1:100 000 GEOLOGICAL MAP COMMENTARY

RUM JUNGLE URANIUM FIELD

NORTHERN TERRITORY

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

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INTRODUCTION

The Rum Jungle uranium field Special map comprises parts of the BYNOE, NOONAMAH, REYNOLDS RIVER, and BATCHELOR 1:100,000 Sheet areas, and extends between latitudes 12°45′ and 13°15′ south and longitudes 130°50′ and 131°15′ east (Fig. 1).

The geology of this area is of particular interest to the understanding of the Pine Creek Geosyncline as a whole in that the Archaean rocks and the basal units of the Early Proterozoic succession are relatively well exposed.

Uranium was first discovered at Rum Jungle by a local prospector, Mr. Jack White, in 1949; this eventually led to the mining and extraction of uranium from a number of open cuts and to the establishment of the township of Batchelor. All operations, apart from exploration, ceased in 1970 and despite intensive exploration no new commercially exploitable uranium deposits have been located. However, a base-metal prospect, Woodcutters, originally discovered by the Bureau of Mineral Resources (BMR) in 1968, has proved to be commercially exploitable. The uranium deposits found so far at Rum Jungle are considerably smaller than the large deposits found in the Alligator Rivers uranium field.

During the 1950s and 1960s the area was intensively prospected by the BMR and Territory Enterprises Pty Ltd (a subsidiary of Consolidated Zinc Pty Ltd) and more lately by several other companies, notably Uranerz Australia Pty Ltd, which has discovered three uranium prospects.

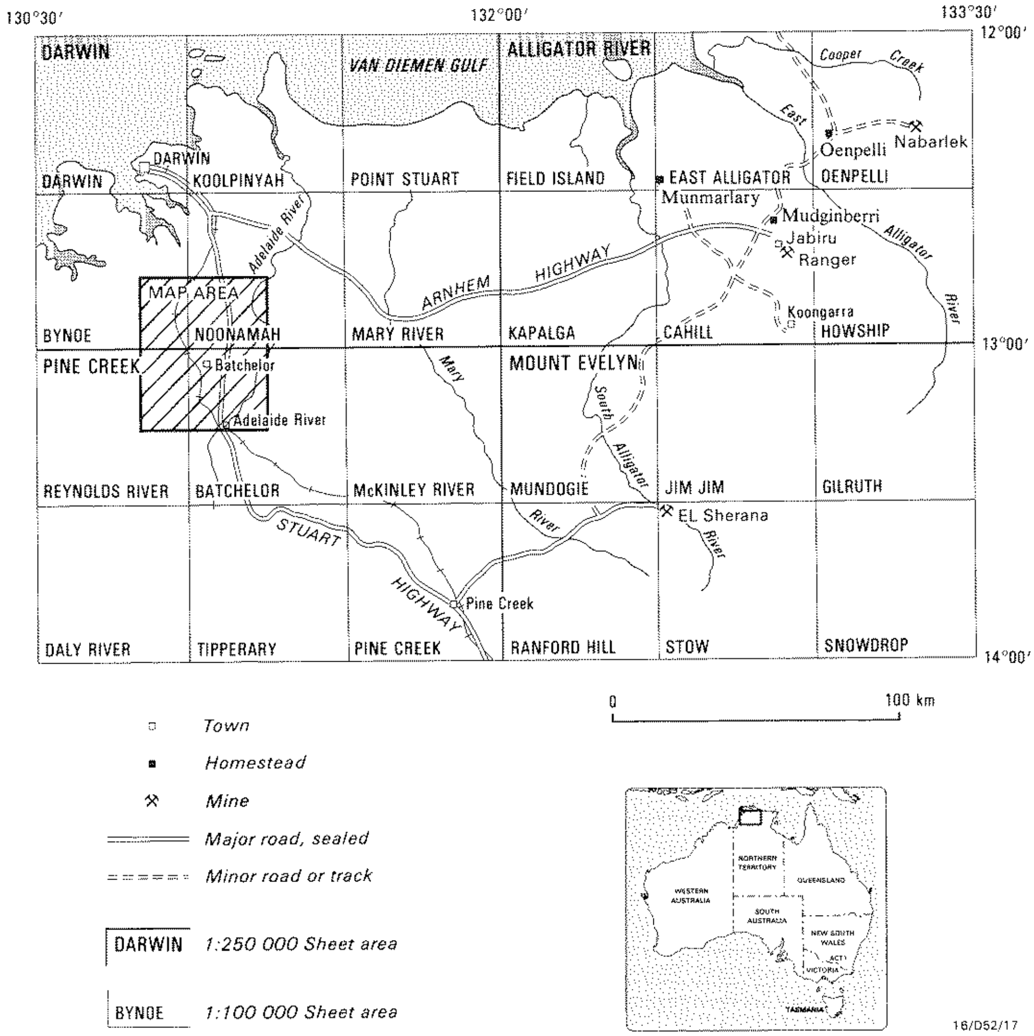

Fig. 1. Location and access

Location and access

The area is centred about 60 km south-southeast of Darwin and is reached by the Stuart Highway which passes through the eastern part (Fig. 1). Batchelor is near the centre of the map area and is connected to the Stuart Highway by a sealed road. The smaller township of Adelaide River is on the Stuart Highway in the far south of the map area.

Several graded gravel roads and many four-wheel-drive tracks provide access to most areas away from the all-weather roads in the dry season (April to November). Long grass impedes off-road travel (and the observation of low-lying outcrop) at the beginning of the dry season, but the grass is usually burnt off during the season.

Previous investigations

During the 1950s BMR mapped the surrounding region and produced maps at 1 inch-to-the-mile and 1:250 000 scales and Explanatory Notes (Malone, 1962a,b) (Table 2). A preliminary report and Preliminary Edition 1:100 000 sheet were prepared by Johnson (1974, 1977) and a second Preliminary Edition of the map was prepared by Crick (1981). Numerous geological, geochemical, and geophysical investigations of various parts of the area have been carried out, the more relevant of which have been cited in other sections of this Commentary and are listed in the References.

STRATIGRAPHY

Two dome-like Archaean granitic complexes occupy the central portion of the map area and are surrounded by Early Proterozoic metasediments. Minor Middle or Late Proterozoic sandstone and conglomerate occur near the margins of the complexes, and two small residuals of Mesozoic sandstone and conglomerate are present in the north. About half of the surface area is occupied by superficial Cainozoic deposits.

ARCHAEAN

Rum Jungle Complex

Originally called the Rum Jungle Granite (Malone, 1962a,b), this complex was found, on more detailed examination, to contain a variety of igneous (mainly granitic) and minor metasedimentary rocks unconformably overlain by Early Proterozoic metasediments (Rhodes, 1965). Exposure is poor: over 90% of the area is covered by superficial deposits. Rhodes (1965) subdivided the complex into six units: (in order of decreasing age) metasediments including banded-iron-formation; schist and gneiss; granite-gneiss and migmatite; metadiorite; coarse to medium granite (adamellite); large-feldspar granite (adamellite); and leucocratic granite (adamellite) (Table 1). Sporadic veins and dykes of pegmatite appear to be mostly associated with the leucocratic granites and large-feldspar granites. Veins of amphibolite intrude both the coarse and leucocratic granites; they are chemically and mineralogically similar to the intrusive amphibolite bodies in the surrounding Early Proterozoic low-grade metasediments. Quartz-tourmaline veins are found along joint planes at the margins of the complex and extend into the Early Proterozoic metasediments.

Phyllite, chlorite, and actinolite schists of the *schist and gneiss unit* (Ar_2) at the margin of the complex may be low-grade metamorphic rocks of the surrounding younger metasediments instead of locally retrogressively metamorphosed schist and gneiss of the complex (Rhodes, 1965).

Johnson (1977) defined an additional metasedimentary unit, *banded iron formation* (Ar_i), which crops out near the southeastern and northeastern margins of the complex. Its age relationship is uncertain as no xenoliths of banded iron formation have been observed in the nearby granitic units of the complex. However, the unconformably overlying Beestons and Crater Formations contain pebbles and boulders of this unit.

Waterhouse Complex

Originally called the Waterhouse Granite (Malone, 1962a), this complex is composed of igneous and metasedimentary rocks similar to those of the Rum Jungle Complex (Johnson, 1977). Likewise, exposure is poor and over 90% of the area is covered by superficial deposits. Granite forms most of the outcrop, the rest being dolerite, amphibolite, schist, gneiss, migmatite, and banded iron formation.

Age of the complexes

Combined U-Pb zircon and Rb-Sr total-rock ages show that the Rum Jungle and Waterhouse Complexes are at least 2400 Ma old (Richards & others, 1966; Richards & others 1977; Page, 1976).

EARLY PROTEROZOIC

NAMOONA GROUP

The Namoona Group in the Rum Jungle Uranium Field consists of the Beestons Formation and the Celia Dolomite. These two formations are considered to be lateral facies equivalents of Namoona Group sediments to the east of Rum Jun-

TABLE 1. LITHOLOGY AND RELATIONSHIPS OF ROCK UNITS IN THE RUM JUNGLE COMPLEX (after Rhodes, 1965 and Johnson, 1977)

Unit	*Description*	*Relationships and remarks*
Ar_7	Leucocratic granite: fine to medium, equigranular, pink or grey adamellite, aplitic and pegmatitic in places	
Ar_6	Large-feldspar granite: adamellite with large tabular or ovoid feldspars up to 6 cm long	Intruded and veined by pegmatites and leucocratic granite. Contains inclusions of schist, gneiss, and diorite
Ar_5	Coarse to medium granite: pink, leucocratic, massive, coarse, equigranular ademellite	Appears to grade into large-feldspar granite; contains xenoliths of schist, and is cut by veins of leucocratic granite
Ar_4	Metadiorite: dark, fine-grained, massive except where locally sheared	Intruded and veined by leucocratic granite; forms inclusions in large-feldspar granite, and appears to grade laterally into it
Ar_3	Granite gneiss, migmatite: medium-grained, equigranular, ranges from well-banded through streaky and nebulitic to homogeneous gneissic granite	Cut by leucocratic granite and pegmatite; contains inclusions of schist and appears to grade into large-feldspar granite
Ar_2	Schist, gneiss: includes biotite gneiss, biotite-muscovite gneiss, biotite granofels, thinly banded feldspathic gneiss, quartz-muscovite schist, minor phyllite, chlorite schist, actinolite schist	Small, poorly exposed outcrop on eastern side of complex; also, inclusions and remnants within younger rocks of complex
Ar_1	Metasediments containing banded iron formation	Possibly youngest unit, although relationships not clear

gle and not part of a separate older group of sediments (Batchelor Group) (Table 2). The group unconformably overlies the Archaean complexes, although its contact with the complexes, where observable in outcrop, is commonly sheared or faulted.

The age of the group is between about 2400 Ma (Richards & others, 1977) and 1880 Ma (Bower & others, 1983).

Beestons Formation (Ꞑnb)

Originally described by Malone (1962a,b), this unit unconformably overlies the Rum Jungle and Waterhouse complexes. It consists of quartz-pebble conglomerate and grit (both commonly with a feldspathic matrix), arkose, quartz sandstone, orthoquartzite, and conglomerate in places made up of pebbles and boulders of banded iron formation. Its thickness ranges from 30 to 300 m. On the eastern margin of the Waterhouse Complex the formation is composed almost entirely of friable quartz sandstone and quartzite. Clear evidence of its unconformable contact with the Rum Jungle Complex exists in one outcrop 3 km north-east of Batchelor where poorly-sorted coarse feldspathic and micaceous sandstone, conglomeratic in places, overlies granite. The sandstone, which in places contains angular vein-quartz fragments up to 30 cm long, consists of immature sediment derived from the granite.

Celia Dolomite (Ꞑnl)

The Celia Dolomite is markedly lenticular and is restricted in outcrop to the eastern edges of the Rum Jungle Complex and Waterhouse Complex; it attains its maximum thickness of about 300 m against the Rum Jungle Complex.

Near the Rum Jungle Complex this unit, originally described by Malone (1962a, b), is composed of stromatolitic magnesite, dolomite (silicified in places), and minor amounts of calcareous para-amphibolite and metapelite. The magnesite averages 90% $MgCO_3$ and less than 1% $CaCO_3$ (Prichard, 1975). The dolomite is rarely preserved near the surface. Minor coarse dolarenite is present and contains ripple marks and small-scale cross-bedding. Pink aggregates of aphanitic talc, forming nodules up to 5 cm in diameter, are also present in small amounts. The magnesite is commonly coarsely crystalline, the crystals having two forms, which are considered by Crick & Muir (1980) to be pseudomorphous after gypsum and halite and by Bone (1983) to be temperature-related polymorphs.

Stratiform, domal, and conical stromatolites are present in this unit. Organ-pipe stromatolites, *Conophyton*, form beds up to 2 m thick which in places overlie large domal stromatolites. The laminae of the stromatolites consist of interlayered chert and carbonate.

Silicification of the Celia Dolomite is variable, and some stromatolite outcrops are totally silicified to chert or quartzite.

Calcareous para-amphibolite and quartz-actinolite schist occur subsurface near the eastern margin of the Waterhouse Complex and are interpreted as a metamorphosed impure dolomitic facies of the Celia Dolomite (Lau, 1971; Johnson, & others 1979).

The depositional environment of this unit is considered to be intertidal to supratidal—largely evaporitic, analagous to that of a sabkha (Crick & Muir, 1980).

TABLE 2. EARLY PROTEROZOIC STRATIGRAPHY OF PAST AUTHORS COMPARED WITH STRATIGRAPHY IN THIS COMMENTARY AND MAP

Malone (1962a, b) Johnson (1977)			*Needham & others (1980)*		*This Commentary*		
Group	*Unit*		*Group*	*Unit*	*Group*	*Unit*	
FINNISS RIVER	Burrell Creek Fm Noltenius Fm		FINNISS RIVER	Burrell Creek Fm	FINNISS RIVER	Burrell Creek Fm	
GOODPARLA	Golden Dyke Fm	Pld$_8$ Pld$_7$ Pld$_6$	SOUTH ALLIGATOR	Kapalga Fm Gerowie Tuff Koolpin Fm	SOUTH ALLIGATOR	Mount Bonnie Fm Gerowie Tuff Koolpin Fm	
	Acacia Gap Tongue	Pld$_5$	MOUNT PARTRIDGE	Wildman Siltstone Acacia Gap Sandstone	MOUNT PARTRIDGE	Mt Deane Volcanics Acacia Gap Quartzite	Wildman Siltstone
	Golden Dyke Fm	Pld$_4$ Pld$_3$ Pld$_2$ Pld$_1$	NAMOONA	Masson Fm		Whites Fm	
BATCHELOR	Coomalie Dolomite Crater Fm		BATCHELOR	Coomalie Dolomite Crater Fm		Coomalie Dolomite Crater Fm	
	Celia Dolomite Beestons Fm			Celia Dolomite Beestons Fm	NAMOONA	Celia Dolomite Beestons Fm	

MOUNT PARTRIDGE GROUP

Crater Formation (Ɽpr)

The Crater Formation was described first by Malone (1962a, b) and later, in a more detailed study, by French (1970). It typically consists of conglomerate interbedded with sandstone and siltstone, and near the southeast margin of the Rum Jungle Complex attains a maximum thickness of 600 m. French (1970) has subdivided the formation into eight lithological units. Along the southern margin of the Rum Jungle Complex and northern margin of the Waterhouse Complex a poorly-sorted conglomerate, commonly containing rounded to subangular pebbles and boulders of banded iron formation (b.i.f.), overlies sheared granite. This conglomerate is identical to, and probably a western extension of, boulder conglomerate containing b.i.f. boulders described by French (1970) near the base of the formation and cropping out along the southeastern margin of the Rum Jungle Complex where it overlies the Celia Dolomite. The uppermost unit of the Crater Formation overlies the Rum Jungle Complex along the northern margin of the complex, and, where the contact is exposed, is sheared (faulted) and dips steeply away from the complex (French, 1970).

Conglomerate beds above the b.i.f.-boulder conglomerate are mostly composed of rounded quartz pebbles in a matrix of fine-grained chlorite, quartz, carbonate, and zircon (Morlock & England, 1971). The lower quartz-pebble conglomerate beds are generally coarser, anomalously radioactive (two to three times background radiation), and in places display graded bedding. Morlock & England (1971) ascribed the radioactivity to thorium in fine-grained phosphate. They also noted minor amounts of hematite, magnetite, and rutile, and a few grains of galena, sphalerite, and chalcopyrite in heavy-mineral separates. Anomalously radioactive thin bands of heavy minerals have been reported near the southeastern margin of the Rum Jungle Complex (French, 1970).

The Crater Formation was probably mostly fluvial. The b.i.f.-boulder conglomerate near the base is interpreted as an alluvial fanglomerate and indicates an unconformity between the Celia Dolomite and Crater Formation, although no outcrop showing the contact between them has been observed. However, the formation is thickest where it overlies the thickest part of the Celia Dolomite, indicating that both units were deposited in a local depression. In addition, rare white chert pebbles, which are probably silicified carbonate derived from the underlying Celia Dolomite, are present in the b.i.f.-boulder conglomerate.

Coomalie Dolomite (Ɽpc)

The Coomalie Dolomite, which was originally described by Malone (1962a,b), is poorly exposed and of irregular thickness. It is more extensive than the Celia Dolomite, which it closely resembles, and conformably overlies the Crater Formation.

The Coomalie Dolomite attains a maximum thickness of about 300 m and is composed of magnesite, dolomite, and some thin interbeds of metapelite and medium to coarse actinolite-rich calcareous para-amphibolite. The carbonates typically contain domal, stratiform, and conical (*Conophyton*) stromatolites. Teepee and polygon structures are also present in places near Batchelor (Crick & Muir, 1980).

XRD analyses of carbonate from drill cores and outcrops indicate that magnesite is the dominant carbonate type (Prichard, 1975). Crick & Muir (1980) report the presence of magnesite pseudomorphs after evaporite minerals in the Coomalie Dolomite, although Bone (1983) considers that these forms may be new types of temperature-related primary polymorphs of magnesite.

Silicification of the Coomalie Dolomite is widespread although locally patchy, and representative outcrops of stromatolitic carbonate are confined to near the southeastern margin of the Rum Jungle Complex. Crick & Muir (1980) noted rare microscopic wisps and lamellae in the stromatolites, suggesting some silicification of the carbonates during diagenesis.

The depositional environment of the Coomalie Dolomite is considered to be the same as that of the Celia Dolomite, i.e. intertidal to supratidal, largely evaporitic, analagous to a sabkha (Crick & Muir, 1980).

Whites Formation (Ɽpi) (new name)

The Whites Formation interfingers with and conformably overlies the Coomalie Dolomite and was probably deposited in an intertidal to subtidal environment. In its type area 2 km southeast of Batchelor it is composed of predominantly fine-grained, commonly pyritic calcareous and/or carbonaceous argillite with minor quartzite, calcarenite, and calcareous para-amphibolite. Rare massive stratiform stromatolites are also present in this area.

Rare outcrops occur on the western sides of the Archaean complexes, but the formation has also been exposed in mine open cuts. SEM-probing of carbonate from mullock heaps near the Intermediate open cut shows the carbonate to be mainly recrystallised dolomite containing minor magnesite veins, while at White's open cut coarse crystalline vein magnesite appears to be the main carbonate type. The dolomite in places displays small cross-beds. The magnesite has probably been derived by remobilisation from the underlying Coomalie Dolomite.

The thickness of the formation is difficult to estimate owing to poor exposure; in the type area it is between 300 and 500 m thick.

Wildman Siltstone (Ꝑpw)

The Wildman Siltstone interfingers with and conformably overlies the Whites Formation. It was first described from exposures in the central and eastern parts of the Pine Creek Geosyncline by Needham & Stuart-Smith (1978) and Needham & others (1980). In the map area the Wildman Siltstone consists mainly of argillite and shale which which is finely laminated in places; orthoquartzite and sandstone (Acacia Gap Quartzite Member, Ppa); and basic, highly altered, volcanics (Mount Deane Volcanic Member, Ppd). The fine laminations are commonly reddish-brown to pale-grey, the reddish laminations probably were formed from pyritic carbonaceous sediment that has been oxidised through weathering. The finely laminated argillite and shale suggest deposition in waters undisturbed by waves or currents such as in a subtidal environment.

The thickness of the Wildman Siltstone is irregular, with a maximum of about 1500 m.

Acacia Gap Quartzite Member (Ꝑpa) (revised name). The name of this member is revised from 'Acacia Gap Tongue Member' (Malone, 1962a, b) and 'Acacia Gap Sandstone Member' (Needham & others, 1980).

The member is composed of medium to coarse quartzite (with minor coarse to gritty sandstone beds from 1 to 10 m thick) interbedded with commonly pyritic and carbonaceous shale and argillite. The quartzite beds form prominent ridges and are composed of well-sorted and well-rounded quartz grains with overgrowths. Coarse disseminated euhedral pyrite is also present and on weathered surfaces has been oxidised to limonite or removed entirely, leaving moulds. Small-scale cross-bedding is rarely noticeable, although, owing to the well-sorted and uniform lithology of the quartzite beds, it may just be hard to detect.

The thickness of the Acacia Gap Quartzite Member varies from about 50 m southeast of Batchelor to about 300 m north and east of the Rum Jungle Complex. On the map it appears to be considerably thicker than 300 m immediately north of the Rum Jungle Complex, but owing to tight folding and overturning, some beds may be repeated in this area.

Mount Deane Volcanic Member (Ꝑpd) (new name). The Mount Deane Volcanic Member forms discontinuous rubbly outcrops of greenish-grey fine to medium-grained, relatively hard or friable rust-brown rock east and northeast of the Rum Jungle Complex; the type area is at Mount Deane, 9 km east of Batchelor. It is stratigraphically above the Acacia Gap Quartzite Member and is separated from it by up to 200 m of shale or argillite.

In places the member contains amygdaloidal rock types with silica-lined amygdales, commonly distorted or stretched, and flow breccias. Near Mount Deane it is highly altered and consists of medium-grained calcite, quartz, chlorite, magnetite, hydrated iron oxides, and accessory sphene.

It varies in thickness from 10 to 100 m.

SOUTH ALLIGATOR GROUP

There was a period of uplift, folding, and erosion before deposition of the South Alligator Group (Stuart-Smith & others, 1980).

The South Alligator Group was originally defined by Walpole (1962) who confined its distribution to the South Alligator Valley, 150 km southeast of Batchelor. However, Crick & others (1978) recognised that it occurred far more extensively in the Pine Creek Geosyncline.

The Group is subdivided into three formations—Koolpin Formation, Gerowie Tuff, and Mount Bonnie Formation—which in the map area, crop out only to the east of the Rum Jungle and Waterhouse complexes, and are possibly faulted out to the west of the complexes. Pagel, Borshoff, & Coles (1984), however, suggested that the Group may extend to the west of the complexes, although no characteristic lithologies are described by them from that area.

The basal unit in the map area, the Ella Creek Member of the Koolpin Formation, was formed mainly by weathering of older formations during the Early Proterozoic, and is overlain by mainly pelitic strata. Following deposition of the Koolpin Formation, distal volcanism (Gerowie Tuff) contributed considerable detritus to these sediments, whereupon the tuff component decreases and thin turbidite beds make an appearance in the Mount Bonnie Formation.

The age of the South Alligator Group is ca. 1880 Ma (Bower & others 1983).

Koolpin Formation (Ꝑsk)

The Koolpin Formation in the map area consists of a basal iron-rich unit up to 10 m thick (Ella Creek Member) overlain by up to 200 m of shale and siltstone. The shale and siltstone are in places highly carbonaceous and pyritic and contain rare beds rich in chert nodules characteristic of the formation elsewhere in the Pine Creek Geosyncline. The carbonaceous beds were probably formed in fresh-water, stagnant conditions (Crick & others, 1980).

In places, east of Batchelor, the pelitic beds contain small disseminated randomly orientated discoidal shapes, a few millimetres long, composed of recrystallised quartz and amorphous iron oxides. Pressure shadows occur at the apices of the shapes and the recrystallised granoblastic texture of the quartz is more evident at the apices; both features indicate that the discs were formed before any regional deformation, i.e., probably during diagenesis. The discoidal shapes and the rare presence of interpenetration twins suggest pseudomorphing after diagenetic discoidal gypsum, in turn indicating that conditions were locally hypersaline during deposition of the Koolpin Formation.

Ella Creek Member (Ꝑse) (new name). The Ella Creek Member is exposed to the north and east of the Rum Jungle Complex and commonly forms small, well-defined, ridges. The member, which is up to 10 m thick, is typically iron-rich and comprises a variety of rock types: massive to rubbly goethitic ironstone commonly containing quartzite (after carbonate); chert-flake breccia with rare quartzite nodules; ferruginous chert breccia with ooids (probably pisolites); siltstone containing chert nodules; and rare ferruginous grit, and pebble and boulder conglomerate.

In places the member appears to have been formed by weathering during the Early Proterozoic as it has features similar to present-day ferricrete, silcrete, and calcrete. The local presence of stylolites in quartz nodules in the chert-flake breccia indicates that the nodules originally consisted of carbonate that was later replaced by chert prior to recrystallisation.

Gerowie Tuff (Ꝑsg)

The Gerowie Tuff conformably overlies the Koolpin Formation east of the Rum Jungle and Waterhouse complexes where it generally forms low, sparsely vegetated, rubble-strewn hills with minimal outcrop.

The tuffaceous nature of this formation was first recognised by Crick & others (1978) elsewhere in the Pine Creek Geosyncline. In the map area, alteration has obscured most of the textures, and the unit is commonly composed mostly of fine-grained amorphous quartz, sericite, and minor iron oxides. In hand-specimen it commonly apears as light-greenish-grey to light-grey argillite, siliceous shale, or siltstone, or dark-grey chert. Thin beds of banded iron formation and rare lobate chert nodules are also present.

One feature, assisting the recognition of this unit in the field, is its background radioactivity, which is generally higher than that of the other formations.

The Gerowie Tuff has an average thickness of about 300 m.

Mount Bonnie Formation (Ꝑso)

The Mount Bonnie Formation conformably overlies the Gerowie Tuff and consists mainly of reddish-brown siltstone and shale. Minor, thin interbeds of tuffaceous, siliceous siltstone, banded iron formation, and greywacke are present. Chert nodules up to 5 mm in diameter are found in a few localities in siltstone beds. In one example, the nodules form about 50% of a 3 m thick siltstone bed.

The formation has an average thickness of about 500 m.

FINNISS RIVER GROUP

The Finniss River Group conformably overlies the South Alligator Group and in the map area is represented by the Burrell Creek Formation.

Burrell Creek Formation (Ꝑfb)

The Burrell Creek Formation consists of well-cleaved, commonly reddish-brown siltstone and shale, greywacke, and quartz-pebble conglomerate. The greywacke ranges from quartz-mica to feldspar-mica type, and generally displays graded bedding and, to a lesser extent, flame structures, small-scale cross-bedding, and intraformational slumping. Flute casts are exposed at the base of some greywacke beds, and in places the complete turbidite sequence, as defined by Bouma (1962), can be recognised in a single bed (Johnson, 1974). Rare small sand volcanoes are also present (Walter, 1972).

The conglomerates and greywackes are more common west and south of the Archaean granitic complexes and form strike ridges.

The Burrell Creek Formation probably was deposited in a distal deltaic environment within a relatively rapidly subsiding basin.

The measured maximum thickness of the formation is 1800 m near Predictor Hill, 15 km north of Adelaide River township, but its actual maximum thickness is probably much greater, particularly to the west and south of the Archaean granitic complexes.

EARLY TO MIDDLE PROTEROZOIC

Buckshee Breccia (Ꝑyb) (new name)

Following deposition of the Early Proterozoic sediments there was a period of regional metamorphism and tectonism, and uplift and erosion, before the onset of a new cycle of sedimentation in the Middle or Late Proterozoic. Before the start of the new cycle, erosion and weathering resulted in formation of the Buckshee Breccia. The Buckshee Breccia unconformably overlies Early Proterozoic rocks in places around the Waterhouse Complex and near the southern margin of the Rum Jungle Complex. It is overlain by the Depot Creek Sandstone Member of the Buldiva Sandstone.

Malone (1962a,b) first described this breccia as a basal element of the Depot Creek Sandstone

Member. It was referred to as the Hematite Quartzite Breccia ('HQB') by Spratt (1965), Walpole & others (1968), and Johnson (1974).

The breccia fragments commonly are of the underlying Early Proterozoic rock types: shale clasts are present where it overlies shale and recrystallised silicified carbonate (quartzite) fragments where it overlies carbonates. The matrix is mainly a reddish ferruginous lutite or arenite.

The thickness of the breccia varies according to the type of rock it overlies. It is no more than a few metres thick where it overlies shale but considerably thicker where it overlies carbonate. Drilling near Castlemaine Hill, 2 km west of Batchelor, has shown that where the breccia overlies carbonates of the Whites Formation or the Coomalie Dolomite it is up to 180 m thick and weakly phosphatic (Pritchard & others 1963). The greater thickness over carbonate rock types has probably resulted from karstic erosion of the Coomalie Dolomite or Whites Formation prior to deposition of the Tolmer Group.

MIDDLE PROTEROZOIC

TOLMER GROUP

The Tolmer Group is represented in the map area by only the basal member, the Depot Creek Sandstone Member, of the group's basal formation, the Buldiva Sandstone.

Buldiva Sandstone

Depot Creek Sandstone Member (Ᵽtd). The Depot Creek Sandstone Member occurs near the southern and western margin of the Waterhouse Complex, the southern margin of the Rum Jungle Complex, and in the southwestern corner of the map area.

The member was first described by Malone (1962a, b). It consists of pink, medium to coarse, quartz sandstone and orthoquartzite, commonly ripple-marked, and rare basal quartz conglomerate lenses and beds; in places the quartz conglomerate beds are graded. The quartz grains in the sandstone have authigenic quartz overgrowths, but the original grain boundaries are well defined by a coating of fine-grained iron oxides; the grains are well rounded, and generally less than 1 mm in diameter. The preserved thickness of the member is irregular, with a maximum of 30 m.

The age of the Depot Creek Sandstone Member is uncertain. Based on regional correlations by Sweet (1977) and Blake & Hodgson (1975), it is between 1200 and 1620 Ma.

INTRUSIVE ROCKS

Zamu Dolerite (Ᵽdz)

Small outcrops of the Zamu Dolerite occur near the Rum Jungle and Waterhouse complexes, and in the Rum Jungle Complex where Rhodes (1965) reported that dolerite dykes cut the youngest granite. It has also been identified in drill core obtained from near the complexes (Johnson & others, 1979; unpublished drill logs of Territory Enterprises Pty Ltd). It intrudes the Namoona, Mount Partridge, and South Alligator groups. Although the dolerite is generally extensively altered, detailed petrological work by Bryan (1962; see also Walpole & others, 1968, p. 125) showed that relict textures, such as corroded laths of plagioclase and relics of ophitic intergrowths of altered pyroxene and plagioclase, are present and demonstrate its igneous origin. Rhodes (1965) considers the dolerite dykes within the Rum Jungle Complex are probably tholeiitic. Ferguson & Needham (1978) report that on a regional scale the dolerite has an essentially continental tholeiitic composition with normative hypersthene, and was emplaced prior to regional metamorphism and deformation of the Early Proterozoic sedimentary rocks.

MESOZOIC

Petrel Formation (Kp)

The Petrel Formation, which was originally defined by Hughes (1978), is Early Jurassic to Early Cretaceous and forms part of a flat-lying sequence that once covered large areas of northern Australia.

Rubbly outcrops of ferruginous, friable, quartz sandstone and conglomerate, extending over a small area northwest of the Rum Jungle Complex, are tentatively considered to be Petrel Formation.

CAINOZOIC

About half the map area is covered by Cainozoic deposits, which are subdivided into four units: *laterite (Czl); quartz sand, quartz vein float, and clayey soil (Czs); alluvial sand, outwash, and colluvial deposits (Qs); and silt, sand, and black soil (Qa)*. Laterite types range between concretionary, pisolitic, and vermicular types, and form residual pavements in places, indicating that the laterite developed before the present weathering cycle. Black soil is common over the Celia Dolomite and Coomalie Dolomite and underlies extensive grassy plains adjacent to the Adelaide River. Quartz sand and quartz vein float are prominent over the Archaean complexes.

METAMORPHISM

Archaean Rum Jungle and Waterhouse Complexes

Rhodes (1965) has suggested that the metasediments within the complexes have been metamorphosed to the almandine-amphibolite facies. Minor retrograde metamorphism occurred in the granite gneiss and metadiorite of the Rum Jungle Complex as evidenced by small grains of secondary epidote in oligoclase. Along the southern margin of the complex, where shearing has been most intense, plagioclase in the coarse granite has been almost completely sericitised, and veinlets of quartz cut the fractured mineral grains (Rhodes, 1965). In places, porphyroblasts of dumortierite formed in shear zones in the granite (W.B. Dallwitz, personal communication).

Early Proterozoic metasediments

The Early Proterozoic metasediments are part of a low-grade metamorphic province of the Pine Creek Geosyncline (Ferguson, 1980) that was metamorphosed to greenschist facies about 1800 Ma ago (Page & others 1980). There appears to be a variation in the map area from biotite zone near the Archaean complexes to chlorite zone well away from the complexes. Metasediments of the Finniss River Group and South Alligator Group are mainly in the chlorite zone, typified by the development, in pelitic rocks, of fine-grained sericite, microcrystalline quartz, chlorite, and minor muscovite. Metasediments of the Namoona Group and Mount Partridge Group are mainly in the actinolite to biotite zones; actinolite is common in some calcareous beds and in places forms para-amphibolite.

Andalusite has been reported in schist of the Whites Formation in mine open cuts near the southern margin of the Rum Jungle Complex, about 7 km northwest of Batchelor (Malone, 1962a). The presence of this amphibolite-grade mineral in an area cut by many faults and shears, suggests that it might have been formed in a local high-temperature/pressure zone rather than by regional metamorphism.

STRUCTURE

Archaean

The structure of the complexes is poorly known. Schist, gneiss, and granite-gneiss of the complexes are strongly contorted, which indicates that at least one episode of deformation occurred before the deposition of the Early Proterozoic sediments. Tightly refolded folds preserved in clasts in basal conglomerates of the Early Proterozoic sequence overlying the complexes are clear evidence of earlier deformations (Johnston, 1984).

Early Proterozoic

The dome-like structure of the Rum Jungle and Waterhouse complexes has been interpreted by Williams (1963) and Rhodes (1965) as the result of polyphase folding during the Proterozoic. Johnston (1984) also concludes that the complexes are structural domes, but were produced by non-cylindrical F2 folding. An early deformational event resulted in a high-strain zone in places around the contacts between the complexes and the Early Proterozoic metasediments that has a consistent vergence and is the product of an early north-west-verging decoupled zone, created prior to major regional folding possibly along a gravitational D1 tectonic slide (Johnston 1984). Stephansson & Johnson (1975) however considered the domes were formed by Proterozoic granites intruding the complexes and diapirically uplifting them.

Williams (1963) identified three periods of deformation in the Early Proterozoic metasediments in the map area. The major, initial, period of deformation (F1) produced tight to open folding about north-trending axes. East-trending fold axes folded the F1 axes, and later tectonism resulted in flexuring of both sets of folds.

To the west of the complexes a major north-trending fault, the Mount Fitch Fault, developed after folding and appears to offset an F4 kink axial trace to the northwest of the Rum Jungle Complex by several kilometres (Johnston, 1984). The fault is offset by the still later Giants Reef Fault. Outcrop of the South Alligator Group ends near the Mount Fitch Fault close to the northwest margin of the Rum Jungle Complex. No outcrop of this group is known anywhere to the west of the complexes, suggesting that the group has been faulted off by the Mount Fitch Fault. However, Pagel & others (1984) have suggested that the South Alligator Group pinches out westwards or may have a facies equivalent represented by a non-outcropping sericite schist unit on the western side of both complexes.

The major Giants Reef Fault is over 200 km long and crosses the Rum Jungle Uranium Field map area from southwest to northeast. It is a dextral wrench fault with an apparent horizontal displacement of about 7 km. Probably all of this apparent movement postdates the Depot Creek Sandstone Member.

Some of the many smaller faults have laterally displaced the margins of the Archaean complexes. Of these, Johnston (1984) recognises two sets: north to north-northeast-trending normal faults at the southern margin of the Rum Jungle Complex, and east-northeast-trending high-angle faults cutting the Waterhouse Complex and the eastern margin of the Rum Jungle Complex; the latter may be conjugate to the north-trending set.

ECONOMIC GEOLOGY

Copper and gold were produced on a small scale before uranium was discovered in 1949. Subsequent intensive exploration in the 1950s and 1960s by BMR and Territory Enterprises Pty Ltd (TEP) led to the discovery of a number of uranium, uranium-base-metal, base-metal, and phosphate deposits. Further intensive exploration by Uranerz Australia Pty Ltd from 1977 to 1983 resulted in the discovery of more uranium deposits (Pagel & others, 1984). TEP mined uranium deposits under contract to the Australian Government during the 1950s and 1960s.

Much of the uranium and base-metal mineralisation occurs in the Whites Formation: Whites (U, Cu), Intermediate (Cu), Browns (Pb, Cu, Zn, Ag), Woodcutters (Pb, Zn, Ag), and Rum Jungle Creek South (U) deposits. It occurs to a lesser extent in the Acacia Gap Quartzite Member near the southern margin of the Rum Jungle Complex: Dysons(U), Whites East(U), and Mount Burton(U, Cu). Minor mineralisation occurs in the Crater Formation (Th, Au), Koolpin Formation (U, Cu), and Burrell Creek Formation (U, Cu, Au). Subeconomic phosphate deposits and minor uranium mineralisation occur in the Buckshee Breccia where it unconformably overlies the Whites Formation or the Coomalie Dolomite.

Several uranium, base-metal, and phosphate deposits occur in the area between the Rum Jungle and Waterhouse Complexes, where uranium, uranium-base-metal, and base-metal deposits are linearly concentrated near or within a northeast trending shear zone in an embayment formed by the displacement of the Rum Jungle Complex along the Giants Reef Fault. There is a marked zonation of mineralisation here, ranging from uranium at the northeastern end of the shear zone to base-metal mineralisation at its southwestern end (see Berkman, 1968; Fraser, 1975, 1980).

URANIUM AND BASE METAL MINES

Dysons

This deposit was found during follow-up investigations of a BMR ground-radiometric survey that delineated a strong radiometric anomaly near the Giants Reef Fault in the embayment. The major phase of open-cut mining began in 1957 and was completed one year later after 156 000 t of ore grading 0.343% U_3O_8 was produced (Berkman, 1968).

Oxidised uranium minerals (mainly saleeite, $Mg(UO_2)_2(PO_4)_2.8H_2O$) were present near the surface, and to a depth in excess of 33 m in one fault (Berkman, 1968). The mineralisation was mainly in the Acacia Gap Quartzite Member, mostly in faults and fractures. Disseminated uraninite was also present in carbonaceous pyritic shale and pyritic grey orthoquartzite of this member. No other metals were associated with the uranium.

The Acacia Gap Quartzite Member is faulted against the Coomalie Dolomite at depth, and against the Buckshee Breccia near the surface. An outcrop of massive, mostly unstrained vein carbonate, adjacent to the Buckshee Breccia on the western side of the open cut, was probably derived from the underlying Coomalie Dolomite.

Whites

This deposit, discovered in 1949 by J. White from the recognition of green secondary uranium minerals on the surface, was mined from 1954 to 1958. A total of 402 000 t of ore at 0.27% U_3O_8 and 2.7% Cu was treated, and 86 000 t of ore at 5.1% Pb, 0.8% Cu, and 0.3% Co was stockpiled (Berkman, 1968).

The mineralisation occurred in the Whites Formation, in carbonaceous pyritic shale and slate adjacent to a generally brecciated contact with carbonates. The pelitic host rocks were commonly sheared or brecciated and altered to chloritic, sericitic, or talcose slate, phyllite, or schist. Mineralisation occurred within the breccias, in fractures and on cleavage planes, or in small veins. Secondary oxidised uranium and copper mineralisation were present at or near the surface, and primary uranium mineralisation at depth. The main sulphide minerals were pyrite, chalcopyrite, and bornite, with lesser amounts of galena, aikinite ($PbCuBiS_3$), native bismuth, gersdorffite ($Ni(Fe,Co)AsS$), chalcocite, covellite, bournonite ($PbCuSbS_3$), bravoite ($(Ni,Fe)S_2$), and members of the linnaeite–carrollite series ($(Co,Ni)_3S_4$–$Cu(Co,Ni)_2S_4$) (Spratt, 1965).

The orebody was steeply dipping and contained similarly steeply dipping zones of uranium-copper, copper-cobalt, cobalt-nickel, and lead-cobalt mineralisation (Berkman, 1968).

Whites Extended

The very small Whites Extended mine was 300 m east of Whites; it was exploited during 1958 when about 100 t of ore at 0.185% U_3O_8 was removed by open cut (Berkman, 1968).

The host rock was a red hematitic mudstone bed that contained thin layers of uranium ochres (Berkman, 1968) and was associated with pyritic carbonaceous slate (Whites Formation) that was commonly chloritic, sheared, and brecciated, and overlay carbonates interbedded with pyritic carbonaceous slate (also Whites Formation).

There was minor uranium mineralisation in the slate and in a hematite quartzite breccia (probably the Buckshee Breccia).

Intermediate

During the 1880s, small amounts of malachite were gouged from this deposit from silicified slate, breccia, and silicified dolomite breccia. Evaluation of the area during the 1950s revealed a copper sulphide deposit at depth. Open-cut mining began in 1964 and ended in 1965. A total of 732 000 t of ore at an average grade of 2.2% Cu was removed from both oxide and sulphide zones (Berkman, 1968).

The primary ore mineral was chalcopyrite with minor traces of cobalt and nickel sulphides; malachite with minor native copper and copper phosphates occurred in the oxidised zone. Fraser (1980) reports that traces of pitchblende were associated with the chalcopyrite outside the ore zone. The sulphides were contained in a breccia composed of pyritic carbonaceous slate, talcose slate, and sericitic to chloritic schist; breccia fragments were up to 6 m across. To the south the ore breccia was truncated at depth by a major shear zone, whereas in the north it ended close to a generally brecciated contact with carbonates (Berkman, 1968).

Rum Jungle Creek South

This blind deposit, the largest of the Rum Jungle uranium deposits, midway between the Rum Jungle and Waterhouse Complexes, was exploited by open-cut mining between 1961 and 1964 and 663 000 t of ore at 0.44% U_3O_8, and 116 000 t at 0.068% U_3O_8 was produced (Berkman, 1968).

Economic mineralisation was confined to a pyritic quartz-biotite-chlorite schist and underlying pyritic carbonaceous slate within a synclinal structure faulted to the northeast against the Buckshee Breccia. On the west wall of the open cut, chloritic schist and slate contain pyritic carbonaceous slate lenses (Berkman, 1964), which suggests that the ore zone rocks developed through alteration of the pyritic carbonaceous slate.

The weathered zone, 20–30 m thick, was virtually devoid of uranium mineralisation except for three near-surface pods of saleeite (Berkman, 1968). Within the ore zone, pitchblende occurred most commonly as fine sooty coatings on foliation planes and joints, and as thicker veins near the chloritic schist/pyritic carbonaceous slate contact (Berkman, 1968). Base-metal mineralisation was absent.

Mount Burton

Open-cut mining of this small deposit took place in late 1958 with the removal of 6100 t of ore at 0.217% U_3O_8 and 1.04% Cu, 2400 t at 0.072% U_3O_8, and 1400 t at 2.66% Cu.

Uranium and copper mineralisation occurred in pyritic carbonaceous slate and grey pyritic quartzite of the Acacia Gap Quartzite Member near its faulted contact with the underlying Coomalie Dolomite, a contact that is altered, sheared, or brecciated, and in places contains tremolitic schist (TEP unpublished drill logs).

Woodcutters

This deposit was discovered in 1966 by the BMR from soil geochemical prospecting for uranium and base metals (Crohn & others 1967; Ivanac & Langron, 1968). It consists of a series of veins of pyrite, sphalerite, and galena with some silver, cadmium, antimony, and arsenic minerals in sediments of the Whites Formation, about 300–500 m above its contact with the underlying Coomalie Dolomite (Taube, 1984). The orebodies occur along fault and dyke structures which are sub-parallel to the axes of a double-nosed faulted anticline and are in part associated with two unusual carbonatised lamprophyric dykes (Taube, 1984).

The ore, as described by Roberts (1973), is generally coarsely crystalline and consists of, in order of decreasing abundance, pyrite, sphalerite, galena, lead sulphosalts, and arsenopyrite. Galena and sphalerite typically occur in veins; galena commonly fills fractures in sphalerite and pyrite and forms irregular intergrowths with lead sulphosalts (Roberts, 1973).

Open-cut mining started in 1985. Estimated reserves at the end of 1982 stood at 1.55 Mt grading 12.9% Zn, 7.5% Pb, and 154 g/t Ag.

GOLD MINES

Batchelor

This property, 5 km east of Batchelor, yielded 340 g gold from 600 kg of ore. The gold occurred in a number of quartz-tourmaline veins (ranging in thickness from several centimetres to over a metre) in coarse arkose and quartz-pebble conglomerate of the Crater Formation (Sullivan, 1946; Crohn, 1965).

Virginia

The Virginia mine, 5 km east of the Waterhouse Complex, was sunk on gold-bearing quartz veins in the Burrell Creek Formation; it yielded 680 g of gold before 1891 (Tenison Woods, 1886; Parkes, 1892).

PROSPECTS

Browns

Browns, discovered in 1954, is a large but low-grade lead deposit, containing only minor zinc, copper, and silver values. It is contained in sheared and altered pyritic carbonaceous shale, phyllite, and schist, which are talcose, sericitic, and chloritic in places; small sills or veins of Zamu Dolerite are present in the hangingwall. Reserves are 20 500 000 t at 5.4% Pb, 0.3% Zn, and 12 g/t Ag (Needham & Roarty, 1980).

The deposit is conformable and nearly vertical; it is broadly tabular, 700 m long, 50 m wide, and 450 m deep (Fraser, 1980). The highest lead values were found in the centre of the body at its maximum width. Generally, the main ore mineral is galena, which is associated with pyrite and minor amounts of chalcopyrite and sphalerite; chalcopyrite is most abundant at the eastern end, and sphalerite dominates at the western end (Thomas & Whitcher, 1965). The ore minerals commonly occur as films and fine particles along the cleavages and as veinlets in small cross-fractures. In places the galena and associated graphite are smeared on local shear planes, whereas the harder and more brittle sulphide minerals, particularly pyrite, are generally fractured. The paragenetic sequence is: pyrite, linnaeite, chalcopyrite, sphalerite, galena; galena replaces all other sulphides (Williams, 1956, 1957a,b).

Whites East

This prospect is close to Whites Extended open cut. Uranium and subordinate base-metal mineralisation, including Cu, Pb, Zn, and Co, occurs in graphitic and pyritic metapelite, above a downfaulted wedge of the Depot Creek Sandstone Member and in greater amount below the wedge in a chlorite-hematite-quartz breccia composed of carbonate fragments and brecciated apatite rock in a completely chloritised and hematitised matrix (Pagel & others, 1984).

Mount Fitch

The Mount Fitch prospect is near the southwestern margin of the Rum Jungle Complex. It was initially explored by TEP, and reserves of less than 1500 t U_3O_8, contained in ore with an average grade of 0.042% U_3O_8, were delineated (Berkman, 1968; Berkman & Fraser, 1980). Subsequent exploration of the prospect by Uranerz Australia extended the known zones of mineralisation, but the calculated tonnages and overall grades were only a marginal improvement on TEP's estimates (Pagel & others, 1984).

Uranium with subordinate base-metal mineralisation, including Cu, Pb, Zn, Ni, and Co, occurs mainly in brecciated chloritised dolomite and dolomite/chlorite/graphite schists in steeply dipping fault zones (Pagel & others, 1984).

Kylie

Kylie uranium prospect was found by Uranerz Australia in 1978 close to the southern margin of the Waterhouse Complex. The mineralisation occurs in steeply dipping metapelite and carbonate next to a downfaulted block of the Middle Proterozoic Depot Creek Sandstone Member (Pagel & others, 1984).

Southeast Kylie

Another uranium prospect—Southeast Kylie—occurs 2 km southeast of the Kylie Prospect. Minor copper and lead are associated with the uranium mineralisation, which is mostly in sheared metapelite (Pagel & others, 1984).

MINOR PROSPECTS

Many small prospects were found during the 1950s and 1960s as a result of intensive geochemical and geophysical prospecting, mostly by BMR. They generally fall into three groups: (1) Uranium-cum-base-metal prospects in the Coomalie Dolomite and Whites Formation, commonly close to their contact, (2) uranium prospects in the Koolpin and Burrell Creek formations, and (3) phosphate prospects in the Buckshee Breccia.

The first group includes the Mount Fitch North prospect where minor green platey metatorbernite was observed in drill core (Berkman & Fraser, 1980) and 'Area 55' between the two Archaean granitic complexes and west of the Giants Reef Fault, where minor oxidised lead, copper, and uranium minerals occur in chloritic and talcose schist of the Whites Formation adjacent to carbonate of the Coomalie Dolomite (Berkman, 1968). Berkman & Fraser (1980) report that isolated moderately anomalous copper values, up to 200 ppm, occur in soils over a strike length of about 4 km from Mount Burton to the Mount Fitch North prospect. Beneath the soil are three flat-lying copper deposits containing fine-grained malachite, native copper, and chalcocite in residual clays overlying the Coomalie Dolomite; they are estimated to contain 290 000 t ore grading 0.6% Cu. Waterhouse No. 2 prospect east of the Waterhouse Complex contains minor amounts of chalcopyrite associated with anomalous radioactivity in pyritic carbonaceous shales. Minor base-metal mineralisation occurs in an area east of the

Rum Jungle Complex in the vicinity of Woodcutters mine and includes 'Area 44', 2 km east of the mine, where a 7 m zone of low grade stratiform chalcopyrite, averaging 0.3% Cu, was intersected in a drill hole just above the base of the Whites Formation (Taube, 1984). Two uranium prospects—Woodcutters and Woodcutters South (not to be confused with the Woodcutter's mine)—occur also in this area but contain only minor surficial secondary uranium mineralisation (I. Ruddock, personal communication).

The second group includes the Brodribb and Ella Creek prospects north of the Rum Jungle Complex and the Waterhouse No. 1 prospect east of the Waterhouse Complex, in which anomalous radioactivity was detected in pelitic, commonly hematitic, strata near the base of the Koolpin Formation. Only two uranium prospects—Tolmer and Waterhouse No. 3—occur in the Burrell Creek Formation, where small veins containing secondary uranium minerals are present.

The third group includes the phosphate prospects at Stapleton, Easticks, and Geolsec (southeast of the Waterhouse Complex) and Castlemaine Hill (between the Archaean Complexes); all are in the Buckshee Breccia. The most abundant phosphate mineral is microcrystalline fluorapatite which contains much dusty hematite (Pritchard & Cook, 1965). Total reserves are in the order of 4 000 000 t, averaging about 10% P_2O_5.

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