

The uranium deposits of the South Alligator River valley occur close to, and in some places in, volcanics and sediments of the Edith River Volcanics. The uranium content of these volcanic rocks has been considered as a possible source of the ore in this area. However, the Edith River Volcanics could not have been responsible for the formation of deposits elsewhere in the province. We believe therefore that the part played by the Edith River Volcanics in uranium mineralization is small, if not insignificant.

During the current investigations, attention has been paid to the Kombolgie Formation, a massive Carpentarian sedimentary sequence which might be considered as a source rock²¹ from which uranium was leached and then precipitated in a suitable environment. As previously stated, the Kombolgie Formation consists of lower and upper sandstone units separated by the basic Nungbalgarri Volcanic Member composed of interbedded volcanics and sediments. The upper sandstone unit includes a thin volcanic unit, the Gilruth Volcanic Member*. The sandstone components of the Kombolgie Formation are composed of compact quartz sandstone and interbeds of pebble conglomerate, both being characteristically low in radioactivity. The Nungbalgarri Volcanic Member is also of low radioactivity. However, significant radiometric anomalies have been recorded over laterite developed locally down-slope from the volcanic members. Anomalous radioactivity is a feature common to most laterites in the Rum Jungle-South Alligator River valley and the Alligator Rivers area.

Concentration of ore near the present-day land surface at some deposits in the Rum Jungle area and at Saddle Ridge in the South Alligator River valley suggests that supergene enrichment has taken place locally, probably by solution and accretion as the surface has been lowered by erosion. At the other deposits, such as Palette in the South Alligator River valley, uranium in the overlying Kombolgie Formation sediments is believed to be a product of hypogene enrichment.

We concluded that the following sequence of events has been responsible for the formation of the uranium deposits of the Rum Jungle-Alligator Rivers Province:

- (1) Syngenetic enrichment of uranium in carbonaceous sediments during the Lower Proterozoic.
- (2) Concentration of ore-grade deposits of uranium minerals in favourable places from mineralized solutions mobilized during a major igneous/tectonic event.
- (3) Relocation of uranium by circulating solutions through leaching and redeposition not far away.

(* Informal name)

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