
Darwin: Northern Territory Geological Survey, 2004
(1:100 000 geological map series, ISSN 0811-6296)

ISBN: 0 7245 7089 6

KEYWORDS: Geological mapping, Structural geology, Metamorphism, Geochronology, Geochemistry, Geophysics, Economic geology, Sedimentary geology, Northern Territory, Noonamah, Archaean, Palaeoproterozoic, Palaeozoic, Mesozoic, Cenozoic, Rum Jungle Dome, Waterhouse Dome, Manton Group, Mount Partridge Group, South Alligator Group, Finniss River Group, Bathurst Island Group, Zamu Dolerite, Mount Bundey Granite, Barramundi Orogeny.

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ABSTRACT

Northeastern and central NOONAMAH\(^1\) is dominated by the Adelaide River floodplain, and the western map area by rubble-strewn ridges of Acacia Gap Quartzite Member, smaller undifferentiated Wildman Siltstone ridges and subcropping South Alligator Group sedimentary rocks. The southwestern corner is dominated by the Rum Jungle Dome, an Archaean dome surrounded by Palaeoproterozoic metasedimentary and minor volcanic rocks. The Giants Reef Fault, a major dextral wrench fault some 200 km in length, strikes northeast to cut the Rum Jungle Complex and pass completely through NOONAMAH. The southern, central and eastern areas are dominated by sedimentary rocks of the South Alligator Group and Burrell Creek Formation. Most of the northern part of the map area consists of a lateritic duricrust impregnated upon Cretaceous sedimentary rocks, which are underlain by carbonate rocks of the Mount Partridge Group.

Palaeoproterozoic sedimentary rocks were metamorphosed and deformed in a major orogenic event (Nimbuwah Event of the Barramundi Orogeny) at 1860–1847 Ma, while the Archaean metasedimentary rocks were refolded and retrograded. Late-to post-orogenic, predominantly I-type granite intruded the succession at about 1825 Ma (Cullen Event). Latest igneous activity is manifested by magnetic dolerite dykes, which intruded pre-Tolmer Group rocks. Cretaceous sediments were deposited over Proterozoic rocks in fluvial and nearshore environments. These lithified sediments were then lateritised during the Cenozoic.

NOONAMAH is a mineral-rich area, hosting stratabound and quartz reef gold mineralisation in the east, and uranium and base metal mineralisation in the southwestern corner, around the Archaean Rum Jungle Complex. Between 1954 and 1971, NOONAMAH produced 4560 t of uranium oxide (U\(_3\)O\(_8\)) and by-product copper. Lead-zinc-silver ore was mined at Woodcutters during 1985–1999, producing 4.65 Mt of ore grading 12.3% zinc, 5.6% lead and 87 g/t silver. Rustlers Roost Mine produced 3425 kg of gold before closing in 1998.

\(^1\) Names of 1:250 000 and 1:100 000 mapsheets are shown in large and small capital letters respectively, eg DARWIN, NOONAMAH.
INTRODUCTION

NOONAMAH was originally compiled in 1983 by the Bureau of Mineral Resources, Geology and Geophysics, in collaboration with the Northern Territory Geological Survey, but neither the map nor the explanatory notes were published. However the results were incorporated in the DARWIN map and explanatory notes. The current mapping utilised 1:20 000-scale aerial photograph interpretation, with limited field checking and remapping. The solid geology and structural interpretation were compiled using previous and recently acquired magnetic, gravity and radiometric data.

Location, access and land use

NOONAMAH is bounded by latitudes 12°30’ and 13°00’S, and longitudes 131°00’ and 131°30’E (Figure 1). The Stuart Highway runs north–south through the western side of the map area and access to the east is gained via the Arnhem Highway. The unsealed Marrakai Track links the Stuart Highway and the Arnhem Highway across southern and central NOONAMAH.

Rural freehold living is taking over from pastoral land as the major land use in NOONAMAH, as Darwin’s rural area spreads south and east. Potential areas for mining and quarrying are being sterilised as a result of this semi-urban sprawl.

Suburbanisation is limited to the areas of Humpty Doo and Freds Pass in the far northwestern corner (Figure 2), but rural living areas such as Berry Springs, Darwin River and Acacia have also taken up much land, since NOONAMAH was first mapped. The western side of the Stuart Highway south of Elizabeth River is reserved for the future suburb of Waddell, and the Manton Dam Catchment Area (Woolnough Reserve) occupies a large area of land, south of Manton Dam and southeast of Darwin River Dam, to the west of the Stuart Highway. A number of new rural housing and recreational areas also exist in NOONAMAH, such as the Arnhem Highway Estate and the Lake Bennett Wilderness Resort area.

A large Aboriginal freehold land parcel (Limilngan-Wulna Land Holding) occupies the northeastern corner of NOONAMAH, north of the Arnhem Highway. The Delissaville/Wagait Aboriginal Land Trust has land west of the Adelaide River in central NOONAMAH and the Finniss River Aboriginal Land Trust owns land near Batchelor. The Northern Territory Land Corporation (Crown Land Perpetual in Figure 2) owns large areas of land north of Batchelor and east of the Adelaide River in southern NOONAMAH as well as the Window on the Wetlands area along the Arnhem Highway.

Climate

NOONAMAH has a semi-tropical climate, with a wet season lasting from October to April, and most precipitation falling between December and March. The mean annual rainfall is 1394 mm, recorded at Middle Point in central-northern NOONAMAH. Temperatures are highest between October and April, when the mean minimum and maximum temperatures are 23.4°C and 33.5°C, respectively. The coolest months are between May and September, when the mean minimum and maximum temperatures are 17.5°C and 32.6°C, respectively. Off-road access during the wet season is extremely limited over most of NOONAMAH.

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Figure 1. Location of NOONAMAH.

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2 BMR, later Australian Geological Survey Organisation (AGSO), now Geoscience Australia (GA).
Geomorphology and vegetation

The geomorphology of NOONAMAH consists of black-soil floodplains, paperbark swamps, minor isolated rainforest, lateritic plains, dissected foothills, hinterland and granitic lowlands (Figure 3). NOONAMAH is dominated in the central region by the floodplain system of the north-flowing Adelaide River, with the width of the alluvial floodplain increasing to the north as the topography becomes more subdued. The subcoastal black-soil floodplains generally consist of black mud, silt and clay, with mangrove swamps extending inland as far as the intertidal limits of the Adelaide River. The
Floodplains are inundated for up to six months of the year. They are generally treeless, but have a heavy grassland cover. In recent years, the noxious weed *Mimosa pigra* has spread rapidly over areas of the floodplain. Grey cracking clays are exposed during the dry season.

In northern Noonamah, sandy alluvial drainage channels are generally inhabited by paperbark trees (*Melaleuca*). These generally narrow, shallow swamps are waterlogged for 6–8 months of the year, having been etched into, or developed over the undulating duricrust. A small patch of tropical rainforest occurs in the north of Noonamah in the Black Jungle Swamp Reserve. The rainforest contains tall trees and thick growth, with the water table close to the surface.

The land surfaces of Noonamah were subjected to a period of deep chemical weathering and continental drying, commencing in the early Cenozoic after the deposition of Cretaceous sediments. This weathering process produced the lateritic duricrust, which is well developed on the Cretaceous plains and to a lesser extent on the hilly hinterland of Noonamah. Lateritic plains are flat to gently undulating, and generally support open eucalypt woodland. Lateritised hinterlands and plains have been further sculpted by more recent riverine processes, producing erosional and depositional features such as alluvial drainages.

In the area east of the Adelaide River floodplain, the topography is of relatively low relief, with poorly developed...
northeast-flowing drainage channels, choked with black soil and silt, between low ridges and hills. These dissected siltstone and greywacke foothills are generally ferruginous and contain quartz reefs, with open woodland vegetation. Between the Rum Jungle Complex and the western edge of the Adelaide River floodplain, Mount Partridge Group sedimentary rocks outcrop as generally north-trending strike ridges and rubbly slopes. This area is referred to as the hinterland. Within the hinterland, ferricrete benches commonly form at breaks in slope, at the bases of ridges and in valley bottoms between ridges, where iron oxides have precipitated from points of groundwater discharge. Ferruginous gravely soils and small rises are found in lower-lying areas between larger ridges. The vegetation within this hinterland area is generally open to eucalypt woodland occurring on shallow gravelly soils.

Granitic lowlands north of Batchelor, in the Manton Dam and Darwin River Dam catchment areas, consist of low whaleback granitic outcrops in advanced stages of denudation, within well drained, sandy and lateritic soils. Vegetation ranges from low- to medium-density woodland and low palm scrub to grassland.

Previous geological investigations

Jim Escreet discovered gold in the Rustlers Roost area in the late 1940s, while prospecting south of Mount Bundey. He worked the area for several years, producing around 120 oz of gold (Rabone 1995). Noakes (1949) was the first to carry out regional-scale geological reconnaissance mapping between Darwin and Katherine, which was followed by the discovery of uranium mineralisation by Jack White at Rum Jungle.

During 1953–1958, BMR conducted regional geological mapping of the Katherine–Darwin region. BMR produced the First Edition DARWIN geological map and various 1:63 000-scale geological maps including Humpty Doo, Marrakai, Mount Bundey and Rum Jungle. Investigations also included regional and detailed geophysics, geochemistry and drilling at many prospects. During the 1950s and 1960s, further intensive exploration and associated geological mapping was carried out in the area by BMR and Territory Enterprises Pty Ltd, which led to the discovery of many uranium prospects.

Geopeko undertook significant exploration in the southeastern corner of the sheet area and on adjacent MARY RIVER during the early 1970s, following acquisition of new BMR aeromagnetic and radiometric survey data, flown in 1970. Interpretation of these geophysical data outlined a number of potential targets, which were further investigated by ground-based geophysics and geochemical sampling. Anomalies identified from these programs were designated ‘Quest’ numbers for identification. The Quest 29 deposit on MARY RIVER has been recently mined for gold by Sirocco Resources.

Field mapping in 1972–1974 was carried out by Johnson (1974) to produce the RUM JUNGLE URANIUM FIELD geological map. Fieldwork by NTGS in 1978–1982, in conjunction with BMR, produced the unpublished NOONAMAH geological map. NTGS conducted regional geological mapping during 1980–1987 to produce the Second Edition DARWIN geological map (Pietzsch and Stuart-Smith 1987) and constituent 1:100 000-scale geological maps. Johnston (1984) studied the structure and mineralisation within the Pine Creek Orogen.

Rabone (1995) wrote a case history of the discovery and development of the Rustlers Roost stratabound gold deposit. A number of publications are also available on the Woodcutters deposit, including Taylor (2000), who studied the structure of the Woodcutters open pit after the cessation of mining. McCready et al (2004) studied base metal mineralisation within the Rum Jungle uranium district at the polymetallic Browns Deposit. Detailed studies into metal zonation, textural variations of mineralisation and alteration assemblages were also conducted. SHRIMP U-Pb zircon dating of granite and overlying sedimentary rocks was carried out by NTGS and this work is ongoing. Lally (2003) compiled a solid geology interpretation of the Rum Jungle Mineral Field. Field mapping was conducted in conjunction with interpretation of airborne geophysical and radiometric data to develop an updated structural history for the area.

REGIONAL GEOLOGICAL SETTING

NOONAMAH lies within the northeastern part of the Pine Creek Orogen (PCO; Figure 4), which comprises Palaeoproterozoic sedimentary and minor volcaniclastic rocks, unconformably overlying Neorarchean granitic basement. The latter is represented by the Rum Jungle (≥2525 Ma) and Nanambu Complexes (2400–2500 Ma), and by the concealed Woolner Granite (2675 ± 15 Ma; McAndrew et al 1985). From east to west, the PCO has been divided into five areas, based on structure and metamorphic grade, by Johnston (1984). They are the Alligator Rivers Region, South Alligator Valley Region, Central Region, Rum Jungle Region and Litchfield Province.

An extensional event at about 2000 Ma resulted in the formation of a basin (PCO), into which a 10–14 km thick succession of sediments was deposited. These include lutite, arenite and carbonate, with interbedded volcanic and tuffaceous units. The Rum Jungle and Waterhouse Domes formed island highs on the ‘Batchelor Shelf’ (Ahmad et al in prep). In this area, the lower part of the sedimentary succession comprises marginal shelf facies arenite and carbonate, which grade upward into deeper-water facies to the east. Dolerite sills intruded the succession, prior to regional compressional deformation and metamorphism at 1860–1847 Ma (Barramundi Orogeny). Regional metamorphic grades range from lower greenschist in the Central and South Alligator Valley Regions to upper greenschist in the Rum Jungle area and upper amphibolite in the Litchfield Province and Alligator Rivers Region (Johnston 1984). To the west of NOONAMAH, late- to post-tectonic granitoids of the Allia Creek Suite intruded around 1852–1840 Ma (Geoscience Australia OZCHRON database). To the east, the Mt Bundey pluton intruded at 1831 Ma (Sheppard 1992), and to the south, the Cullen Batholith intruded at around 1825 Ma (Stuart-Smith et al 1993).

Pine Creek Orogen rocks are unconformably overlain by the Katherine River Group to the east and Tolmer Group to the south of NOONAMAH. In the north of the mapsheet, PCO
relationships, distribution and depositional environment for details the lithology, thickness, stratigraphic

Table 1

<table>
<thead>
<tr>
<th>GROUP</th>
<th>RIVER</th>
<th>BEAGLE</th>
<th>GULF</th>
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Figure 4. Regional geological setting of Noonamah.

rocks are unconformably overlain by a thin interval of flat-lying Cretaceous marine sandstone and claystone of the Money Shoal Basin.

STRATIGRAPHY

Table 1 details the lithology, thickness, stratigraphic relationships, distribution and depositional environment for all stratigraphic units of Noonamah.

Archaean

Stanley Metamorphics (As)

The Stanley Metamorphics (Ahmad et al in prep) are exposed on the eastern edge of the Rum Jungle Dome, both north and south of the Giants Reef Fault. The unit consists of gneiss, metasedimentary schist and banded ironstone. Outcrops are small and scattered in low-lying topography. SHRIMP U-Pb
<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology (thickness)</th>
<th>Basal contact</th>
<th>Distribution</th>
<th>Depositional environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BATHURST ISLAND GROUP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Darwin Formation (Kid)</td>
<td>Sandstone and claystone (70 m)</td>
<td>Unconformable on Proterozoic rocks</td>
<td>Generally restricted to northern NOONAMAH</td>
<td>Shallow marine</td>
</tr>
<tr>
<td><strong>UNGROUNDED</strong></td>
<td></td>
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</tr>
<tr>
<td>Geolsec Formation (Eyg)</td>
<td>Hematite quartzite breccia, breccia fragments of shale and recrystallised carbonate; matrix of reddish ferruginous lutite or arenite (&lt;200 m)</td>
<td>Underlies Prd; unconformable on Palaeoproterozoic rocks</td>
<td>Southern margin of Rum Jungle Dome and around Waterhouse Dome</td>
<td>Shallow marine</td>
</tr>
<tr>
<td><strong>INTRUSIVE IGNEOUS ROCKS</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mount Bundey Granite (Egu)</td>
<td>Pink, medium to coarse biotite-hornblende monzogranite</td>
<td>Intrudes Ewp, Es</td>
<td>Southeastern NOONAMAH, southwestern MARY RIVER</td>
<td>Intrusive</td>
</tr>
<tr>
<td>Zamu Dolerite (Elz)</td>
<td>Mafic intrusive rock: dolerite metamorphosed to amphibolite</td>
<td>Intrudes Ar, Ep, Es</td>
<td>Mainly subsurface, limited outcrop in NOONAMAH; extensive in central PCO</td>
<td>Intrusive</td>
</tr>
<tr>
<td><strong>UNGROUNDED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsurface dolostone in Berry Springs area (Elb)</td>
<td>Grey, yellow, red massive dolostone, heavily fractured, fresher at depth (&gt;163 m)</td>
<td>Underlies Kld, Prd; overlies Prb.</td>
<td>Subsurface around Berry Springs</td>
<td>Shallow marine</td>
</tr>
<tr>
<td><strong>FINNISS RIVER GROUP</strong></td>
<td></td>
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</tr>
<tr>
<td>Burrell Creek Formation (Efb)</td>
<td>Shale, siltstone and phyllite, colour-banded; fine to very coarse sandstone, greywacke, feldspar and arkose, quartz pebble conglomerate and quartz-mica schist (~3000 m)</td>
<td>Conformable on Eso; may also be un/conformably overlain by Dlm</td>
<td>East of Adelaide River</td>
<td>Turbidite flows in submarine fan environment</td>
</tr>
<tr>
<td><strong>SOUTH ALLIGATOR GROUP</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mount Bonnie Formation (Eso)</td>
<td>Multi-coloured laminated siliceous, argillaceous and tuffaceous siltstone; common chert beds and nodules; ironstone and massive feldspathic greywacke (&lt;300 m)</td>
<td>Conformable on Esg</td>
<td>Generally restricted to southern NOONAMAH; extensive in central PCO</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Gerowie Tuff (Esg)</td>
<td>Grey and purple silicified shale and siltstone; with grey black chert bands; black glassy vitric tuff, spotted crystal tuff; minor tuffaceous chert (&lt;750 m)</td>
<td>Conformable and gradational on Esk</td>
<td>Generally restricted to southern NOONAMAH; extensive in central PCO</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Koolpinyah Formation (Esk)</td>
<td>Carbonaceous and ferruginous siltstone and shale with chert bands and nodules (&lt;1000 m)</td>
<td>Unconformably overlies Ep</td>
<td>Generally restricted to southern NOONAMAH; extensive in central PCO</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Koolpinyah Member (Ese)</td>
<td>Massive to rubbly goethitic ironstone, commonly containing paraquartzite; breccia, quartz flute breccia, ferruginous chert breccia with ooids, siltstone with chert nodules, pebble and boulder conglomerate. Basal interbedded black shale and sandstone</td>
<td>Lower member of Esk</td>
<td>North of Darwin River Dam and east of Adelaide River</td>
<td>Shallow marine</td>
</tr>
<tr>
<td><strong>MOUNT PARTRIDGE GROUP</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Wildman Silstone (Epw)</td>
<td>Grey and purple siltstone and shale, commonly containing sandstone and quartzite beds; commonly pyritic (&lt;2000 m)</td>
<td>Conformable on, and partially? interdigitates with Epi</td>
<td>Widespread, generally outcropping as strike ridges</td>
<td>Shallow subtidal marine</td>
</tr>
<tr>
<td>Mount Deane Volcanic Member (Epd)</td>
<td>Altered basic volcanic rocks, locally vesicular or brecciated</td>
<td>Conformable within Epw</td>
<td>Limited outcrop in ridges between Stuart Highway and Adelaide River</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Acacia Gap Quartzite Member (Epa)</td>
<td>Pyritic quartzite with interbedded phyllite, sandstone</td>
<td>Conformable and tightly folded within Epw</td>
<td>Margin of Rum Jungle Dome and north-northwesterly strike ridges in western NOONAMAH</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Koolpinyah Dolostone (Epk)</td>
<td>Grey silicified dolostone interbedded with chlorite schist; dolomitic marble, dolomitic mica schist, dolomitic limestone, calcareous quartzite</td>
<td>Underlies Epw; presumed conformable on Epi?</td>
<td>Underlies Cretaceous sedimentary rocks in northern NOONAMAH and most of Koolpinyah</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Whites Formation (Epi)</td>
<td>Dark graphitic shale, carbonaceous pyritic argillite, dolostone and calcareous para-amphibolite (&lt;500 m)</td>
<td>Conformable on Epc</td>
<td>Margin of Rum Jungle Dome</td>
<td>Intertidal to subtidal</td>
</tr>
<tr>
<td>Coomalie Dolostone (Eppc)</td>
<td>Stromatolitic magnesite and dolostone, stromatolitic silicified carbonate occurring as chert or paraquartzite; rare calcareous para-amphibolite, metapelite (&lt;300 m)</td>
<td>Conformable on Epr</td>
<td>Margin of Rum Jungle Dome</td>
<td>Shallow marine</td>
</tr>
<tr>
<td>Crater Formation (Epr)</td>
<td>Conglomerate, in places showing graded bedding; conglomerate containing banded ironstone; sandstone, commonly ripple marked; arkose; minor siltstone and shale (300–600 m)</td>
<td>Unconformable on Epl</td>
<td>Margins of Rum Jungle and Waterhouse Domes</td>
<td>Fluviatile to shallow marine</td>
</tr>
<tr>
<td><strong>MANTON GROUP</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Celia Dolostone (Enl)</td>
<td>Stromatolitic magnesite and dolostone, stromatolitic silicified carbonate occurring as chert or paraquartzite; rare calcareous para-amphibolite, metapelite (&lt;300 m)</td>
<td>Conformable on Ebb</td>
<td>Eastern edges of Rum Jungle and Waterhouse Domes</td>
<td>Lacustrine; pertidal to shallow marine? Fluviatile</td>
</tr>
<tr>
<td>Beeston Formation (Eb)</td>
<td>Quartz conglomerate and grit, arkose, sandstone, minor banded ironstone, pebble to boulder conglomerate (&lt;200 m)</td>
<td>Unconformable on granite of Ar</td>
<td>Eastern edges of Rum Jungle and Waterhouse Domes</td>
<td>Fluviatile</td>
</tr>
<tr>
<td><strong>ARCHAEOAN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rum Jungle Complex (Ar)</td>
<td>Leucocratic, porphyritic, coarse to medium to large-feldspar and undifferentiated granite; metadiorite, granite gneiss, schist</td>
<td></td>
<td>Rum Jungle and Waterhouse Domes</td>
<td>Mostly intrusive</td>
</tr>
<tr>
<td>Stanley Metamorphics (As)</td>
<td>Schist, gneiss, banded ironstone, minor granite</td>
<td></td>
<td>Rum Jungle and Waterhouse Domes</td>
<td>Uncertain</td>
</tr>
</tbody>
</table>

Table 1. Pre-Cenozoic stratigraphy of NOONAMAH.
zircon dates from granite samples from the Rum Jungle and Waterhouse Domes are $2525 \pm 5$ Ma and $2535 \pm 7$ Ma, respectively (NTGS unpublished data), indicating that deposition of Archaean protolith sediments of the Stanley Metamorphics began before this time. The Stanley Metamorphics are a possible correlative of the Dirty Water Metamorphics, a similar lithological package that unconformably overlies the Woolner Granite (2675 Ma) in Koolpinyah-Point Stuart.

**Rum Jungle Complex (Ar)**

First described by Fisher and Sullivan (1954) and originally called the Rum Jungle Granite (Malone 1962a, b), the Rum Jungle Complex (Rhodes 1965) is exposed as a faulted dome, north of Batchelor. The Rum Jungle Complex contains a variety of granitic and metasedimentary rocks, unconformably overlain by younger, Palaeoproterozoic metasedimentary rocks. The Waterhouse Complex (Johnson 1974) contains similar rock types exposed in a dome to the south of Batchelor. Granites in both domes comprise both S and I types, are of similar age (unpublished NTGS data), and have the same geochemistry (Ferguson et al 1980, McCready et al 2004). Ahmad et al (in prep) have therefore extended the Rum Jungle Complex to include the now defunct Waterhouse Complex and used the names Rum Jungle Dome and Waterhouse Dome to describe rocks in these two different areas. Gravity data suggest that the domes are joined at a depth of around 2 km (Major 1977). Only the Rum Jungle Dome is exposed in Noonamah. The oldest rocks of both domes consist of metasedimentary schist, gneiss and banded ironstone.

Outcrop in the Rum Jungle Dome is poor, generally being restricted to low whaleback exposures. Most of the complex is covered by superficial deposits. Rhodes (1965) subdivided the complex into seven units, in order of decreasing age: metasedimentary rocks and banded ironstone; schist and gneiss; granite-gneiss and migmatisite; metadiorite; coarse to medium granite; large-feldspar granite; and leucocratic granite. Johnson (1977) added an additional metasedimentary unit containing banded ironstone, now included within the Stanley Metamorphics. Ahmad et al (in prep) have recognised fifteen constituent units on the basis of airborne radiometric and magnetic responses, and limited field mapping. Age relationships between the units are based on the original observations of Rhodes (1965).

The Rum Jungle Dome consists predominantly of granitic bodies that intrude the Stanley Metamorphics (Rhodes 1965). The granite contains quartz, feldspar, biotite and hornblende. According to Crick (1987), veins and dykes of pegmatite are commonly associated with the leucocratic and large-feldspar granites, whereas amphibolite veins intrude both the coarse and leucocratic granites. Quartz-tourmaline veins are abundant along the margins of the dome and extend into the sedimentary rocks.

**Palaeoproterozoic**

**Manton Group**

The Manton Group was formerly regarded as being synonymous with the Namoona Group, but is now considered to be a western equivalent (Lally 2003). It contains the oldest Palaeoproterozoic sedimentary rocks of the PCO and these unconformably overlie the Rum Jungle Complex. The basal Beestons Formation contains arkose and rudite, and is overlain by dolostone and magensite of the Celia Dolostone.

**Beestons Formation (Pnb)**

The Beestons Formation outcrops as a series of strike ridges, commonly offset by minor faulting, along the eastern margin of the Waterhouse Dome, and as more or less continuous ridges along the eastern side of the Rum Jungle Dome. Johnson (1974) suggested that the Beestons Formation marked part of an old shoreline around both Archaean basement domes. However, Ahmad et al (in prep) considered that the Beestons Formation was never deposited on the western side of the domes. Only the Crater Formation and younger rocks are exposed on the western side. The discontinuous outcrop pattern to the east of the domes is probably an expression of the differing depths of erosion reached (Johnson 1974).

The Beestons Formation consists of arkose, quartz pebble conglomerate, quartz sandstone, grit and orthoquartzite. The conglomerate has a feldspathic/arkosic angular matrix, indicating a nearby granitic source, and comprises angular quartz clasts up to 40 cm in size, in a medium to coarse arkosic matrix. The Beestons Formation marks the base of the Palaeoproterozoic succession in the PCO. The unconformable contact between the underlying Rum Jungle Complex and Beestons Formation (Figure 5) is exposed in Batchelor, about 4 km north of Batchelor township. The Beestons Formation is overlain by the Celia Dolostone and is correlated with the Masson Formation, further east in Mary River.

**Celia Dolostone (Enl)**

The Celia Dolostone, formerly termed Celia Dolomite (Malone 1962a, b), outcrops on the eastern sides of the Rum Jungle and Waterhouse Domes. Its maximum thickness has previously been estimated at 300 m, where abutting the Rum Jungle Complex (Crick 1987), but may be as thick as 600 m, as indicated by drilling north of the Batchelor Road in Batchelor (Goulevitch and Turner 1996). Outcropping carbonate rock is variably silicified, with remnant stromatolites, and also exhibits a saccharoidal texture. Varied forms of stromatolite, including stratiform, domical and conical types, are present (Bone 1985).

Drilling a few kilometres south of Noonamah, north of the Batchelor Road, targeted Celia Dolostone and intersected impure (25–42%) magensite and only minor amounts of dolomite, calcite and siderite (Goulevitch and Turner 1996). According to Bone (1985), the magensite is completely recrystallised, with mineral form being either bladed or rhombic, depending on the temperature of recrystallisation. BHP (1983) observed textures ranging from fine to recrystallised coarse subhedral aggregates. Talc is also present, generally occurring between magensite grains (BHP 1983). Minor para-amphibolite, metapelite and calcareous sandstone have also been intersected by drilling (Johnson et al 1979).

Stromatolites, teepee structures and a trace element geochemistry of low Na, K and Sr, and high F, Fe and Mn were interpreted by Bone (1985) to indicate a lacustrine
depositional environment. A palaeokarst surface exists between the Celia Dolostone and overlying Crater Formation.

Mount Partridge Group

The two lowest units of the Mount Partridge Group, the Crater Formation and Coomalie Dolostone, represent a lithofacies repetition of the Manton Group. The Crater Formation is predominantly an arkosic and conglomeratic unit, overlain by shallow marine carbonate rocks of the Coomalie Dolostone. The Whites Formation conformably overlies the Coomalie Dolostone and represents an alternating interval of carbonaceous shale and dolostone. Conformably overlying the Whites Formation in southern NOONAMAH is the Wildman Siltstone, a laminated pelitic unit containing bands of sandstone and volcanic units. The laminated nature of the Wildman Siltstone indicates that it was deposited in a subtidal environment (Crick 1987). In northern NOONAMAH, the Wildman Siltstone overlies the Koolpinyah Dolostone, which contains massive dolostone, interbedded at depth with laminated chloritic schist. This unit has been interpreted as shelf deposits surrounding the Woolner Granite (Pietsch and Stuart-Smith 1987). The Mount Deane Volcanic Member is a minor mafic igneous extrusive unit within the Wildman Siltstone. The Acacia Gap Quartzite Member is also a constituent.

Crater Formation (Epr)

The Crater Formation forms a series of ridges around the Rum Jungle and Waterhouse Domes, and attains a maximum thickness of 600 m (Crick 1987). It is predominantly arkosic and most of the constituent lithoclasts of the lower beds were derived from the underlying granitic rocks. The unit grades upward from arkose to siltstone and thence to sandstone (French 1970).

French (1970) carried out detailed investigations, including mapping, and divided the Crater Formation into eight lithological units. These are, in descending order: upper siltstone shale and sandstone; No 2 conglomerate; sandstone; shale band; No 1 conglomerate; grit and pebble beds; hematite boulder conglomerate; and grit with pink/brown cross-bedded sandstone. Hematite boulder conglomerate near the base of the Crater Formation outcrops around the southern margin of the Rum Jungle Dome in southwestern NOONAMAH and around the northern margin of the Waterhouse Dome.

The formation is a clast-supported conglomerate, which contains vein quartz and banded ironstone pebble-to-boulder-sized clasts in a sandy hematitic matrix. The boulders average 10–20 cm (Figure 6), but may be up to 60 cm in diameter. Ironstone was evidently sourced from material within the Stanley Metamorphics. Rare chert clasts (Crick 1987), and sandstone and silicified dolostone clasts (Ahmad et al in prep) were probably derived from erosion of underlying Manton Group rocks. This unit thins laterally and has been interpreted as an alluvial fanglomerate deposit (French 1970).

The No 1 and No 2 conglomerates, higher in the formation, contain small to medium pebbles in a dark matrix. The shale band overlying the No 1 conglomerate ranges between 20 m and 60 m in thickness, acts as a good marker interval and contains elevated base metal concentrations (French 1970). Morlock and England (1971) determined that the radioactivity of some of the conglomerates was due to an amorphous or metamict phosphate of Th, Ca and Fe within certain opaque minerals. French (1970) stated that the grit and pebble beds had different levels of radioactivity to the hematite boulder conglomerate and that silt bands overlying the conglomerate commonly had higher values, probably due to concentrations of heavy minerals. Drilling shows that weathering extends deeper into shale beds than it does into sandstone (French 1970).

The Crater Formation was deposited after a period of minor uplift, and overlies the Beestons Formation and Celia Dolostone. It is considered to be mostly fluviatile, as suggested by asymmetric ripple marks and trough cross-beds (French 1970). The upper siltstone, shale and sandstone unit overlies granite of the Rum Jungle Complex near Manton Dam. The contact is sheared and dips steeply away from the complex (French 1970). A large F₂ fold, to the south of

Figure 5. Sharp unconformable contact between Archaean granite of Rum Jungle Complex and overlying Beestons Formation. Beestons Formation basal conglomerate comprises angular vein conglomerate fragments in an arkosic matrix, including grains of bluish opalescent quartz, similar to that in underlying granite. Hammer is 30 cm long. 718270mE, 8559490mN, 200 m east of Rum Jungle road, northwestern Batchelor.
Manton Dam in the arkose/conglomerate ridges, exhibits pronounced foliation (Ahmad et al. in prep).

**Coomalie Dolostone (Ppc)**

The Coomalie Dolostone is poorly exposed around both the Rum Jungle and Waterhouse Domes. It has a maximum thickness of about 300 m (Crick 1987). In outcrop, the Coomalie Dolostone is commonly either heavily silicified, or lateritised, or both (Shatwell 1966). The dolostone may also be thickly covered by ferruginous or kaolinitic quartz sand (Shatwell and Duckworth 1966). It contains thin interbeds of metapelite and calcareous para-amphibolite (Crick 1987). Mineralogically, the Coomalie Dolostone comprises recrystallised magnesite and dolomite. Magnesite is almost pure and at least two types are recognised: rhombohedral and bladed (Bone 1985). Extensive brecciation is present at both the Huandot and Winchester magnesite deposits. Chalcedony and quartz replace microbial structures (Bone 1985).

Teepee structures and various stromatolite types (stratiform, domical and conical) are typically present in the Coomalie Dolostone (Crick and Muir 1980). The deposition of the underlying Crater Formation ceased with a return to stable, shallow marine conditions, which resulted in the formation of microbial reefs, and the deposition of the Coomalie Dolostone in a lagoonal environment. The distribution of this carbonate tract marks the limit of the Batchelor Shelf, beyond which the basin was deeper, resulting in deposition of mainly argillaceous sediments.

South of the Woodcutters Mine, in northern Batchelor, the Huandot magnesite deposit is located in Coomalie Dolostone. In this area, the upper Coomalie Dolostone is composed almost entirely of magnesite, striking north and dipping moderately eastward (Barnes 1995), with limited small outcrops of white to grey massive magnesite.

The Coomalie Dolostone conformably overlies the Crater Formation; dolomitic sandstone at the top of the Crater Formation grades upward into dolostone at the base of the Coomalie Dolostone. It is conformably overlain by the Whites Formation and may be a stratigraphic equivalent of the Koolpinyah Dolostone, further to the north (Pietsch and Stuart-Smith 1987).

**Whites Formation (Ppi)**

Rocks of the Whites Formation (Crick 1984) were previously assigned to the now defunct Golden Dyke Formation (Malone 1962a, Johnson 1977) and to the Masson Formation (Needham et al. 1980). The unit is poorly exposed on the eastern side of the Rum Jungle and Waterhouse Domes, and best exposures are within mine open cuts. The Whites Formation conformably overlies the Coomalie Dolostone. Crick (1987) considered the two units to have an interfingering relationship, but cited no supporting evidence. Stratigraphic logs, from drilling at the Woodcutters deposit, show that the Whites Formation has a maximum thickness of about 1200 m (Goulevitch and Butler 1998), but both the Whites Formation and Coomalie Dolostone thin in the vicinity of Manton Dam. The type section for the Whites Formation is 2 km southeast of Batchelor, in Batchelor. Figure 7 shows a generalised section through the Whites Formation in the Woodcutters area. The upper interval is composed of pyritic calcareous and/or carbonate black slate, minor quartzite, calcarenite and calcareous para-amphibolite (Crick 1987). Tuff beds are common and an ooid dolostone bed is also present. The middle interval is a continuation of bedded carbonaceous shale, containing tuff marker beds, and minor quartz and quartz-carbonate veins (Goulevitch and Butler 1998). The lower interval is composed of alternating bedded slate, dolostone and mudstone, including persistent tuff marker beds. Five defined dolostone units (C1–C5), containing thin quartz-carbonate veins, were described by Nicholson et al. (1990); these are interbedded with four mudstone units (M1–M4). The lowest mudstone unit, M1, contains stratiform and disseminated sphalerite, galena and chalcopyrite, and disseminated pyrrhotite (Goulevitch and Butler 1998).

The Intermediate Mine open cut shows the carbonate to be mainly recrystallised dolostone with minor magnesite veins, whereas Whites open cut contains coarse crystalline vein magnesite and dolostone displaying small cross-beds.
**Koolpinyah Dolostone** (Lppk)

The Koolpinyah Dolostone does not outcrop anywhere. It is restricted to northern Noonamah, generally underlying Cretaceous sedimentary rocks and locally, Wildman Siltstone. All stratigraphic information on the unit has come from drillholes in Koolpinyah and waterbore within Noonamah. The Koolpinyah Dolostone consists of grey silicified dolostone interbedded with chloride schist, dolomitic marble, dolomitic mica-schist and dolomitic quartzite. Petrographic examination of drillcore from Koolpinyah shows the dolostone to have a dolospar matrix containing finer fragmental dolomite, with limonite intergrowths and granular chert. Some fine-grained turbid bodies within the samples may represent dolomitised ooids or peloids.

Pietsch and Stuart-Smith (1987) correlated the Koolpinyah Dolostone with the Coomalie Dolostone. It is probably a shelf equivalent of the Coomalie Dolostone around the Woolner Granite, which extends southward toward the Arnhem Highway, and is there overlain by the northern extremity of the Wildman Siltstone.

North of the Arnhem Highway in the Fogg Dam and Harrison Dam area, the dolostone is overlain by about 30 m of Cretaceous sandstone and claystone. Further west toward the Stuart Highway, the depth of Cretaceous cover ranges up to 60 m.

Pietsch and Stuart-Smith (1987) mentioned an unexposed unit, intersected in drillholes to the south and west of the Woolner Granite; this consists of conglomerate and dolomitic breccia at least 15 m thick, is foliated and contains clasts derived from the Dirty Water Metamorphics and Woolner Granite. The conglomerate and breccia therefore provide evidence of an unconformity in this area, either at the base of the Koolpinyah Dolostone or at the base of the Mount Partridge Group; however, these may also represent strata equivalent to the Manton Group.

**Wildman Siltstone** (Lpw)

The Wildman Siltstone was first described from exposures in the central and eastern PCO by Needham and Stuart-Smith (1978) and Needham *et al* (1980). In Noonamah, outcrop is mostly in areas south of the Arnhem Highway and east of the Rum Jungle Dome. The formation generally outcrops on the flanks of ridges of the Acacia Gap Quartzite Member, and as low domed hills. Further north, the Wildman Siltstone is generally covered by Cretaceous sedimentary rocks, but it can be traced on aeromagnetic images. The thickness of the Wildman Siltstone is irregular, with a maximum of about 1500 m (Crick 1987).

The Wildman Siltstone consists mainly of finely laminated pyritic argillite and carbonaceous shale, orthoquartzite, and sandstone. Lutitic rocks comprise around 90% of the formation (Pietsch and Stuart-Smith 1987). Laminations are commonly reddish-brown, pale grey-green or dark–light grey in outcrop (*Figure 8*), depending on the relative proportions of iron oxides to pyrite within the unweathered material. Calcite veins are present in black siltstone, west of the Howard River in Koolpinyah. Vein quartz and quartzite boudins commonly occur parallel to bedding. Quartz grains constitute the bulk of the Wildman Siltstone, although siltstone beds also contain sericite and muscovite. The formation is commonly ferruginised at surface, giving it a dark colouration. Weathered siltstone contains kaolinite and smectite clays.

The Wildman Siltstone includes the Acacia Gap Quartzite Member and highly altered mafic volcanic rocks (Mount Deane and Yarrawonga Volcanic Members). The latter member is restricted to Koolpinyah. Further east, in Mary River, the Wildman Siltstone is underlain by the Mundogie Sandstone, a fine to coarse sandstone that is considered to be correlative with the Crater Formation (Pietsch and Stuart-Smith 1987), and contains another, unnamed weathered...

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### Figure 7. Whites Formation: schematic stratigraphic subdivision

(Crick 1987). The absence of microbial structures higher in the formation indicated to Bone (1985) that that a portion of the Whites Formation was deposited in a subtidal environment.

### Koolpinyah Dolostone (Lppk)

**Figure 8.** Schematic stratigraphic subdivision of the Wildman Siltstone (from Goulevitch & Butler, 1998).
volcanic interval. The fine laminations suggest deposition in waters undisturbed by waves or currents, such as in a subtidal environment (Crick 1987). The Wildman Siltstone conformably overlies the Whites Formation east of the Rum Jungle and Waterhouse Domes, whereas further north it overlies the Koolpinyah Dolostone.

Recent NTGS geochronology indicates that the age of deposition of the Wildman Siltstone and Acacia Gap Quartzite to be around 2025 Ma (Worden et al 2004).

**Acacia Gap Quartzite Member (Epa)**
Crick (1987) revised the name of this member from the Acacia Gap Tongue Member of Malone (1962a, b) and Acacia Gap Sandstone Member of Needham et al (1980). The thickness of the Acacia Gap Quartzite Member ranges from about 50 m, southeast of Batchelor, to about 300 m, north and east of the Rum Jungle Complex (Crick 1987). In NOONAMAH, the member is generally exposed in north-northwest-striking ridges. Around Darwin River Dam and Manton Dam, the folded quartzite ridges strike easterly. Further north, in the Milners Creek area in DARWIN, rubbly outcrops of quartzite, partially buried by Cretaceous sedimentary rocks, are steeply dipping, folded, faulted, heavily jointed and interbedded with phyllite. The quartzite is pale grey, fine to medium, evenly grained and dense. Minor white sericite and kaolinite enclose quartz grains (Doyle 2001). Numerous quarries and cuttings have exposed such quartzite beds (Figure 9), usually 0.2–6.0 m in width, well jointed and interbedded, with up to 30% phyllitic siltstone (Doyle 2001).

The quartzite is a product of regional metamorphism and silicification of quartz sandstone. It is well sorted with well rounded quartz grains, indicating lengthy transport. The quartzite is commonly impregnated with pyrite cubes, which on weathered surfaces have been oxidised to limonite or removed entirely, leaving cavities. An overprinting foliation is visible in certain areas (Doyle 2001). Quartz veining is abundant.

**Mount Deane Volcanic Member (Epd)**
The Mount Deane Volcanic Member discontinuously outcrops east and north of the Rum Jungle Complex, and consists of altered basic volcanic rocks that are, in places,
vesticular and brecciated. It is up to 200 m in thickness (Pietsch and Stuart-Smith 1987) and lies stratigraphically above the Acacia Gap Quartzite Member, separated from it by up to 200 m of shale and siltstone (Crick 1987). Its weathered rubbly outcrops contain amygdaloidal rock types with silica-lined amygdales, commonly distorted or stretched, and flow breccias (Crick 1987). It is highly altered near its type area at Mount Deane in Batchelor. The Mount Deane Volcanic Member can be correlated with the Yarrawonga Volcanic Member further to the north in Koolpinyah (Pietsch and Stuart-Smith 1987).

**South Alligator Group**

The South Alligator Group was originally erected by Walpole (1962) for rock units in the South Alligator Valley area. Later, Crick et al (1978) recognised that the group was far more extensive across the PCO. Stuart-Smith et al (1980) interpreted a period of uplift, folding and erosion, prior to deposition of the South Alligator Group, but there is no evidence of this in Noonamah. The South Alligator Group gradually thins westward toward the Rum Jungle and Waterhouse Domes. Three formations constitute the group: in ascending order, the Koolpin Formation (including Ella Creek Member), Gerowie Tuff and Mount Bonnie Formation. To the east of Noonamah, the South Alligator Group is intruded and contact metamorphosed by the Mount Bundey Granite and Mount Goyder Syenite.

**Koolpin Formation (Esp)**

The Koolpin Formation is restricted to southern and central Noonamah, outcropping as strike ridges and dark, rubbly ferruginous hills. It consists of ferruginous siltstone and shale, ferruginous breccia, minor silicified dolostone, chert bands and carbonaceous mudstone up to 200 m in thickness. Elongate chert lenses and rounded nodules are visible in outcrops and cuttings.

The Koolpin Formation includes a basal iron-rich unit, the Ella Creek Member (Crick 1987), which is observed in the Rum Jungle area, and which can be traced at various locations across to Mary River, where Sheppard (1992) correlated it with the lowermost of three interpreted units within the Koolpin Formation. Siltstone and shale are discernibly carbonaceous in proximity to the Mount Bundey Granite and Mount Goyder Syenite in Mary River (Pietsch and Stuart-Smith 1987), where the formation is intruded and contact metamorphosed. These carbonaceous beds were deposited in a reducing environment (Crick et al 1980). Also in Mary River, irregular Zamu Dolerite sills within the Koolpin Formation are visible in the eastern pit wall of the Quest 29 Mine.

The Koolpin Formation unconformably overlies the Wildman Siltstone, and its lower contact is defined as the base of the first breccia (Sheppard 1992). The formation is conformably overlain by the Gerowie Tuff.

**Ella Creek Member (Es)**

The Ella Creek Member is exposed as small strike ridges, north and east of the Rum Jungle Dome. East of the Adelaide River, it is well exposed in ridges faulted against other units of the South Alligator Group by a wrench fault, described by Pietsch and Stuart-Smith (1987) as a possible continuation of the Noonamah Fault. The Ella Creek Member is the basal iron-rich unit of the Koolpin Formation, and consists of both ferruginous and quartzitic breccia, pebble to boulder conglomerate, minor ferruginous siltstone and chert flake breccia (Crick 1987). At depth, the unit comprises black siltstone and carbonaceous shale, interbedded with saccharoidal quartzite and minor limonitic breccia (Pietsch and Stuart-Smith 1987).

The interbedded saccharoidal quartzite (after carbonate) and black shale were probably deposited in shallow water, with periods of restricted circulation, allowing both carbonate development and the deposition of carbonaceous sediments (Pietsch and Stuart-Smith 1987). Surficial goethitic ironstone and the ferruginous nature of the brecciated rocks point to subsequent subaerial exposure. The surficial ironstone units are similar to more recent ferricrete and, to a lesser extent, silcrete development.

**Gerowie Tuff (Esg)**

The Gerowie Tuff is generally restricted to the southern half of Noonamah. This unit forms lighter-coloured strike ridges and low hills, sandwiched between the darker Koolpin and red-brown Mount Bonnie Formations. Crick et al (1978) first recognised the tuffaceous nature of this formation in other parts of the PCO. The thickness of this unit is difficult to estimate due to folding, but is probably about 300–400 m (Stuart-Smith et al 1984).

The Gerowie Tuff consists of laminated silicified tuffaceous siltstone, black argillite, black glassy crystal tuff and tuffaceous chert. Tuff shards are detectable in hand specimens. The Boral Mount Bundey hard rock quarry to the east of Noonamah in Mary River is located in Gerowie Tuff within the hornfelsed contact zone of the Mount Bundey Granite (Figure 10). The original rock type was tuffaceous siltstone, which during metamorphism, was devitrified and recrystallised into hard cherty material. The tuff beds are folded, faulted and well jointed. Parts of the quarry face exhibit tight disjamband folds within the limbs of larger folds. The dip of the beds increases toward the contact with the syenite. The quarry also contains a north-northwest-trending lamprophyre dyke 2–3 m in thickness. Cordierite and garnet are present as contact metamorphic minerals. The Gerowie Tuff is conformable on the Koolpin Formation, with its base defined as the first tuff bed (Pietsch and Stuart-Smith 1987).

Recent NTGS SHRIMP U-Pb ages for Gerowie Tuff of 1864 ± 3 Ma and 1862 ± 3 Ma indicate a younger depositional age than the 1885 ± 2 Ma of Needham et al (1988).

**Mount Bonnie Formation (Eso)**

The Mount Bonnie Formation outcrops in the southern half of Noonamah, as a series of distinctly coloured red-brown strike ridges and low hills. It conformably overlies the Gerowie Tuff and the contact is defined as the base of the first greywacke bed (Sheppard 1992). The formation has an average thickness of about 500 m and is conformably overlain by the Burrell Creek Formation in the east.

The formation consists of predominantly red, brown and purple laminated siltstone. Chert, greywacke and banded
Ironstone beds are common lower in the unit. Minor tuffaceous beds occur in its upper part (Sheppard 1992). Chert nodules up to 5 mm in diameter can be found in siltstone beds (Crick 1987). The best exposures of the Mount Bonnie Formation are in the open-cut Rustlers Roost Mine (Figure 11) in far eastern Noonamah, where gold is present in thin iron-rich beds and quartz stockwork veins. Greywacke is massive and contains numerous examples of graded bedding (Sheppard 1992).

In eastern Noonamah, the unit is intruded by the Zamu Dolerite and further east, in Mary River, it is intruded and contact metamorphosed by the Mount Bundey Granite and Mount Goyder Syenite. Decorative stone used around gardens in Darwin has come from mining waste heaps at Rustlers Roost and is given the trade name ‘Rooster Red’.

**Finniss River Group**

The Finniss River Group (Walpole et al 1968) includes flyschoid sedimentary rocks. It originally comprised the Noltenius and Burrell Creek Formations. The former is no longer recognised as a separate unit. The Burrell Creek Formation is the most extensive unit and conformably overlies the South Alligator Group. Other units, which are restricted to the Litchfield Province, include the Chilling Sandstone, Wars Volcanics and Mulluk Mulluk Volcanics. Finniss River Group sediments are believed to have been derived from a source to the west (Crick 1987).

**Burrell Creek Formation (Pfb)**

The Burrell Creek Formation dominates outcrop in southeastern Noonamah and conformably overlies the Mount Bonnie Formation. Poor exposure and the transitional relationship between the two formations makes the contact difficult to identify, although pelite in the Burrell Creek Formation has abundant quartz veining and is less ferruginous than that in the Mount Bonnie Formation. The Burrell Creek Formation is also very extensive in outcrop in areas to the south and west. In Noonamah, it forms low rises between sediment-choked drainages, in contrast to the steeper strike ridges west of the Rum Jungle Complex.
The Burrell Creek Formation consists of reddish-brown siltstone and shale with a well defined cleavage, greywacke, and quartz pebble to boulder conglomerate. Rare, small sand volcanoes are present (Walter 1972). Crosscutting quartz veins are prolific and pegmatites are common to the north and northwest of Noonamah. The maximum measured thickness of the formation is 1800 m near Predictor Hill, 15 km north of Adelaide River township (Crick 1987), but the true maximum thickness is considered to be much greater, as the top of the formation is marked by a pronounced unconformity.

Interbedded siltstone and greywacke are most common in Noonamah, whereas coarser-grained sedimentary rocks (conglomerate and coarse feldspathic arenite) occur to the west. Mass-transport turbidity flows were probably the main transport mechanism, depositing sediment in a submarine fan environment (Pietsch and Stuart-Smith 1987). The formation was deformed during the Barramundi Orogeny.

### Ungrouped

#### Subsurface dolostone in Berry Springs area (Elb)

Subsurface massive dolostone underlies the Berry Springs area and can be traced discontinuously northward to Palmerston and Darwin using waterbore drill logs. Stratigraphic relationships are uncertain, but the most probable inference from waterbore drill logs is that the dolostone overlies siltstone of the Burrell Creek Formation, and is, in turn, unconformably overlain by the Depot Creek Sandstone of the Tolmer Group.

The unit is at least 163 m thick according to drillholes. The dolostone lies below an unconformity surface at the base of the Cretaceous, throughout much of the Berry Springs area, and below probable Depot Creek Sandstone in eastern Bynoe. The unconformity surface is composed of quartz gravel, clay, chert and dolostone fragments. The unit has a silicified cap that grades into fresher dolostone below. Mineralogically, the dolostone consists of 65% dolomicrosparite, with around 25% coarser dolospar and minor quartz. Silicified rocks with carbonate textures are common on the surface in the Berry Springs area.

Waterbore RN33031, drilled near Berry Springs, intersected dolostone at 36.2 m, beneath Cretaceous claystone and sandstone, with the hole terminating in the same dolostone unit at 199 m depth. The dolostone is variably coloured, ranging from light grey to pink, yellow and brown. Solution cavities are often present and are lined by iron-rich crusts. Rock textures, superficially resembling stromatolites, are interpreted to be a tectonic foliation. This foliation and the presence of steeply inclined stylolites suggest that the dolostone has undergone Barramundi Orogeny deformation. It is thus thought to have been deposited in a small, shallow basin above the adjacent Burrell Creek Formation, prior to the Nimbuwah event of 1860–1847 Ma.

This dolostone cannot be named until a cored stratigraphic hole is drilled through it to determine the underlying stratigraphic relationships.

#### Intrusive igneous rocks

##### Zamu Dolerite (Edz)

Small outcrops of Zamu Dolerite occur south and west of Noonamah, although outcrop in the present mapsheet is limited. The dolerite is exposed in the creek bed at the Marrakai Crossing on the Marrakai Track, and it intruded the Manton, Mount Partridge and South Alligator Groups, prior to regional metamorphism and deformation. The dolerite is generally extensively altered and deformed, and occurs as both dykes and irregular sills. Figure 12 shows an irregular sill of Zamu Dolerite, intruded into the Koolpin Formation at the Quest 29 Mine in Mary River.

Ferguson and Needham (1978) reported that on a regional scale, the dolerite has an essentially continental tholeiitic composition with normative hypersthene. Sheppard (1992) suggested that small pods and sills of dolerite and gabbrro, which intrude the South Alligator Group in eastern Noonamah, are Zamu Dolerite.

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**Figure 12.** Zamu Dolerite sill (light yellow-brown) intruding Koolpin Formation (grey). Pit wall approximately 45 m high. 779132mE, 8566958mN, eastern wall of Quest 29 Mine, Mary River.
Mount Bundey Granite (Pgu)

The Mount Bundey pluton is located approximately 100 km southeast of Darwin in Mary River. It includes the Mount Bundey Granite and Mount Goyder Syenite (Figure 13), which have intruded deformed metasedimentary rocks of the South Alligator Group. The pluton also contains genetically associated K-rich shoshonitic lamprophyre (minette) and felsic dykes (Sheppard 1995).

The Mount Bundey Granite (1831 ± 6 Ma; Page in Sheppard 1995) occupies about 70% of the total pluton outcrop and forms hills up to 150 m above the surrounding floodplains west of the Mary River. It is a pink, medium- to coarse-grained biotite-hornblende monzogranite, with minor fine-grained porphyritic monzogranite (Sheppard 1995). Away from the main pluton, 12 km to the west in Noonamah, a mafic phase of altered fine-grained biotite-hornblende-pyroxene monzonite outcrops north of Marrakai Creek (765402mE, 8575496mN). These outcrops are very small, up to 1 m in size. Petrographically, the monzogranite contains abundant plagioclase and orthoclase in roughly equal proportions (30–35%), whereas the mafic component comprises 25% pyroxene with minor amounts of hornblende, biotite and quartz.

The Mount Goyder Syenite, which does not outcrop in Noonamah, comprises brown-purple, medium- to coarse-grained porphyritic syenite (Sheppard 1992).

Ungrouped

Geolsec Formation (Pyg)

The Geolsec Formation (Lally 2003), part of which was formerly referred to as the Buckshee Breccia (Crick 1987), unconformably overlies Palaeoproterozoic rocks near the southern margin of the Rum Jungle and Waterhouse Domes and in the Embayment area (southwestern Noonamah–southeastern Bynoe). The Geolsec Formation consists of hematitic quartzite breccia, hematitic sandstone, siltstone, mudstone and minor shale breccia (Ahmad et al in prep).

The lower portion of the formation, which unconformably overlies the Coomalie Dolostone, mainly consists of hematitic quartzite breccia and interbedded sandstone and pelite, whereas the upper portion comprises medium to coarse massive sandstone (Ahmad et al in prep). Deposition postdated the deformation of Pine Creek Orogen sedimentary rocks. Various breccia types are recognised in both outcrop and drillholes, including both clast- and matrix-supported breccias with angular to rounded quartz clasts of varying size (Figure 14). The most common

Figure 13. Lamprophyre dykes (dark grey) within Mount Goyder Syenite. 780800mE, 8575900mN, Halkitis Brothers Quarry, Mary River.

Figure 14. Geolsec Formation: cross-bedded quartz-pebble conglomerate (below) and coarse sandstone of the hematitic quartzite breccia (above). 718150mE, 8563975mN, north of Whites Mine.
breccia (Figure 15) contains a matrix of hematite sandstone-siltstone, with angular quartz clasts (Ahmad et al in prep). An additional, phosphatic siltstone variety occurs at the Geolsec phosphate deposit in northwestern Batchelor.

The hematitic quartzite breccia was first described by Malone (1962a, b) as a basal element of the Depot Creek Sandstone, and by Spratt (1965), Walpole et al (1968) and Johnson (1974) as the Hematite Quartzite Breccia. Crick (1984) considered the breccia to have been formed by regolith collapse into karstified Coomalie Dolostone. Another interpretation is that it formed as a fault-bounded talus slope deposit (Paterson et al 1984). The Geolsec Formation is interpreted to be disconformably overlain by Depot Creek Sandstone, but the contact has not been observed.

**Palaeozoic**

**Late dolerite dykes**

A number of strong positive and negative magnetic linear anomalies are interpreted from aeromagnetic data, but are not exposed. There are two orientations, the first to the northwest, apparently emplaced en echelon into fractures subparallel to the Pine Creek Shear Zone and the Noonamah Fault. The second set trends northeast, subparallel to the Giants Reef Fault.

Tucker et al (1980) mentioned a negative magnetic linear anomaly in the Mount Bundey area, which was drilled to intersect a magnetite- and pyrrhotite-bearing dolerite dyke. Newton (pers comm 1980 in Stuart-Smith et al 1993) mentioned NTGS drilling of another linear anomaly in the southeastern corner of Noonamah, which intersected picrite and dolerite.

Dolerite dykes in Noonamah have the same orientation as fine-grained flow-banded dolerite dykes and porphyritic dolerite dykes encountered further south in the Cullen Mineral Field (Stuart-Smith et al 1993). The dykes crosscut all other rock types and structures, making them younger than the Tolmer Group and the latest Giants Reef Fault movement.

**Mesozoic**

**Bathurst Island Group**

**Darwin Formation (Kld)**

The Darwin Formation (Mory 1988 after Hughes 1978) is the basal unit of the Bathurst Island Group and overlies basement rocks in northern Noonamah. Lithologically, it includes claystone, sandy claystone, clayey sandstone and sandstone, some of which is currently unconsolidated. Quartz and dolomite fragments in clay highlight an unconformity surface, where it overlies Koolpinyah Dolostone (Doyle 2001). The maximum known thickness of the Darwin Formation in the sheet area is at least 63 m, from drillholes north of Girraween Road (EM48/49 in Table 2), but the average thickness is about 30 m.

**Cenozoic**

**Palaeogene–Neogene**

**Ferricrete (Czl)**

Various forms of lateritic soil and gravel, as well as ferricrete hardpans and benches, are encountered throughout Noonamah, but are best developed, as duricrust, over Cretaceous sedimentary rocks in the northern part of the mapsheet. Pisolitic and nodular ferruginous gravel is composed of goethite, hematite and maghemite, in concentric layers around a nucleus of quartz and clay grains. Complete lateritic weathering profiles are not always developed.

Ferricrete benches are common, having developed over both Cretaceous and Proterozoic sedimentary rocks. They generally form at breaks of slope or at the edges of drainage channels, where iron oxides have precipitated out of solution. Various forms of ferricrete texture are present. Vermiform, platy cemented hardpans occur over the Wildman Siltstone near Townend Road (733350mE, 8595380mN), whereas more indurated ferricrete benches have formed on scree slopes of the Acacia Gap Quartzite Member in the same area (735520mE, 8596100mN).

![Figure 15. Geolsec Formation: typical matrix-supported angular quartz-clast breccia in hematitic siltstone matrix. 718150mE, 8563955mN, north of Whites Mine.](image-url)
Ferruginous sandy soils (Czs)

Ferruginous sand and gravel predominates in southern NOONAMAH, where the topography changes from Cretaceous plains to hinterland areas with ridges and valleys. Minor alluvium and slope-wash soils occur between ridges. Granitic sands and grit occur in the southwestern corner of the mapsheet. Thin skeletal soils overlie Proterozoic outcrops.

Quaternary

Colluvium (Qc)

Colluvium, derived from ridges, generally occurs on slopes of outcropping Acacia Gap Quartzite Member. Slope debris ranges from pebble- to boulder-size angular clasts within thin gravelly soils.

Alluvium (Qa)

Sand, silt and clay occur in drainage channels. The sediment thickness generally does not exceed 1 m in smaller drainages. Extractive mineral operators often source fine sand from scrapes within these drainages during the dry season. The sediment load is often underlain by lateritic duricrust.

Clay-rich soil (Qaf)

The Adelaide River floodplain covers an extensive area oriented north–south through Noonamah. It consists predominantly of silt and clay, which exhibits shrinkage cracks when dry. The floodplain is inundated during the wet season and covered in grasses during the dry season.

Coastal alluvium (Qca)

An area of coastal alluvium, consisting of black mud, silt and clay with minor mangrove development, occurs in the upper tidal reaches of the Adelaide River, at the intersection with Marrakai Creek.

Mangrove swamp (Qcm)

Areas of mangrove swamp are located along the intertidal reaches of the Adelaide River in northern parts of the mapsheet.

Table 2. Selected drillhole locations in NOONAMAH.

<table>
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<th>Northing (mN)</th>
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Table 2. Selected drillhole locations in NOONAMAH.
GEOPHYSICS

NOONAMAH is covered by three regional airborne geophysical surveys, the extents of which are shown in Figure 16. Survey specifications are detailed in Table 3. Data from individual surveys were stitched together to produce the magnetic and radiometric images used in the solid geology interpretation.

Magnetics

The Rum Jungle Dome in the southwestern corner of NOONAMAH is the most prominent magnetic feature. Areas of higher magnetic intensity within the dome correspond to banded ironstone and possibly to mafic schist assimilated within granite. Curvilinear zones of high magnetic intensity occur parallel to the margins of the Rum Jungle Complex, within the Wildman Siltstone and Acacia Gap Quartzite Member. These have been attributed to stratiform pyrrhotite horizons within sedimentary units (Tucker et al 1980). Whites Formation, South Alligator Group and Burrell Creek Formation rocks contain weak magnetic anomalies parallel to bedding that are presumably caused by stratiform pyrrhotite or magnetite within certain beds.

Most of the Proterozoic sediments in the northeastern quadrant of NOONAMAH have no discernible anomalous magnetic response. This is due to a combination of the low magnetic susceptibility of the rocks, the higher terrain clearance of the Litchfield North survey that covers this area

Figure 16. Extent of airborne geophysical surveys over NOONAMAH.
in the northwest of NOONAMAH probably reflect the higher Jungle and Woolner basement highs. Higher gravity readings northwest-trending depocentre situated between the Rum mapsheet reflects an increase in sediment thickness within a density younger sedimentary rocks. An increase in gravity readings toward the central and northwestern parts of the southwestern corner of NOONAMAH (along the Stuart Highway and Marrakai Track. 11 km grid spacing, with some more closely spaced stations these cover the southwestern corner of NOONAMAH. The Waterhouse Domes were undertaken by BMR in 1974, and Detailed gravity profiles across the Rum Jungle and Gravity Complex. Preliminary modelling of this feature indicates that it may be a magnetic intrusive body as deep as 2500 m (R Brescianini and R Clifton, NTGS, pers comm 2002).

A broad, low-amplitude positive magnetic anomaly occurs in the Berry Springs area to the north of the Rum Jungle Complex. Preliminary modelling of this feature indicates that it may be a magnetic intrusive body as deep as 2500 m (R Brescianini and R Clifton, NTGS, pers comm 2002).

Gravity

Detailed gravity profiles across the Rum Jungle and Waterhouse Domes were undertaken by BMR in 1974, and these cover the southwestern corner of NOONAMAH. The remainder of the mapsheet is covered by gravity stations at 11 km grid spacing, with some more closely spaced stations along the Stuart Highway and Marrakai Track.

The Rum Jungle Dome produces a gravity low in the southwestern corner of NOONAMAH (Figure 17), consistent with lower-density granitic basement surrounded by higher-density younger sedimentary rocks. An increase in gravity readings toward the central and northern parts of the mapsheet reflects an increase in sediment thickness within a northwest-trending depocentre situated between the Rum Jungle and Woolner basement highs. Higher gravity readings in the northwest of NOONAMAH probably reflect the higher density of the Koolpin Formation compared to that of the Mount Partridge and South Alligator Groups.

Examination of profiles reveals that gravity data cannot be used to map the Coomalie Dolostone/Whites Formation boundary (Major 1977). The boundary is gradational and both formations contain amphibolite bodies, so that there is no clear density contrast between them. Williams (1970) showed that gravity lows occur over the Celia and Coomalie Dolostones and are probably due to extensive silicification, weathering or fissuring.

Table 3. Specifications for airborne geophysical surveys covering NOONAMAH.

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<td>World Geoscience</td>
<td>090°</td>
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<td>Mary River</td>
<td>TMI, DTM, radiometrics</td>
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<td>Kevron</td>
<td>090°</td>
<td>400</td>
<td>180°</td>
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</table>

Radiometrics

Stitched airborne radiometric data for NOONAMAH are shown on the map as an RGB ternary image (red = K, green = Th, blue = U). The Adelaide River, Howard River and Marrakai Creek channels and floodplains in the southeast exhibit pastel green, due to low amounts of thorium and leaching of uranium. The Rum Jungle Complex shows the highest radiometric responses in all three channels, and geochemistry indicates that the granitic rocks are anomalously high in uranium and thorium (Ferguson et al 1980). Variations in radiometric response, combined with magnetic data, have been used to differentiate the Rum Jungle Complex into fifteen constituent units (Ahmad et al in prep). Manton Group sedimentary rocks have low responses in all channels. The lower part of the Crater Formation is characterised by anomalously high responses in the thorium channel, and BMR investigations confirmed the presence of a conglomerate containing thorium-bearing minerals, near the base of the unit (French 1970). The Whites Formation is commonly dark blue on the image, which is related to the fixing of uranium by carbonaceous matter in the original sediment.

Ridges of Acacia Gap Quartzite Member and Wildman Siltstone are marked by red to orange colours, from low thorium and uranium, and higher potassium (probably from granite-derived K-feldspar within these rocks). The South Alligator Group, outcropping in eastern NOONAMAH, has a distinctive radiometric response; the Koolpin Formation and Gerowie Tuff have higher uranium and uranium + thorium, respectively, when compared with the Wildman Siltstone and Burrell Creek Formation. In central and southern NOONAMAH, the South Alligator Group is not easily distinguished by radiometric data and has a more subdued response. Outcropping Burrell Creek Formation shows up as pink to brown, indicating low amounts of potassium and negligible thorium and uranium in these sedimentary rocks. Lateritic plains are generally green, from uranium and potassium leaching. The Giants Reef Fault is visible in the southwestern portion of the image as a prominent break in the radiometric pattern of the Rum Jungle Complex.

STRUCTURE

Johnston (1984) divided the PCO into five domains, on the basis of structural style and metamorphic grade. NOONAMAH comprises elements of the Rum Jungle Domain and Central
Marrakai Domain. Both contain low-grade metamorphic rocks, but the Rum Jungle Domain is characterised by the presence of decollement zones, formed early in the overall structural history. The first event within the PCO (D₁ local cleavage, related to monoclinal warping about major northwest-trending synsedimentary faults) is not considered here, as it only occurs in the South Alligator River Domain. However, it should be noted that it predates the D₁ event in Noonamah. Ahmad et al. (in prep) have recognised nine deformation events in their solid geology interpretation of the Rum Jungle area, seven of which impacted Noonamah.

D₁ in Noonamah is represented by bedding-parallel shear zones in sedimentary rocks near the Archaean basement contact, east-trending upright F₁ folds, and S₁ cleavage. Measurements of L₁ stretching lineations and kinematic indicators on D₁ shear zones around the Rum Jungle and Waterhouse Domes show that movement was directed toward the northwest along subhorizontal planar surfaces, interpreted as a gravitationally driven tectonic slide (Johnston 1984). Southwest of Woodcutters Mine, northeast-trending F₁ fold axes are overprinted by a north-trending S₁ cleavage. East-trending F₁ folds are also inferred along the northern margin of the Rum Jungle Complex, but no unequivocal overprinting relationships have been observed there. In the low-grade Central Marrakai Domain, D₁ thrusts are brittle features several metres wide (Sheppard 1992).

D₂ deformation is characterised by tight to isoclinal, upright F₂ folds, plunging 0–30° to the north and south, and an axial planar S₂ slaty cleavage (Figure 18), trending northwest to north-northeast. Quartz-filled tension gashes parallel to S₂ are locally present in greywacke. The D₁ and D₂ deformation events are correlated with the Nimbuwah Event (1860–1847 Ma) in the eastern PCO (Ahmad et al. in prep).

D₃ deformation consists of east-trending open upright folds that were tightened during emplacement of the Cullen Batholith granitoids (1840–1820 Ma). F₃ folds are not

Figure 17. Bouguer gravity image of Noonamah.
abundant in NOONAMAH, but the broad change in strike of $F_2$ fold axes from northeast to northwest in the eastern sheet area is probably related to emplacement of the Mount Bundey Granite at this time. $D_4$ deformation is represented by northwest- and northeast-trending, open upright megakinks that deform $F_2$ folds. An $S_4$, northeast- and northwest-trending crenulation cleavage is commonly developed within the Wildman Siltstone. Northeast-oriented folds are generally restricted to areas north of the Giants Reef Fault and northwest-oriented folds to the south. $D_3$ and $D_4$ imply late north–south compression of the PCO.

$D_5$ produced northeasterly to northerly faults with reverse east- or west-side-up sense of movement. In NOONAMAH, $D_5$ fault traces are extensions of structures mapped further south, as interpreted from aeromagnetic data. $D_6$ structures are regional northwest-trending faults that have apparent left-lateral offsets. They are defined from offsets and truncation of stratigraphy, and by aeromagnetic interpretation. $D_6$ faults in NOONAMAH appear to be extensions of a series of structures, which can be traced from the Pine Creek Shear Zone to the southeast (also interpreted as a left-lateral strike-slip fault), and which include the Noonamah Fault. The Pine Creek Shear Zone is interpreted to have been active during the 1780–1760 Ma Shoobridge Event (Stuart-Smith et al. 1993).

In the Woodcutters Mine area, mineralisation is controlled by the north-trending, sinistral reverse (east-side-up) Woodcutters and Huandot Faults. These faults offset $F_2$ fold axes and are overprinted by minor faults associated with movement on the Giants Reef Fault. No other structural overprinting relationships have been recorded that would provide better constraints on the relative timing of these faults. The Giants Reef Fault has a total length over 200 km and trends northeast across the sheet area. It is a dextral wrench fault, with an apparent horizontal displacement of about 7 km (Crick 1987) and variable vertical displacement along its length (Ahmad et al. in prep). Most of the dextral movement postdates deposition of the Depot Creek Sandstone and predates emplacement of the magnetic dolerite dykes. The Giants Reef Fault is clearly defined where it transects the Rum Jungle Complex and the folded Mount Partridge Group in central NOONAMAH. Further northeast, the trace of the fault is unclear as outcrop is lost in the floodplain. Aeromagnetic data show that magnetic dolerite dykes are parallel to the fault trace, but not within the fault itself. Several northeast-trending dextral strike-slip faults offset ridges of Acacia Gap Quartzite Member and were probably associated with movement on the Giants Reef Fault. The Noonamah Fault, which starts on the northern side of the Giants Reef Fault, strikes northwest for approximately 35 km through Acacia Gap Quartzite Member ridges, and is also cut by northeast-trending faults.

Many smaller faults associated with the Giants Reef Fault have laterally displaced the margins of the Archaean complexes. Of these, Johnston (1984) recognised two sets: north- to north-northeast-trending normal faults at the southern margin of the Rum Jungle Dome and east-northeast-trending high-angle faults cutting the Waterhouse Dome and the eastern margin of the Rum Jungle Dome. The latter may be conjugate to the north-trending set. The Giants Reef Fault displaces the Woodcutters Fault and minor base metal mineralisation is present along part of that fault, north of the Giants Reef Fault at the Acacia South and Manton Prospects.

**METAMORPHISM**

Archaean metamorphism of the metasedimentary units of the Rum Jungle Complex reached amphibolite facies grade, according to Rhodes (1965). Secondary epidote in oligoclase is evidence of retrograde metamorphism in granite gneiss and metadiorite, and plagioclase has been sericitised and then cut by quartz veins along shear zones in granite, around the margins of the complex (Rhodes 1965).

Palaeoproterozoic rocks in the region have been regionally metamorphosed to greenschist facies during the Nimbuwah Event of the Barramundi Orogeny during 1860–1847 Ma, although Crick (1987) cited evidence for localised higher-grade events around the Rum Jungle Complex. Retrogressed andalusite porphyroblasts are recorded in Whites Formation pelite in the Embayment, which overgrow and are slightly flattened parallel to an $S_2$ slaty cleavage, indicating growth early during $D_4$ (Ahmad et al. in prep).

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**Figure 18.** Koolpin Formation: upright $F_2$ folds with axial planar $S_2$ cleavage. 752000mE, 8599300mN, Beatrice Hill roadcut on Arnhem Highway.
Away from the Archaean domes, the metasedimentary rocks generally show little alteration of their original texture and mineralogy. In the Central Marrakai Domain, metamorphic grade is lower greenschist (Johnston 1984). Alignment of white mica and chlorite defines an S2 slaty cleavage within pelitic rocks.

Rocks of the South Alligator Group and Burrell Creek Formation, 10 km east of the mapsheet boundary in Mary River, were contact metamorphosed by the Mount Bundey Granite at around 1830 Ma. Tuffaceous siltstone of the Gerowie Tuff has been altered to hornfels, with associated hydrothermal cordierite and garnet minerals. A thorough metamorphic history of a wider area was provided by Pietsch and Stuart-Smith (1987).

GEOLOGICAL HISTORY

The oldest rocks in Noonamah are the metasedimentary rocks of the Stanley Metamorphics, which were probably derived from the Woolner Granite to the north sometime between 2675 Ma (age of Woolner Granite) and 2535 Ma, when the Rum Jungle Complex was formed. These originally sedimentary rocks were deformed and metamorphosed during the Archaean. They were then intruded by granites of the Rum Jungle Complex. A period of weathering and erosion ensued, probably caused by the uplift and rifting which initiated the Pine Creek Orogen.

Sedimentation in the Pine Creek Orogen probably began around 2100 Ma. The lowermost rocks in the succession, the Manton Group, rest unconformably or tectonically on Neoarchaean basement. The Manton Group consists of fluvialite arkose, sandstone and conglomerate of the Beestons Formation, which probably formed shoreline deposits around the Archaean domes. Overlying stromatolitic magnesite, dolostone and metapelite of the Celia Dolostone was then deposited in an intertidal to supratidal environment. Uplift and erosion of the source area (Malone 1958) ended deposition and caused brecciation of the Celia Dolostone.

Mount Partridge Group sediments, consisting of a basal succession similar to that of the Manton Group, were then deposited. The Celia Dolostone was overlain by fluvialite fan deposits (conglomerate, arkose and sandstone) of the Crater Formation, which grade vertically and distally into magnesite and dolostone of the Coomalie Dolostone. The Whites Formation conformably overlies and interfingers with the Coomalie Dolostone, both having been deposited in intertidal environments. Dolomitic and carbonaceous shale of the Whites Formation grades into overlying Wildman Siltstone sedimentary rocks. At about the same time to the northeast, dolomitic mud, now massive dolostone of the Koolpinyah Dolostone, was also being deposited, on the edge of the open shelf around the Woolner Dome and to the south. Finely banded pelite of the Wildman Siltstone was then deposited below wave base across large areas of Noonamah. Interbedded with these pelitic rocks were sands of the Accacia Gap Quartzite Member, deposited in shallow water during periods of instability (Pietsch and Stuart-Smith 1987), and overlying minor volcanic rocks of the Mount Deane and Yarrawonga Volcanic Members. Andesitic volcanism was also active in adjacent Mary River at this time.

An intervening period of tectonism was followed by a marine transgression and the deposition of chemical and organic-rich sediments of the South Alligator Group (Pietsch and Stuart-Smith 1987). Shallow-water, pyritic graphitic shale and siltstone, chert and dolostone comprise the Koolpin Formation, which passes abruptly upward into subaqueous tuff, siltstone and chert of the Gerowie Tuff and Mount Bonnie Formation. Rocks high in the succession consist of greywacke, siltstone and banded ironstone, which are conformably overlain in the east by interbedded greywacke and siltstone of the Finniss River Group. Sedimentation of the Mount Bonnie and Burrell Creek Formations accompanied a shift to deeper-water flysch and turbidity current sedimentation.

Toward the end of Finniss River Group sedimentation, sills of Zamu Dolerite were emplaced into the succession. The end of sedimentation heralded an extended period of deformation, metamorphism, felsic volcanism and plutonism at 1870–1800 Ma. A craton-wide event, the Barramundi Orogeny, has been constrained to 1860–1845 Ma (Lally and Worden 2004), which coincides with the regional-scale Nimbuwah Event within the PCO. Granites were emplaced in the PCO soon after regional deformation and metamorphism. The Cullen Batholith and Mount Bundey pluton to the south and east of Noonamah were emplaced at around 1825 Ma, during the Cullen Event.

Following erosion, weathering and karstification, a new episode of sedimentation began at, or around the commencement of the Mesoproterozoic, resulting in the deposition of the Geolsec Formation. The Depot Creek Sandstone was deposited before a period of fault activity, including late-stage movement on the Giants Reef Fault and other faulting. Undated and unnamed dolerite dykes then crosscut all existing rock types and faults.

Basement orogenic rocks were covered and exhumed by various sedimentary events, before being inundated by seas, in which Cretaceous sedimentary rocks were deposited. These rocks are part of the larger, mainly offshore Money Shoal Basin, which thickens rapidly northward.

Together with much of continental Australia, the land surface of Noonamah was subject to a period of deep chemical weathering and continental drying, commencing in the early Cenozoic and following the deposition of the Cretaceous sediments. This weathering process produced the well developed ferruginous duricrust on the Cretaceous surface, and to a lesser extent, on Palaeoproterozoic outcrops. These lateritised hinterlands and plains have been further sculpted by more recent riverine and coastal marine processes, producing the present erosional and depositional landscape.

ECONOMIC GEOLOGY

Mineral prospects in Noonamah are documented in Table 4.

Gold

Rustlers Roost Mine is located 90 km southeast of Darwin, near the eastern boundary of Noonamah. Gold was first found in the area in 1948 by Jim Escreet, who worked the area for 3–4 years. In 1977, Ben Hall and Cameron Cleary were granted EL1473 over the area, which became known as Rustlers Roost. Various companies explored and worked the area during 1977–1988, with mixed results. It was not until
1988 that cosemaining outlined multiple mineralised gold zones over a strike length of 1.25 km (Rabone 1995).

The first hole was drilled in August 1988 and intersected several broad low-grade gold zones, including 10.75 m at 1.26 g/t Au at the southern end of the deposit. The resource was first drill-defined in 1990 and estimated to contain 3.7 Mt at 1.7 g/t Au (Rabone 1995). Construction of the mine commenced in April 1994 as a joint venture between Valdora Mining Pty Ltd (80%) and Ben Hall and Stanley Fletcher (20%). Heap leaching began and the first gold bar was poured on 6 October 1994.

The initial mine plan involved the treatment of 8.1 Mt of ore at a grade of 1.2 g/t Au from four open pits (Backhoe, Beef Bucket, Dolly Pot and Sweat Ridge) (Figure 19) over a mine life of 5.4 years (Rabone 1995). A highly successful exploration program in 1994 increased the geological resource to 34.0 Mt at 1.17 g/t Au for 1 277 000 oz and as a consequence, a new mine plan saw the mine developed as a single large open pit (Rabone 1995). Low gold prices, low grades and poor recoveries forced the mine to close in 1998. Total production up to March 1998 was 3425 kg Au and 337 kg Ag from 4.58 Mt of ore (Ahmad et al 1999).

Table 4. Mineral prospects of NOONAMAH.

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Oxidised ore extends to a depth of 80 m and ore minerals include gold (grains 1–50 \(\mu\)m), pyrite, arsenopyrite, chalcopyrite, marcasite, pyrrhotite and sphalerite (Ahmad \textit{et al} 1999). The mine is currently on a care and maintenance program with a large low-grade resource still in place.

The William and Bandicoot reefs are approximately 12 km southeast of Rustlers Roost Mine. The Bandicoot reef system (Bandicoot A 764200mE, 8564867mN) was discovered by H Robertson (MIM) in 1987. The William Prospect (762774mE, 8564207mN) was discovered by WJ Fisher in 1986. Both areas were explored by Carpentaria Exploration in 1990–1991. The leases have costeans, trial pits, bulk sample pits, stockpiles and drillholes from prior operations. Gold is visible in hand specimen and grades range up to hundreds of grams per tonne in high-grade zones. RUB Pty Ltd, current operator of this venture, moved on site in early 2002 to begin mining.

The Bandicoot Prospect consists of thin quartz veins 0.1–2.0 m in width, dipping east parallel to bedding, and placed stratigraphically between footwall greywacke and hangingwall siltstone beds of the Burrell Creek Formation. There are four auriferous reefs (Bandicoot A–D) and other barren reefs, over a strike length of less than 1.5 km. The quartz veins are oriented between north and northwest, and generally dip 40–60° to the east, although Bandicoot B is near-vertical. MIM Exploration stated a measured gold resource of 13 235 t at 3.84 g/t for Bandicoot A and B (Langley 1996).

The William Prospect is more complex, with variable vein orientation and dip directions. McGeough (1991) stated an indicated gold resource of 15 619 t at 3.57 g/t Au. Veins at both prospects are iron-rich stockwork quartz veins, which were probably formed by hydrothermal fluids during the intrusion of the Mount Bundey pluton, and emplaced in en echelon shears.

Uranium

The highly prospective Embayment area is a triangular tract of sedimentary rocks, immediately west of the Giants Reef
Fault in the southwestern corner of NOONAMAH. It hosts the Dysons, Whites, Intermediate and Browns uranium and base metal deposits.

**Dysons** deposit is located 8 km north of Batchelor township. It was discovered by a BMR ground radiometric survey that delineated a strong radiometric anomaly near the Giants Reef Fault. Mining between 1957 and 1958 produced 156 000 t of ore grading 0.343% U₃O₈ (Berkman 1968). Mineralisation is hosted in the Whites Formation, near the contact with the underlying Coomalie Dolostone. It is overlain by the Geolsec Formation. Saleeite, an oxidised uranium mineral, was responsible for surficial uranium enrichment (Berkman 1968), and disseminated uraninite was also present in carbonaceous pyritic shales and pyritic grey orthoquartzite (Crick 1987). Unlike other mineral deposits in the Embayment area, Dysons is a single-commodity occurrence.

**Whites** deposit is located in the Rum Jungle Embayment area north of Batchelor. It was discovered in 1949 by Jack White, who recognised green secondary uranium minerals on the surface. An open pit was mined during 1954–1958, producing 402 000 t of ore at 0.27% U₃O₈, as well as 2.7% Cu, which was treated. A further 86 000 t of ore at 5.1% Pb, 0.8% Cu and 0.3% Co was also treated (Berkman 1968).

Mineralisation is in the Whites Formation, in brecciated carbonaceous pyritic shales and slates, within a shear zone oriented subparallel to the Giants Reef Fault. Secondary oxidised uranium and copper mineralisation were present near-surface, and the primary orebody, like others in the area, was steeply dipping at depth (Crick 1987). Ore minerals included pyrite, chalcopyrite and bornite, with minor galena, native bismuth, covellite and other Co-Ni minerals (Spratt 1970).

**Whites Extended** is a small open cut, 300 m east of Whites. It was mined in 1958, producing 100 t of ore at 0.185% U₃O₈ (Berkman 1968). The host rock is a red hematitic mudstone bed within the Whites Formation (Berkman 1968), associated with brecciated pyritic carbonaceous shale. Minor uranium mineralisation also occurs in overlying hematitic quartzite breccia of the Geolsec Formation.

**Base metals**

The **Intermediate** deposit is located in the Embayment area, between the Whites and Browns deposits. It was discovered in the 1880s, but it was not until further exploration in the 1950s that a copper sulfide deposit was discovered at depth. Open-cut mining during 1964–1965 produced 732 000 t of ore at an average grade of 2.2% Cu from both oxide and sulfide zones (Berkman 1968).

Mineralisation was hosted in a breccia of carbonaceous pyritic shale and sericitic schist in the Whites Formation, with ore minerals including chalcopyrite, and minor cobalt and nickel sulfides (Crick 1987). Malachite and copper phosphates occurred near the surface and Fraser (1980) reported that pitchblende was associated with the chalcopyrite outside the ore zone.

**Browns** deposit was discovered in 1954 and is centred a few kilometres northeast of Batchelor, just beyond the southeastern corner of NOONAMAH, within BYNOE. However, the Browns resource includes an area underlying the previously mined Whites, Whites Extended and Intermediate pits, known as Browns East, and therefore a description is included here. Owned by Compass Resources, it is the largest known orebody in the Rum Jungle Mineral Field and has a total resource of 70 Mt at 2.6% Pb, 0.8% Cu, 0.12% Co, 0.11% Ni and 10 g/t Ag (McCreary et al. 2004). Metallurgical problems associated with the fine-grained polymetallic nature of the ore have prevented exploitation of the orebody. To date, Compass Resources has carried out additional resource definition drilling and excavated a trial pit for bulk metallurgical sampling.

The deposit occurs in carbonaceous and dolomitic phyllitic black shale of the Whites Formation. It is described as a polymetallic sulfide deposit with zoned mineralisation, extending over 2 km in length, open below 400 m depth and up to 100 m thick (McCreary et al. 2004). The orebody is sheetlike, dipping steeply to the south, but attains shallower dips near the surface. Galena, sphalerite, chalcopyrite, pyrite and siegenite are the main ore minerals and are generally very fine grained, occurring along fractures, cleavage planes and veinlets. Folded and crenulated ore minerals reveal that early mineralisation predates Barramundi Orogeny deformation, whereas later crosscutting veinlets, comprising Pb and Cu sulfides, imply a later period of remobilisation (McCreary et al. 2004).

The **Woodcutters** Zn-Pb-Ag base metal deposit, 80 km south of Darwin, was discovered in 1966 by BMR drill testing of a soil geochemical anomaly (Crohn et al. 1967). Open pit mining commenced in 1985 and underground mining in 1986. The mine closed in 1999 and is currently undergoing rehabilitation. Ore production totalled 4.65 Mt at 12.28% Zn, 5.65% Pb and 87 g/t Ag (Taylor 2000). The Woodcutters orebody was emplaced in dilatational sites along sinistral-reverse transpressional faults which were active post-D₃ and pre-Giants Reef Fault. Ore minerals were deposited preferentially in the Whites Formation, at the intersection between faults and a domical segment of the hinge of the regional F₂ Woodcutters Anticline (Taylor 2000).

Woodcutters base metal mineralisation consists of numerous irregular sulfide lenses, which generally fill the steeply dipping north–south faults within the Woodcutters Anticline (Williams 1999). Thicker sections of the lenses and in some cases, the very presence of mineralisation, are controlled by the intersection of these faults with dolostone intervals and cross-faults. The mineralisation varies in thickness both vertically and along strike, and the orebody shows replacement textures as well as vein-like features (Williams 1999). The most common sulfide minerals are pyrite, arsenopyrite, sphalerite, galena and lead-antimony sulfosalts.

**Magnesite**

The **Huandot** magnesite deposit is located about 85 km from Darwin via the Stuart Highway, a few kilometres south of the Woodcutters Mine (at 728132mE, 8561659mN). Although the deposit occurs in BATCHelor, the possibility exists that an economic deposit extends northward into NOONAMAH. Nicron Resources estimated the magnesite resource to be 5.8 Mt (Barnes 1995). To date only a 25 000 t bulk sample has been mined from the site. The deposit is hosted by the Coomalie
Dolostone. The magnesite grade is 45.5% MgO, 2.3% SiO₂, and 0.6% acid-soluble CaO (Barnes 1995), with the main impurities being talc and fine quartz with trace pyrite.

**Extractive minerals**

Three abandoned and two current hard-rock quarries, located in the Acacia Gap Quartzite Member, provide construction materials, mainly aggregate and roadbase, for the Darwin, Palmerston and rural areas. Alluvial fine sand scrapes are common, north of Girraween Road and south of the Arnhem Highway, to the east of Humpty Doo. Lateritic gravel deposits are common over most of NOONAMAH, having been used in the past to supply natural gravel for World War 2 airstrips and current road infrastructure. A brick clay pit north of the Elizabeth River supplied raw material to the Norbrick Factory in Berrimah prior to closure of the factory in 1992.

**Groundwater**

Fractured silicified dolostone in an unnamed unit in the Berry Springs area and Koolpinyah Dolostone in the north are the main aquifers in NOONAMAH. The highest sustainable yield from dolostone in the Berry Springs area is 32.0 Ls⁻¹ in bore RN26686, and groundwater potential yield in this unit is generally >5.0 Ls⁻¹. Groundwater yield from the South Alligator Group is in the range 0.5–5.0 Ls⁻¹ and the water is generally clear. Groundwater potential from the Mount Partridge Group ranges from <0.5 Ls⁻¹ in the Wildman Siltstone and Acacia Gap Quartzite Member to 0.5–5.0 Ls⁻¹ in the Whites and Crater Formations, and >5.0 Ls⁻¹ in the Coomalie Dolostone (Verma 1994). Recharge from local rainfall and is about 30–40% of total rainfall. Water from all the dolostone units is very hard, but water from dolostone in bore RN9485 near Berry Springs is being bottled as mineral water for its commercial quality.

**ACKNOWLEDGMENTS**

The text was prepared with reference to petrographic descriptions commissioned from Frank Radke (Amdel Limited, Adelaide) and Allan Purvis (Pontifex and Associates Pty Ltd, Adelaide). Masood Ahmad, Barry Pietsch and Phil Ferenczi contributed much discussion on aspects of the regional geology. Gary Andrews drafted the figures. Richard Jong and Russell Poole compiled the geological map. Marianne Fuller formatted the manuscript and converted it to Acrobat format.

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