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SOME ENVIRONMENTS OF FORMATION OF URANIUM DEPOSITS

by

R.G. Dodson

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SUMMARY

Uranium minerals in Australia occur in a variety of host rocks; their wide range of occurrence is mainly due to the chemical characteristics of uranium, notably the high solubility of the uranyl ion. Regional distribution of uranium is discussed and an account given of conglomerate and sandstone deposits, with brief descriptions of areas in Australia which have been prospected for such deposits. Some other Australian uranium deposits are described and brief histories of their exploration given. The oregenesis of the recently discovered deposits of Northern Australia, collectively known as the Alligator Rivers deposits, is discussed; the writer considers a syngenetic origin, an origin dependent on leaching of uranium from a massive source with subsequent deposition in a suitable environment, and deposition from mineralized solutions introduced by igneous activity.

INTRODUCTION

Economic deposits of uranium occur in a variety of geological environments - in extrusive or intrusive rocks, in metamorphic rocks, and in stratiform and non-stratiform sedimentary deposits. By far the largest known reserves of uranium occur in sediments. The variety of geological environments in which uranium mineralization is found is due to the high solubility of the uranyl ion $(UO_2)^{2+}$, its isomorphism with certain elements such as calcium, iron, zirconium, and thorium, and the stability range of uraninite (Heinrich, 1958 p. 154). Acid igneous rocks on average contain about ten times as much uranium as ultrabasic rocks. The average content of uranium in igneous rocks is as follows:

Type	Uranium (p.p.m.)
Ultrabasic	0.3
Basic	1
Basaltic	1
Intermediate	1.5 - 3
Granitic	4

Uranium Provinces

The concept of regional uranium enrichment has been discussed by Davidson 1951; Saum & Link 1969; and Klepper & Wyant 1955. A uranium province is defined by the writer as a region in which anomalous concentrations of uranium occur either in a single formation or in a variety of host rocks in one general area. The uranium may have been deposited in a single epoch, or it may be the product of more than one phase of mineralization. In Australia uranium is concentrated in three regions or 'uranium provinces' (Dunn & Dodson, in prep.):

(1) Rum Jungle/Alligator Rivers

(2) Mary Kathleen/Westmoreland; and

(3) Mount Painter/Radium Hill.

In the Rum Jungle/Alligator Rivers province, mineralization is largely contained in Lower Proterozoic (2300-1800 m.y.) sediments, in the Mary Kathleen/Westmoreland province within sediments and volcanic rocks of Carpentarian age (1800-1400 m.y.), Dunn et al. (1966), and in the Mount Painter/Radium Hill province within metamorphic rocks and granite also of Carpentarian age, as well as in early Tertiary sediments derived from the older rocks (see Fig. 1). The Rum Jungle uranium deposits in rocks of Lower Proterozoic age are about 190 km from the present outcrop edge of Carpentarian rocks, but the present land surface at Rum Jungle is believed to correspond closely with the unconformity surface from which the younger rocks have been removed by erosion. No palaeogeographic connection between the three Australian uranium provinces is known.

GEOLOGICAL ENVIRONMENTS

Assuming an adequate source of uranium, concentration of ore is dependent on geological environment. The most important types of orebody throughout the world are:

Conglomerate type deposits

Sandstone deposits

Vein deposits

In Australia no exploitable uraniferous conglomerate has been discovered, although selected areas have been investigated for this type of deposit. Uranium deposits in sandstone have been discovered in South Australia and at present are being tested. No significant vein deposits occur in Australia. As examples of different geological environments of deposition, the uranium deposits of the Rum Jungle/Alligator Rivers province, the Mary Kathleen mine, and the area extending northwest from Mary Kathleen to Calvert Hills, are also described.

Conglomerate type deposits such as those of the Elliot Lake area, Canada (Joubin, 1960, pp. 1751-6; Roscoe & Steacy, 1956, pp. 475-83), and Witwatersrand, South Africa (Heimstra, 1968, pp. 1-67; Ramdohr, 1958), constitute by far the greatest known reserves of exploitable uranium in the western world. In the conglomerates of the Elliot Lake area and the Witwatersrand, the uranium and associated gold are found in quartz pebble beds interbedded with predominantly arkosic and other quartzose sediments derived at least in part from acid igneous rocks. The pebble beds typically consist of subrounded to rounded quartz pebbles set in a matrix of fine recrystallized quartz grains, sulphides (mainly pyrite), sericite, chlorite, secondary quartz, carbonaceous material, and accessory minerals.

The origin of uranium in conglomerates has attracted considerable discussion. Two main theories have been advanced: a placer origin (Ramdohr, 1958), and a hydrothermal origin (Davidson, 1957 & 1960). The scope of this paper does not permit lengthy discussion of this much argued question. Objections to the placer origin have centred around the extreme solubility of uranium oxides, the softness of uranium compounds, and the virtual absence of detrital uranium minerals in present-day placer deposits. Arguments against a hydrothermal origin are the absence of mineralized channels of access to the orebody, the comparative lack of mineral zoning, and the sympathetic distribution of uranium and gold, a relationship considered by some to be more difficult to explain by hydrothermal action. The writer is familiar with the mineralogy of the Witwatersrand conglomerates and favours the suggestion proposed by Derry, (1960) that uranium was precipitated from solutions in contact with sediments composed of a carbonaceous, clay matrix and quartz pebbles during sedimentation. Of prime importance to deposition is not so much the source - the high solubility of oxidized uranium minerals would allow leaching from practically any weathered rock mass - but environmental conditions capable of precipitating uranium from mineralized solutions in contact with a pebble bed. The most likely reducing agents are hydrogen sulphide derived from the decay of organic carbonaceous

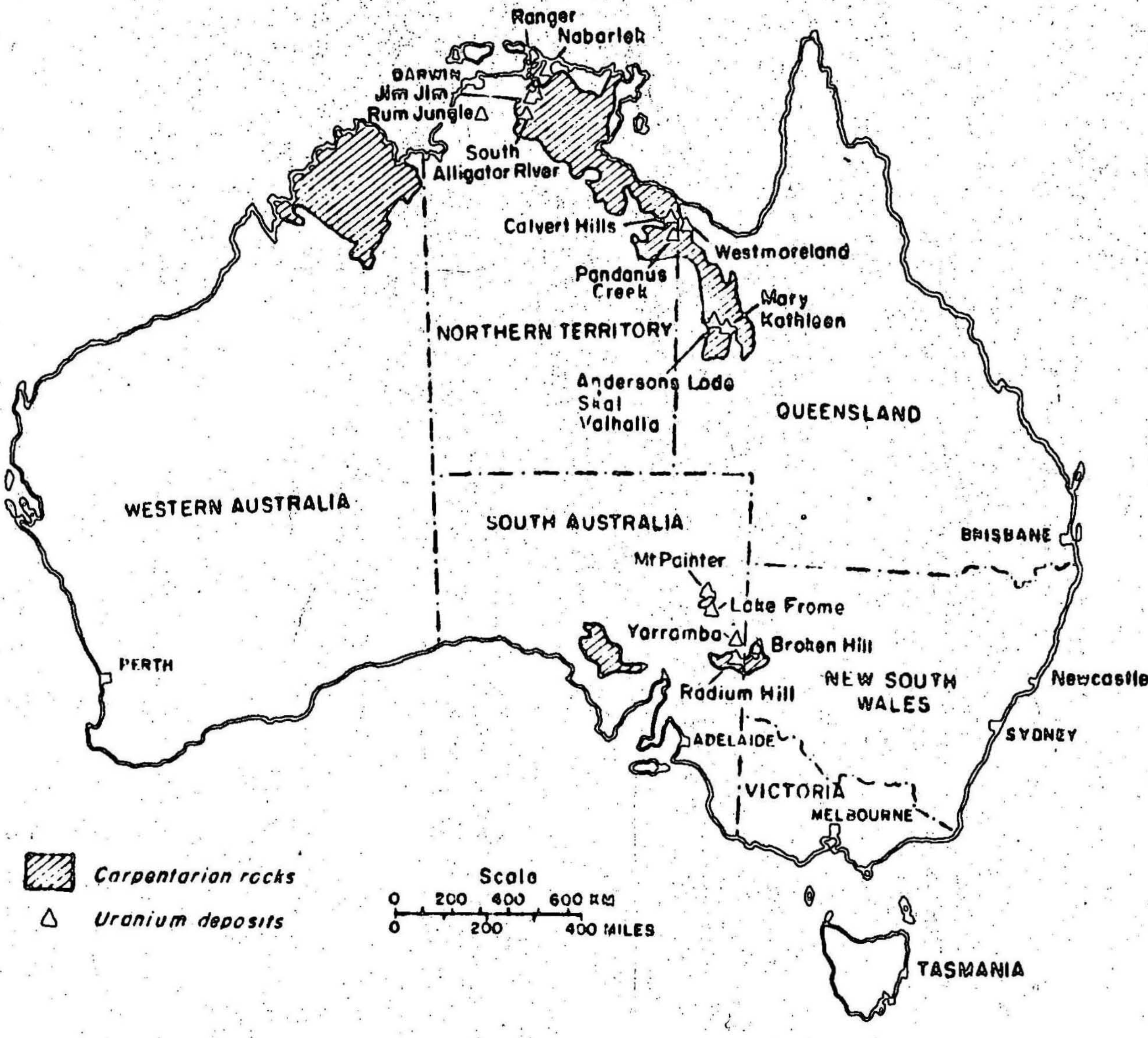

Fig.1 DISTRIBUTION OF THE MAIN DEPOSITS OF URANIUM IN AUSTRALIA

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matter, and certain bacteria. The common association between uranium and carbonaceous material, and the carbonaceous mineral thucolite in the Witwatersrand ore, strongly suggest that organic matter played an important role in the precipitation of the uranium.

Because of certain lithological and environmental similarities between Lower Proterozoic conglomerates in northern Australia and those at Elliot Lake and Witwatersrand, the conglomerates at Rum Jungle and the Kimberley district have been investigated as possible deposits of uranium. At Rum Jungle pebble conglomerates occur in the Crater Formation within the Batchelor Group. The Crater Formation south of the Rum Jungle Complex consists of a sequence of over 600 m of arkose, quartzite, and shale, dipping southeastward at between 40° and 60°. The formation contains at least three lenses of conglomerate up to 13 m thick and 1200 m long. The following is a generalized geological section of this area, adapted from Walpole et al. (1968), and Morlock & England, (1971).

TABLE 1. SUMMARY OF THE STRATIGRAPHY SOUTH OF RUM JUNGLE COMPLEX

Age	Rock Unit		Thickness (m)	Lithology
Lower Proterozoic	Goodparla Group	Golden Dyke Formation	3000	*Graphitic shale, chloritic shale, blue-grey siltstone, quartzite
	Batchelor Group	Coomalie Dolomite	300	Coarse-textured biohermal dolomite, magnesite, medium to fine-grained calcilutite
		Crater Formation	600	Siltstone, sandstone, arkose, with two, and locally three, interbedded pebble conglomerates
		Celia Dolomite	300	Magnesite, dolomite, calcareous Sandstone
Archaean	Rum Jungle Complex			Granite, gneiss, banded ironstone.

*The uranium deposits at Rum Jungle are contained in graphitic and chloritic shale of the Golden Dyke Formation.

At the surface, radioactivity of the conglomerates is locally as high as 30x background (background = 0.01 m R/hr). To obtain specimens of unleached conglomerate for detailed examination and analysis, two diamond drill holes were put down in 1970, by the Bureau of Mineral Resources (Morlock & England, 1971). Unweathered conglomerate core from two lenses was obtained. Superficially, the conglomerate resembles the Witwatersrand 'banket' in that both are composed of angular to subrounded pebbles of quartz set in a matrix of fine quartz, chlorite and sericite. In the Crater Formation conglomerate pyrite is, however, rare and carbonaceous matter has not been recorded to date. England (Morlock & England, 1971) examined the conglomerate and concluded that the source of radioactivity in the pebble conglomerates is thorium contained in a red-brown amorphous or metamict phosphate believed to be cheralite. No uranium minerals or gold were identified.

Three mining companies have briefly investigated pebble conglomerates in the King Leopold Sandstone of the Carpentarian Kimberley Group, and to a lesser extent pebble beds in the Lansdowne Arkose and O'Donnell Formation, both of the Speewah Group which underlies the Kimberley Group, in the southeastern part of the Kimberley district, northern Western Australia. Cuttings and core from the drill holes known to have intersected conglomerate bands from the three formations investigated have been found to be devoid of uranium minerals, their anomalous radioactivity being due to the presence of heavy mineral concentrations of thorium-bearing minerals such as thorogummite.

Sandstone deposits are typified by the numerous complex uranium deposits of the Colorado Plateau area, the Wyoming Basin area, and the Texas Gulf coast in the U.S.A. Other notable examples are the deposits of Catamarca and Mendoza Provinces in Argentina, the deposits of the Republic of Niger, and of the Ferghana Basin in the U.S.S.R. The Colorado Plateau contains by far the greatest known reserves of uranium in the U.S.A., and in an area of about 380,000 sq. km over 2000 individual deposits are known. The geology of the Colorado Plateau deposits has been described in detail (e.g. Fisher, 1956 & 1970; Kelley, 1955 & 1956).

In the sandstone deposits, a close relationship exists between the concentration of ore and sedimentary features such as ancient stream channels and deltaic deposits. The most common type of host rock is coarse sandstone with moderate permeability, usually overlain by an impervious unit. The host rocks also include conglomerate and less commonly, siltstone. Factors favourable to ore deposition are: thickening of the sandstone host rock, a high ratio of sandstone to mudstone in the sequence, and the presence of carbonaceous matter in the host rock.

The recent discovery in South Australia of sandstone type deposits of Tertiary age at Lake Frome, about 500 km north of Adelaide, and at Yarramba, about 75 km northwest of Broken Hill, N.S.W. (see Fig. 1), is an example of successful selective exploration following an environmental study. The Lake Frome uranium occurs in flat-lying sediments of Tertiary age. The mineralization occurs in sandstone, siltstone, and gravels about 100 m below the surface. The uranium is present as finely divided pitchblende, mainly in carbonaceous siltstone and to a lesser extent in siltstone and consolidated gravels. The sediments at Lake Frome are derived partly from granite and metamorphic rocks near Mount Painter which contain uraniferous breccia deposits, and partly from slightly metamorphosed and unmetamorphosed rocks of Adelaidian (1400-600 m.y.) age (Dunn et al., 1966). Exploration at Lake Frome, reported by Petromin N.L. in an interim report released on 20th April 1971, has indicated the presence of two deposits separated horizontally by about 730 m of untested ground. It is possible that the two deposits may in fact be part of a single more extensive deposit. The reserves given in April 1971 are:

Prospect Beverley	5,600 short tons U_3O_8	(average ore grade 0.24% U_3O_8)
Prospect 37A	4,400 short tons U_3O_8	(average ore grade 0.15% U_3O_8)

Similar deposits occur at Yarramba in Tertiary sediments derived from the Radium Hill area, the site of the former uranium mine.

Vein deposits are the most common form of uranium ore. They vary considerably in size, shape, and mineralogy, and because they are normally unrelated to the country rock in which they occur, uranium-rich vein deposits are found in a variety of host rocks, usually of Precambrian age. The veins are often rich in sulphides. Perhaps the best known vein deposits in the western world are those in the Goldfields area of Saskatchewan, Canada (Buffau, 1951; Robinson, 1955), and the Shinkolobwe deposits of the Katanga Province in the Congo Republic (Derriks & Vaes, 1956). Less extensive vein deposits are found in most parts of the world. No vein deposits closely comparable with those of the goldfields area Canada, or of the Shinkolobwe area, Congo Republic, occur in Australia.

Uranium Deposits of the Rum Jungle/Alligator Rivers Province, Australia. The most important uranium deposits in Australia occur in a roughly semi-circular area in the north central Australia. The region includes the uranium mines at Rum Jungle, South Alligator River, and the newly discovered deposits of Nabarlek, Ranger and Jim Jim. The deposits which have been mined occur in folded and sheared low-grade metamorphosed sediments of Lower Proterozoic age. Uranium minerals also occur in dolomite, and sandstone and volcanic rocks of Carpentarian age. The main deposits of the region are:

Rum Jungle. Uranium has been mined from three deposits of moderate size and two minor deposits at Rum Jungle, about 64 km south of Darwin, Northern Territory. The deposits (Spratt, 1965; Berkman, 1968), occur in carbonaceous black shale or chloritic shale of the Golden Dyke Formation, near to the contact with dolomite/magnesite of the Coomalie Dolomite (see Table 1). The deposits are concentrated in a broad syncline, each located close to, or in, shears, faults or folds. A summary of the geology of the deposits is given in Table 2.

TABLE 2. SUMMARY OF THE MAIN FEATURES OF THE RUM JUNGLE MINES

Name of Mine	Approximate Dimensions of Lode (m)	Production of ore (tons)	Remarks
Whites	100 x 10	± 396,000 (0.31% U_3O_8)	Steeply dipping, layered uranium/copper deposit in black shale with lead, cobalt and nickel minerals. Secondary torbernite, autunite, saleeite, gummite, phosphuranylite, and johannite. Pitchblende occurs about 9 m below surface.
Whites Extended	Small	± 100 (0.2% U_3O_8)	Located 500 m east of Whites in chloritic slate. Mainly secondary gummite, autunite and saleeite.
Dysons	40 x 25	± 154,000 (0.39% U_3O_8)	Steeply dipping ovoid lode in black pyritic shale. Mainly saleeite, with rare autunite and skodowskite.
Rum Jungle Creek South	270 x 70	± 653,000 (0.48% U_3O_8)	Elongated irregular-shaped lode in chloritic shale. Sooty pitchblende.
Mt Burton	Small	± 6,000 (0.21% U_3O_8)	Uranium and copper minerals in black shale. In the oxidized zone torbernite, malachite, chalcocite, and rarely native copper. Primary pitchblende, pyrite and chalcopyrite.

About 8 km northwest of the Rum Jungle treatment plant a low-grade uranium prospect is located in a shallow syncline. The ore is contained mainly in magnesite, dolomite, and breccia of the Coomalie Dolomite, and in the overlying Golden Dyke Formation shale. In the carbonate rocks uranium is present as thucolite in fine veinlets; in the shale it occurs as both thucolite and fine grains of pitchblende in veinlets along cleavage planes and minor fractures. Diamond drilling has proved a low-grade orebody of about 800,000 tons (0.16% U_3O_8).

Uranium was discovered at Rum Jungle in 1949 by a prospector, J.H. White, who recognized secondary uranium minerals illustrated in a Bureau Mineral Resources prospectors handbook. Following the initial discovery, the Rum Jungle area was subjected to intensive investigation by Bureau of Mineral Resources and Territory Enterprises Pty. Ltd. The investigations consisted of detailed mapping, geochemical survey, and radiometric and other geophysical surveys. Interpretation of data together with information derived from drilling have revealed that at Rum Jungle:

(1) Uranium deposits can be related to structure; they are either close to or fill faults or shears. The Rum Jungle Creek South lode is located in a tight fold.

(2) The uranium tends to be concentrated in black shale or chloritic shale of the Golden Dyke Formation, near the contact with Coomalie Dolomite.

(3) The uranium occurs close to the surface, seldom deeper than 100 m.

(4) At White's and Mt Burton, uranium occurs with copper minerals. Most radiometric anomalies are coincident with copper/zinc/cobalt/nickel surface anomalies (Dodson & Shatwell, 1964).

The most successful method of exploration in the Rum Jungle area has been radiometric survey, followed by test drilling. Experience proved the most favourable lithological target to be the Golden Dyke Formation shale, close to the contact with the Coomalie Dolomite (see Table 1.). Experimentation showed that initial testing by auger drilling is advisable as numerous radiometric anomalies, particularly those located in areas covered by lateritic soils, are surface features which rapidly decline in strength below the surface. Auger drill holes were put down on surveyed grids and were also used for the collection of geochemical samples, radiometric probing, and experimentally, for radon detection surveys.

South Alligator River. Uranium deposits in the South Alligator River area occur in a geological environment comparable with Rum Jungle. The mines are smaller and individual lodes are of higher grade, for example El Sherana, the largest of the mines, produced 59,800 tons of ore (0.73% U_3O_8). Uranium has been mined at thirteen small mines (Taylor, 1968; Prichard, 1965). The mines extend over a distance of about 21 km along an almost vertical major fault zone striking at about 300°. Most of the deposits occur in steeply dipping carbonaceous shale and ferruginous siltstone of the Lower Proterozoic Koolpin Formation close to the unconformity with the overlying flat-lying Kombolgie Formation of Carpentarian age.

Minor uranium deposits also occur just above the unconformity separating Lower Proterozoic and Carpentarian rocks; for example in the Kombolgie Formation (Palette mine), in the Edith River Volcanics (Coronation Hill). At Scinto 6, uranium occurs in much altered dolerite below the unconformity. Pitchblende is the predominant uranium mineral in most of the deposits; Saddle Ridge is the only deposit composed almost exclusively of secondary uranium minerals. The ore at El Sherana, Palette, and Coronation Hill has a significant gold content.

TABLE 3. SUMMARY OF STRATIGRAPHY, SOUTH ALLIGATOR RIVER VALLEY

Age			Thickness (m)	Lithology
Carpentarian	(Katherine (Group	Kombolgie Formation	1700	Conglomerate, greywacke, sandstone, with interbedded volcanic rocks
		Unconformity		
	(South (Alligator (Group	Fisher Crk Siltstone	5000	Siltstone, micaceous siltstone, greywacke/siltstone
Lower Proterozoic	(	Gerowie Chert	1000	Chert, siliceous, siltstone (facies varient of underlying Koolpin Formation)
	(	Koolpin Formation	1700	Algal dolomite, pyritic carbonaceous siltstone
		Unconformity		
Archaean	(	Stag Crk Volcanics		Altered basalt

In the South Alligator Valley, secondary minerals were first recognized in the field at Coronation Hill in 1953. Subsequent discoveries were made by geological mapping and low level airborne radiometric surveys.

Alligator Rivers Area. The newly discovered uranium deposits of Nabarlek, Ranger and Jim Jim to the north-northeast of South Alligator River occur in a geological environment similar to South Alligator River deposits and, to some extent, Rum Jungle. The limited information available about the Nabarlek occurrence indicates that it is a vein deposit, probably occupying a slip shear. The main deposit is a vein, part of which is massive pitchblende, which extends over a strike length of about 270 m and is concordant with the schistosity of the host rock (chlorite-muscovite schist). The vein apparently cuts out before a gently inclined dolerite dyke at a depth of about 65 m. Massive pitchblende occurs within 1.5 m of the surface, and is coated with gummite, autunite, saleeite, and rare torbernite, which are also disseminated in the schist and hornfelsed schist near the dolerite contact. In addition to the disseminated ore, narrow veinlets of secondary minerals follow joint planes and cleavage planes. There does not appear to be any connection between the dolerite beneath the deposit, other dolerites in the Carpentarian rocks near Nabarlek, and the uranium mineralization.

Ranger deposit, situated about 60 km southwest of Nabarlek, consists mainly of fine veinlets or stringers of uranium minerals in quartz-chlorite schists (Fisher Creek Siltstone?). At a surface exposure the host rock dips steeply to the east, but drilling results indicate that below the surface the band flattens out to become nearly horizontal. The quartz-chlorite schist typically consists of fine laminae of quartz and chlorite, and locally, the chlorite bands contain widely dispersed, rare, fine flakes of graphite. The uraniferous stringers (secondary minerals at the surface, sooty pitchblende below the zone of oxidation) are seldom more than a few millimetres thick and are concentrated in brecciated parts of the host rock. The veinlets are mainly cross-cutting, often thickening around brecciated lumps of rock. In addition to the pitchblende, the veins contain rare pyrite and galena, with traces of copper and vanadium. The gold content is variable, ranging from a trace to 5 dwt per ton. The host rock conformably overlies a band of siliceous cherty breccia (Gerowie Chert?). The presence of fragments of silicified siltstone retaining their original bedding indicates that the rock was formed by the silicification of a disrupted argillite. A band of sericite-chlorite schist (Koolpin Formation?) underlies the chert, apparently conformably. The sericite-chlorite schist overlies a band of pegmatitic/ granitic rock composed essentially of quartz and feldspar with abundant prisms of tourmaline; the pegmatitic rock contains veins of pitchblende, seldom more than 2 cm thick. In the Ranger area highly chloritic rocks, believed to be altered dolerites, are patchily mineralized, but the less altered dolerites, believed to be of Carpentarian age, do not contain uranium minerals.

The writer's information about Jim Jim uranium deposit, located about 20 km south-southwest of Ranger, is limited. As far as is known, like Ranger the deposit consists of uraniferous veinlets in a mica schist. A band of highly folded quartzite apparently occurs within the mica schist.

In July 1971 Pancontinental Mining Ltd announced the discovery of a uranium prospect about 40 km southwest of Nabarlek and about 20 km north of Ranger (The Australian Financial Review, July 29, 1971). The announcement described uranium mineral deposits in both Lower Proterozoic metasediments (grab samples ranging from 0.1% to 3.4% U_3O_8) and in conglomerate of the Carpentarian Kombolgie Formation (grab samples 0.03% to 2.5% U_3O_8).

The uranium deposits of Nabarlek, Ranger, and Jim Jim were discovered by airborne gamma ray spectrometer surveys; the radiometric anomalies were first located on the ground by detailed radiometric gridding, the defined anomalies tested by drilling, trenching and costeaning. Testing of the large number of radiometric anomalies outlined by airborne surveys over areas which include the three deposits and other adjoining areas will not be completed for years to come. An interesting feature of the exploration in the region is that detailed ground investigations have established a number of anomalies not recorded by airborne survey. These anomalies were located by hand-held scintillometer, usually but not always on steep slopes where overburden has concealed the radioactivity from airborne gamma ray spectrometry. Most of the area west of the newly discovered prospects is at least partly covered with superficial deposits, the area to the east overlain by sediments of the Kombolgie Formation.

Although a vast amount of work is required before an accurate assessment can be made of the field, the following observations are drawn from available information.

(1) The region is an important uranium field which will take many years to test fully.

(2) The bulk of the uranium deposits discovered so far occurs in metasediments of Lower Proterozoic age near the surface, which was recently stripped of a cover of Carpentarian Kombolgie Formation rocks. The deposits are grouped close to the present day erosional edge of Kombolgie Formation rocks. Uranium minerals also occur in the basal beds of the Kombolgie Formation.

(3) Primary uranium has been intersected in granitic rock. Future exploration of the Alligator Rivers area will be greatly assisted if the genesis of uranium ore is established. The source of uranium and manner of deposition is probably similar to the deposits at South Alligator River and Rum Jungle. In the light of admittedly insufficient available data, three possible origins for the uranium are considered:

(i) Syngenetic deposition in a favourable host rock with later concentrations of ore.

(ii) Concentration from a massive source rock.

(iii) Hydrothermal/mesothermal deposition from an underlying igneous host rock.

<u>Syngenetic Origin</u>

Reference has been made to the preferential concentration of uranium ore in carbonaceous shale, of the Golden Dyke Formation at Rum Jungle, and the Koolpin Formation at South Alligator River. The high background content of uranium in carbonaceous shale $\pm$ 125 ppm (Robertson & Douglas, 1970) would ensure a more than adequate source of uranium. Concentration of lodes would require leaching and redeposition, possibly induced during the late consolidation stage of sedimentation - mineralized solutions being squeezed into fractures. Although this hypothesis is attractive, its applicability to the deposits of Nabarlek, Ranger and Jim Jim might be questioned on the grounds that carbonaceous shale is not, in the present state of knowledge, known near any of these deposits. The high solubility of uranium and the fractured nature of the country would however allow transportation of uranium over considerable distances, particularly under the stress of tectonic pressure. Relocation of syngenetic uranium may explain a characteristic feature of the deposits: the concentration of ore in the Lower Proterozoic rocks near the unconformity with Carpentarian rocks. If the uranium predates the Kombolgie Formation sedimentation, progressive lowering of the Lower Proterozoic surface by erosion would tend to concentrate ore near the surface by successive solution and accretion. (Age determinations carried out on pitchblende from South Alligator River and Nabarlek, Cooper (in prep.), have indicated age ranges of between 550 and 700 m.y. and 710 and 815 m.y. respectively, but there is no proof that the pitchblende tested had not been redeposited.)

Concentration from a massive source rock

The relationship between the distribution of Australian uranium deposits and rocks of Carpentarian age has been noted. Furthermore, in the Alligator Rivers area, the close spatial relationship between known deposits and the Kombolgie Formation has been pointed out. Concentration of ore from a massive overlying source rock such as the Kombolgie Formation consisting of greywacke, sandstone and conglomerate would simply require leaching of soluble uranium minerals, prolonged interstratal migration and deposition at the unconformity separating the underlying sediments. The Kombolgie Formation is invaded by, and interbedded with, a variety of volcanic rocks of the Katherine River Group which may also be considered as possible source rocks of uranium. Status of the volcanic rocks as source rocks is enhanced by the fact that they are contemporaneous with, and might be correlatable with, uraniferous volcanic rocks in the Westmoreland/Mary Kathleen uranium province to the southeast of the Alligator Rivers Area (see Fig. 1). This hypothesis is appealing because of certain known features of the uranium deposits; uranium is typically concentrated in the upper part of the Lower Proterozoic rocks and locally in the basal beds of the Kombolgie Formation rocks. The deposits at South Alligator and Rum Jungle tend to narrow below the surface of the older rocks. Reducing conditions are likely to have prevailed at the unconformity, after deposition of up to 1700 m of overlying sediments.

However certain objections can be levelled at this theory: (Taylor, 1968 p.43) noted that the ages of pitchblende at South Alligator River indicate that uranium ore was deposited between 550 and 700 m.y. ago. He considered redistribution of uranium by meteoric waters during the interval unlikely. The gold content of Ranger and certain of the South Alligator River deposits would also present some difficulty in explaining as a redeposition from meteoric water leaching of an overlying source rock.

Hydrothermal/mesothermal deposition

At Ranger deposit primary uranium has been intersected in granitic rock below the host rock. Further work in this area may prove the presence of channelways from depth rather than from an overlying source. Taylor, 1968, described 'hydrothermal' wallrock alteration around ore in the South Alligator River in unoxidized rock. The relationship between structures and ore deposition at Rum Jungle and South Alligator Valley may be related to the introduction of mineralized solutions from the igneous source at depth along shears and faults. The relationship between ore deposition and the Kombolgie Formation may be accounted for by the assumption that ascending mineralized solutions moved freely up to the cap of nearly horizontal Kombolgie Formation sediments which acted as a restricting control, channelling movement of the solutions along the unconformity zone. A relationship between igneous activity and ore deposition may explain the frequent coincidence of ore and anomalous ground magnetism.

Future exploration in the Alligator Rivers area will require shallow drilling to investigate areas blanketed by superficial deposits. The shallowness of the water table in this area, probably less than 10 m, will be an aid to radiometric hydrogeological investigations.

The Mary Kathleen Mine

The Mary Kathleen Mine (Hughes & Munro, 1965) is situated about 52 km east of Mount Isa. Mining operations by open cut method ceased in 1962 when the mine had reached a depth of about 61 m and had yielded a total of about 3714 tons of U_3O_8.

The deposit is contained in the predominantly calc-silicate upper part of the Corella Formation. Host rock to the ore is a breccia conglomerate composed mainly of quartzitic and feldspathic pebbles in a fine grained matrix composed mainly of garnet, scapolite, and feldspar. The lode is located in the axis of a syncline and is bounded by two roughly north-south shears. The mineralization is considered to be the result of deposition of late phase metasomatic emanations from the Mt Burstall granite, an environment unique in Australia, and rare throughout the world. The primary mineral is uraninite, and is generally accompanied by the rare earth minerals allanite and stillwellite.

The Westmoreland and Mary Kathleen Area deposits

In the area between Mary Kathleen and the Calvert Hills, a belt straddling the Queensland and Northern Territory boundary, numerous, mostly small, uranium deposits have been discovered (Brooks, 1960). At Westmoreland pitchblende is present in marginal shears of a trachyandesite dyke and in sandstone and conglomerate adjacent to the dyke. (Secondary minerals have been transported as far as 1700 m from their original source.) At Pandanus Creek pitchblende occurs in acid volcanics. The deposits northwest of the Mary Kathleen mine, typified by Anderson's lode, Skal, and Valhalla, are mainly contained in sheared sediments within the Eastern Creek Volcanics.

Although a number of the deposits in this region are of little or no economic significance, their widespread distribution provides proof of an overall uranium enrichment in the Carpentarian volcanics. Exploration for deposits of uranium in the region should be governed firstly by investigation of porous interbedded sediments or pyroclastic layers in the volcanics capable of containing concentrations of relocated uranium ore and secondly, by investigation of the larger tectonic features such as breccias, shears and folds in the volcanics in which fill or replacement lodes could be located.

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