1:250 000 GEOLOGICAL MAP SERIES

EXPLANATORY NOTES

GROOTE EYLANDT REGION SD 53-7,8,11,12

B.A. PIETSC, D.J. RAWLINGS, P.W. HAINES and M. PAGE*

* Groote Eylandt Mining Company Limited
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Figure 1 Location of GROOTE EYLANDT REGION
ABSTRACT

GROOTE EYLANDT REGION is located on the western side of the Gulf of Carpentaria, within the Arnhem Land Aboriginal Reserve. The region comprises a cluster of rugged sandstone-dominated islands of which the largest, Groote Eylandt, supports the mining of manganese from a world-class deposit of Cretaceous age.

Geologically, GROOTE EYLANDT REGION includes two major provinces: the Palaeoproterozoic Arnhem Inlier and the Palaeo- to Mesoproterozoic McArthur Basin, which respectively represent basement and platform cover of the North Australian Craton. Outliers of the Mesozoic Carpentaria Basin mantle the older rocks in places.

The Arnhem Inlier in GROOTE EYLANDT REGION comprises the turbiditic succession of the Grindall Formation, which was tightly folded and, in adjacent map-sheet areas, locally metamorphosed during the ~1870 Ma Barramundi Orogeny and intruded by post-orogenic granites. The Arnhem Inlier is unconformably overlain by the Groote Eylandt Group, which represents the post-orogenic North Australian Platform Cover sequence. The lower Groote Eylandt Group (Bustard Subgroup) contains siliciclastic and rhyolitic rocks dated at ~1814 Ma. The disconformably overlying siliciclastic and mafic igneous rocks of the upper Groote Eylandt Group (Alyangula Subgroup) correlate with the lower part of the Taanaah and Katherine River Groups which form the basal part of the McArthur Basin succession elsewhere.

A relatively thin veneer of flat-lying terrestrial and marine Cretaceous sandstone and mudstone locally mantles older strata. Psolitic sedimentary manganese ore is contained within mudstones along the western side of Groote Eylandt. Cainozoic deposits including substantial aeolian coastal dune fields predominate around the fringes of the island.

INTRODUCTION

GROOTE EYLANDT REGION is a non-standard 1:250 000 map sheet bounded by latitudes 13°30'S and 14°30'S and longitudes 136°00' E and 137°00' E (Figure 1). It includes the four adjacent 1:100 000 map sheets common to BLUE MUD BAY, PORT LANGDON, CAPE BEATRICE and ROPER RIVER, and is designed to cover Groote Eylandt, Bickerton Island and adjacent smaller islands in the Gulf of Carpentaria as a single map sheet.

The first systematic mapping of GROOTE EYLANDT REGION was carried out by the Bureau of Mineral Resources, Geology and Geophysics (BMR) in 1962, for the First Edition geological maps of BLUE MUD BAY-PORT LANGDON (Plumb & Roberts 1965) and ROPER RIVER-CAPE BEATRICE (Dunn 1963). The second-generation mapping for the present map sheet and notes was conducted mainly by David Rawlings and Peter Haines, with contribution by Barry Pietsch of the Northern Territory Geological Survey (NTGS). Description of the economic geology and contributions to the Mesozoic and mining history sections are by Mike Page of the Groote Eylandt Mining Company Limited (GEMCO). Field mapping was undertaken during the 1992 and 1993 field seasons, simultaneously with mapping on BLUE MUD BAY and ARNHEM BAY-GOVE.

A summary of NTGS field data is available in Rawlings et al. (1995). Geophysical data (airborne magnetic and radiometric), flown at 100 m terrain clearance along 500 m-spaced east-west lines for the NTGS, are available as contour maps or in digital format.

Habitat, access, land use

GROOTE EYLANDT REGION is within the Arnhem Land Aboriginal Reserve. Most inhabitants are Aboriginals who live mainly in the townships of Angurugu and Umbakumba and in several small outstations on Groote Eylandt, and in the settlement of Milyakburra on Bickerton Island. Alyangula (population 1113 according to the Australian Bureau of Statistics (ABS), 1991 census) mainly houses employees of GEMCO and those providing supporting infrastructure. The total population of Groote Eylandt is 2563 (ABS, 1996 census).

The majority of non-Aboriginals are resident on Groote Eylandt because of their direct or indirect involvement with manganese mining. Open-pit mining is located near the town of Angurugu on the central-western side of the island; the ore is hauled to the ship loading facilities near Alyangula, approximately 18 km to the north. Alyangula and Angurugu are linked by a sealed road. The road from Angurugu to Umbakumba is a well formed all-weather gravel road, but access elsewhere is by tracks that are inaccessible during the wet season.

An all-weather sealed airstrip near Angurugu allows the provision of regular daily local and interstate commercial air services. Bickerton Island has an all-weather gravel airstrip, suitable for light aircraft, adjacent to the settlement of Milyakburra.

Otherwise, most of Groote Eylandt consists of rugged sandstone hills and is largely inaccessible by vehicle. Apart from mining for manganese on the west coast, the land is used for traditional purposes by its Aboriginal owners.

Climate and vegetation

The climate is dominated by a distinct monsoonal wet season (October to April) and dry season (May to October). The area is subject to tropical cyclones during the wet season. Long-term meteorological records have been kept at Angurugu since 1921. According to the Bureau of Meteorology (1988), Angurugu has a mean annual rainfall of 1300 mm with an average of 84 rain days per year. January, February and March are the wettest months. Relative humidity remains high throughout the year. The mean daily maximum temperature ranges from 34.5°C in December to 28.4°C in July, while the mean daily minimum ranges from 24.3°C in January and February to 14.4°C in July. Southeasterly trade winds blowing across the Gulf of Carpentaria maintain a higher than normal humidity and rainfall along the east coast of Arnhem Land well into the dry season in comparison to other areas in the north of the Northern Territory.

Lowland plains adjacent to the coast support open eucalypt woodland. Mangroves grow along the coastal

* References to 1:250 000 map sheet areas in this report are designated by capital letters, e.g. ROPER RIVER.
fringe and in small estuaries. The rugged rocky hills support spinifex and low scrubby trees which are tolerant of the annual fires resulting from Aboriginal land use practices.

Physiography
The topography of most of Groote Eylandt and Bickerton Island is rugged, consisting of deeply dissected, predominantly sandstone hills with elevation of up to 220 m. Along the western and parts of the northern edge of Groote Eylandt, coastal plains (which extend up to 10 km inland) are developed over flat-lying Cretaceous sedimentary rocks. Coastal aeolian dunefields extending 9 km inland occupy the eastern and southern sides of the island.

Exploration and mining history
The presence of manganese on Groote Eylandt was noted by many individuals before GEMCO commenced its mining operations in 1966. Local Aboriginal artists had used manganese in traditional bark painting and carving before contact with Europeans. Groote Eylandt art is distinctive for the black manganese base employed in most paintings (Cole 1979).

The possible presence of manganese in eastern Arnhem Land was reported in 1803 by the explorer Captain Matthew Flinders. His observations of the Blue Mud Bay area, on the Arnhem Land mainland 80 km west of Groote Eylandt, suggested that manganese may occur there (Cole 1983).

H.Y.L. Brown, South Australian Government Geologist, briefly visited Groote Eylandt in 1907 and provided the first documented report of manganese on the island. Brown considered the occurrence, near the present site of the manganese product-stockpiling area at the Milner Bay port, to be sedimentary in origin (Brown 1908). However, the small size of the outcrop prevented Brown from recognising it to be part of a major continuous manganese horizon.

The occurrences of manganese on Groote Eylandt would have been noted by Anglican missionaries after they established missions on the island from 1921, initially at Emerald River and since 1942 at the current Angurugu township site. Angurugu lies in the middle of the Groote Eylandt manganese deposit, with one occurrence (Deposit B in Figure 2) having been recognised in excavation for a septic tank for the Mission Superintendent (Crohn 1962).

During the course of a regional geological survey of manganese-bearing and adjacent areas by the BMR (Plumb & Roberts 1965), geologist P.R. Dunn noted outcrops of high-grade manganiferous material about 1600 m southwest of Angurugu (area of Deposit A in Figure 2). Subsequent work during 1961-62 confirmed the occurrence of at least five separate deposits (Deposits A-E in Figure 2) of manganese-rich ore producing high-grade beneficiated material (Crohn 1962). At that time, BHP geologist W.C. Smith became aware of the BMR investigations. Manganese is primarily used as a hardening agent in steel production and BHP, as Australia’s only steelmaker, was the logical market for any manganese produced. The BMR and mission authorities thus acceded to Smith’s request to visit the deposits (Smith 1962). BHP was at this time importing significant quantities of manganese from overseas as well as using small amounts of manganese ore from minor deposits in the Pilbara area of Western Australia.

Smith concluded that reserves were sufficiently large (possibly several million tonnes of lump ore at 45% Mn) to warrant negotiation for access to explore and develop the deposits. A major exploration programme was conducted between 1963 and 1967 over the main deposit area and adjacent areas of mineralisation, involving mapping, gravity surveying, drilling, pitting and bulk metallurgical testing.

The early exploration work established the main orebody as continuous for over 20 km north-south and up to 5 km east-west. Smaller occurrences were recognised in the southeastern corner of Groote Eylandt. However, it was proven that these were either smaller or of lower grade than the main Groote Eylandt orebody and, as a consequence no work has been conducted on the smaller deposits since 1966.

REGIONAL GEOLOGICAL SETTING
GROOTE EYLANDT REGION incorporates the northeastern McArthur Basin and the southern exposed margin of the Arnhem Inlier. The major tectonic elements of the McArthur Basin are shown in Figure 3. The regional geological setting of GROOTE EYLANDT REGION is shown in Figure 4. The Arnhem Inlier is part of the Palaeoproterozoic North Australian Orogenic Province and comprises deformed paragneiss and migmatite (Bradshaw and Mirarrmina Complexes), a younger, essentially undeformed granite batholith and in GROOTE EYLANDT REGION, tightly folded, unmetamorphosed siliciclastic sediments (Grindall Formation). Regional deformation and high-temperature low-pressure metamorphism took place at 1870 Ma during the Barramundi Orogeny, a major regional event geochronologically documented by Page & Williams (1988). According to Rawlings et al. (1997), this event was zonal and resulted in the formation of zones of anomalously high temperature which grade over short distances into essentially unmetamorphosed rocks.

Post-orogenic (~1840 Ma) granite plutons (Garrthalala, Giddy, Bukudal and Dhalinybuy Granites) which display A-type chemical characteristics were emplaced at shallow crustal levels in the Arnhem Inlier. These are correlatives of shallow granites of distinctive I- and lesser A-type chemistry which were emplaced in various ‘basement terranes’ throughout the North Australian Craton during the period 1860-1810 Ma (Wyborn et al. 1987).

Overlying silicic volcanic and associated immature sedimentary rocks (Bustard Subgroup) in GROOTE EYLANDT REGION form the basal element of the North Australian Platform Cover sequence described by Plumb et al. (1981). These rocks have a minimum age of 1815 Ma on Bickerton Island (Plietsch et al. 1994) and show affinities with rocks of the Edith River Group underlying the McArthur Basin along its southwestern margin.

The Statherian-Calymytian McArthur Basin is the principal component of the regional platform cover. This thick, unmetamorphosed, relatively flat-lying but extensively faulted basin succession is exposed over an area of approximately 180 000 km² in the northeastern Northern Territory. In GROOTE EYLANDT REGION the McArthur Basin is represented by sandstone and basal of the
Figure 2 Location of quarries for GEMCO manganese mining operation, Groote Eylandt
Alyangula Subgroup of the Groote Eylandt Group, resting disconformably on the Bustard Subgroup. The Alyangula Subgroup correlates closely with the lower units of the Tawallah Group in the southern McArthur Basin. The absence of the remaining McArthur Basin units may be the result of removal by extensive uplift and erosion. It is more probable that because Groote Eylandt lies at the basin margin, most of the younger units may never have been deposited in this region.

Flat-lying remnants of Cretaceous rocks which probably blanketed much of the area are preserved at various topographic levels, and along the western side of the island host the large manganese deposits.

**STRATIGRAPHY**

**ARNHEM INLIER**

**PALAEOPROTEROZOIC**

**OROSIRIAN**

**Grindall Formation (Pw)**

The Grindall Formation is a unit of tight to open folded, interbedded sandstone and mudstone exposed on wave-cut platforms on northern Bickerton, Burney and nearby small islands. It is the oldest known rock unit in GROOTE EYLANDT REGION. Exposure is restricted, but the
abundance of clasts derived from this unit in various levels of the Groote Eylandt Group indicates that distribution of the Grindall Formation as basement is widespread in the region.

Plumb & Roberts (1965) originally named this unit the Grindall Metamorphics and subsequently defined it (Plumb & Roberts 1992), nominating a type locality on the eastern end of Morgan Island (around GR PF195103) to the north of GROOTE EYLANDT REGION. The present nomenclatural change has been made because most outcrops are essentially unmetamorphosed.

Neither base nor top of the Grindall Formation are exposed. The formation is unconformably overlain by both the Bustard and Ayangula Subgroups of the Groote Eylandt Group and is intruded by the Bukudal Granite on Morgan Island; elsewhere adjacent to the map sheet area it is intruded by the Bradshaw Complex and by felsic and mafic dykes.

Rocks of the Grindall Formation comprise thin to medium, cyclically interbedded mudstones and fine- to medium-grained sandstones forming fining-upward sequences. The sandstones are sharp-based with gradational tops, and some thick-bedded units contain water-escape structures (Plate 1) which display regular, near-parallel orientation.

The formation is tightly to openly folded with locally well developed axial-plane cleavage. Metamorphism in GROOTE EYLANDT REGION is absent, although in the adjacent Coast Range area of BLUE MUD BAY (Haines et al. 1997) the Grindall Formation has been subjected to low-grade regional and locally, contact metamorphism closely related to granite intrusion.

The rocks are notably 'flysch-like', suggesting that the sequence was deposited in a distal turbidite environment. It would appear from grain size and thickness trends that the poorly exposed sequence to the west on Coast Range in BLUE MUD BAY is more proximal than that in GROOTE EYLANDT REGION. Based on similarities in rock types, structures and stratigraphic relationships, the Grindall Formation is interpreted to correlate with rocks in the Pine Creek and Murphy Inliers and the Mirarrmina Complex.

MCARTHUR BASIN

PALAEOPROTEROZOIC

GROOTE EYLANDT GROUP

The newly defined Groote Eylandt Group (see APPENDIX) is a succession of flat-lying to gently dipping sandstones and conglomerates interbedded with intervals of felsic and mafic volcanic rocks (Table 1). The Group is subdivided into two new subgroups, the Bustard Subgroup and the overlying Ayangula Subgroup. The preserved thickness is extremely variable, ranging from a few tens of metres along Coast Range (in BLUE MUD BAY) up to at least 1000 m on southern Groote Eylandt. The composite of maximum estimated thicknesses of the constituent formations on Groote Eylandt, where the top and bottom are not exposed, is about 1650 m. However, not all units may be present in a single section.

The group unconformably overlies the Grindall Formation and in BLUE MUD BAY, granite on Morgan Island. The top is eroded and unconformably overlain by Cretaceous sedimentary rocks and Cenozoic sediments.

The name 'Groote Eylandt beds' was first used by Plumb & Roberts (1965), and defined by Plumb & Roberts (1992). Under this usage the 'Groote Eylandt beds' was conceived as a single sandstone-conglomerate unit locally overlying the felsic 'Bickerton Volcanics'. Formalisation to the Groote Eylandt Group essentially encompasses the old 'Groote Eylandt beds', but with minor modification: the 'Bickerton Volcanics' at their nominated type area (South Bay, Bickerton Island - Plumb & Roberts 1992) are now interpreted as interbedded within the sedimentary pile. Renamed Bickerton Rhyolite to reflect its monolithic character, this unit is now included within the Groote Eylandt Group. Other rocks previously mapped as 'Bickerton Volcanics' are now recognised as belonging to separate units which have been assigned new names (Abarungkwa Sandstone and Erringkarri Rhyolite).
Figure 4 Regional geological setting of GROOTE EYLANDT REGION
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<td>ALEYANGULA SUBGROUP</td>
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<tr>
<td>Dalumbu Sandstone</td>
<td>Sandstone: white, coarse-grained, cross-bedded, pebbly (mainly quartz), granule lenses, quartz-rich; sandstone: white to pink, medium-grained, cross-bedded, quartz-rich. <strong>Ped</strong>: angular chaotic blocks of <strong>Ped</strong>: talus deposits of unknown age. <strong>Ped</strong> - basalt: very weathered, ferruginised</td>
<td>Predominantly braided fluviatile, with minor marine incursion</td>
<td>Conformably overlies Bartalumba Basalt. Top is eroded and unconformably overlain by Cretaceous rocks and Cainozoic sediments</td>
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<td>Bartalumba Basalt</td>
<td>Basalt: amygdaloidal; microdolerite</td>
<td>Subaerial lava flows</td>
<td>Lower contact not exposed, but no evidence of disconformity. Upper contact concordant with Dalumbu Sandstone</td>
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<td>Alyinga Sandstone</td>
<td>Thin basal granule to boulder conglomerate and pebbly and cobbly sandstone: polymict; sandstone: white, medium-to coarse-grained, locally pebbly, quartz-rich, very large trough cross-beds in lower part, interbedded ripple horizons at top</td>
<td>Predominantly high-energy braided fluviatile, minor marginal marine</td>
<td>Disconformable over underlying Milyema Formation. Regional disconformity interpreted from presence of &quot;basement&quot; (Arnhem Islier)-derived clasts. Inferred concordant contact with overlying Bartalumba Basalt. Interpreted lateral equivalent of Woodah Sandstone</td>
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<tr>
<td>Woodah Sandstone</td>
<td>Isle Woodah- sandstone: pink and white, medium-grained. Burney Island- basal cobble to boulder conglomerate: polymict, interbedded with coarse- to very coarse-grained, pebbly sandstone. Bickerton Island- lower mudstone: red-brown, micaceous, interbedded with medium- to coarse-grained sandstone; upper sandstone: white to pink, medium-grained. Cape Barrow- sandstone: coarse-grained, pebbly, grades into conglomerate</td>
<td>Braided fluviatile</td>
<td>Unconformably overlies Grindall Formation and Bukudal Granite. Inferred to unconformably overlie Milyakburra Formation and Aberungkwa Sandstone and underlie Bartalumba Basalt. Elsewhere the top is eroded and unconformably overlain by Cretaceous rocks and Cainozoic sediments. Interpreted lateral equivalent of Alyinga Sandstone</td>
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<td>UNIT, WITH MAP SYMBOL AND THICKNESS</td>
<td>LITHOLOGY</td>
<td>DEPOSITIONAL ENVIRONMENT</td>
<td>STRATIGRAPHIC RELATIONSHIPS</td>
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<tr>
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<tr>
<td><strong>BUSTARD SUBGROUP</strong></td>
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<tr>
<td><strong>Milyema Formation</strong></td>
<td>Basal granule to boulder conglomerate; polymict; interbedded coarse-grained pebbly lithic sandstone; cross-bedded; sandstone: pink, predominantly medium-grained; minor granule lenses: cross-bedded</td>
<td>High-energy braided fluviatile, possible shallow marine influence in uppermost part</td>
<td>Correlated laterally with Milyakburra Formation to the east. Base not exposed, but conglomerate clasts are derived from lower units in Bustard Subgroup and 'basement' sources (Grindall Formation, Bradshaw Complex and granite). Disconformably overlain by Alyinga Sandstone</td>
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<tr>
<td>Pel</td>
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<td>50 m exposed in boundary stratotype but probably significantly thicker in North Point Island area</td>
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<tr>
<td><strong>Milyakburra Formation</strong></td>
<td>Cobble and boulder conglomerate: matrix- to clast-supported, polymict, coarse sand to granule matrix, massive to cross-bedded; locally interbedded with granule conglomerate and medium- to very coarse-grained lithic sandstone</td>
<td>High-energy fluviatile and alluvial fan. Facies probably represent a mixture of debris flow, talus and channel-base deposits</td>
<td>Erosional contact with underlying Bickerton Rhyolite. Where Bickerton Rhyolite is absent, unconformable contact with underlying Abarungkwa Sandstone is marked by erosive channelling. Contact with overlying Woodah Sandstone is obscured. Laterally correlated with Milyema Formation</td>
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<td>Bem</td>
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<td>Maximum 40 m in incomplete sections</td>
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<td><strong>Bickerton Rhyolite</strong></td>
<td>Rhyolite: red, porphyritic (K-feldspar)</td>
<td>Large domes and coulees in a dry terrestrial environment</td>
<td>Intrudes Abarungkwa Sandstone. Locally lies between Abarungkwa Sandstone and Milyakburra Formation</td>
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<td>Eei</td>
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<td>Maximum estimated 150-250 m</td>
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<td><strong>Abarungkwa Sandstone</strong></td>
<td>Sandstone: white, coarse- to very coarse-grained, cross-bedded, pebbly, quartz-rich (lithic at base); granule conglomerate: quartz-rich; pebble and cobbles conglomerate: polymict; minor medium-grained quartz sandstone</td>
<td>High-energy braided fluviatile</td>
<td>Overlies Erringkarri Rhyolite with erosional contact and unconformably overlies Grindall Formation. Overlain by Bickerton Rhyolite or erosional by boulder conglomerate of Milyakburra Formation</td>
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<tr>
<td>Eea</td>
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<tr>
<td>Estimated 100-150 m in most complete section</td>
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<tr>
<td><strong>Erringkarri Rhyolite</strong></td>
<td>Rhyolite: dark red, variably porphyritic (K-feldspar)</td>
<td>Large domes and coulees in a dry terrestrial environment</td>
<td>Inferred to directly overlie 'basement' (Grindall Formation, Bradshaw Complex, granite). Overlain by Abarungkwa Sandstone with erosional contact</td>
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<td>EcC</td>
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<td>20 m+</td>
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OROSIRIAN

BUSTARD SUBGROUP
Sandstone, conglomerate and felsic volcanics in the lower part of the Groote Eylandt Group have been assigned to the Bustard Subgroup. These rocks are closely interrelated, having formed in a depositional environment dominated by rapid uplift related to tectonic intrusin which scree deposits at the margins of rhyolite bodies were reworked by fluvial processes.

On Groote Eylandt the Bustard Subgroup is separated from the overlying Alyangula Subgroup by an erosive, though not noticeably angular contact. On Bickerton Island the contact between the two subgroups is inferred to be disconformable, as the Woodah Sandstone (the basal unit of the Alyangula Subgroup) is widely distributed and overlies a variety of older units.

A good indication of the age of this unit is given by the Bickerton Rhyolite, with a U-Pb zircon age of 1814±8 Ma (Pietsch et al. 1994). On the basis of this age the rhyolite forms part of the younger suite (~1800-1840 Ma) of the ‘transitional phase’ of Rawlings (1994). The Bickerton Rhyolite and associated felsic volcanics and immature fluvio-lacustrine clastic rocks can be equated with similar rock types of the Edith River Group which underlie the McArthur Basin on its southwestern margin.

Erringkarri Rhyolite (Rec)
Outcrop of the newly defined Erringkarri Rhyolite (see APPENDIX) is confined to the southern shoreline of North Bay on Bickerton Island. The outcrop forms the base of weathered cliff walls and consists of blocks and boulders of red to brown rhyolite.

The Erringkarri Rhyolite comprises a discrete rhyolite unit in the lower part of the ‘Bickerton Volcanics’ as defined by Plumb & Roberts (1992). The upper boundary stratotype for the Erringkarri Rhyolite is centered at GR PE260790, where up to 20 m of the uppermost part of the unit is
exposed. The Abarungkwa Sandstone overlies the Erringkarri Rhyolite with erosional contact, and also unconformably overlies the Grindall Formation where the Erringkarri Rhyolite is absent. The base of the rhyolite is not exposed. The exclusive presence of clasts derived from the Erringkarri Rhyolite and known older units within the region in the overlying Abarungkwa Sandstone indicates that there is no concealed intervening unit and that the rhyolite directly overlies these older units. In addition, the predominance of clasts derived from the Grindall Formation and its proximity in outcrop suggests that this formation probably directly underlies the Erringkarri Rhyolite.

The rhyolite is mainly cryptocrystalline and porphyritic but locally may be aphanitic. Most phenocrysts are relict K-feldspar, with minor ferromagnesian minerals and rare quartz. K-feldspar phenocrysts average 2 mm in diameter, but some anomalously larger (to 7 mm diameter), intricately embayed crystals are also recognised. Flow banding has not been observed. Alteration and/or weathering are typical but variable, resulting in the replacement of the feldspar components by green, yellow or white clay, sericite and muscovite. However, some specimens are leached or ferruginous. A notable spheroidal weathering effect is visible in the main body of the unit and in volcanic rock clasts in the overlying sandstone unit.

It is envisaged that the volcanic rocks formed large domes and coulées in a dry terrestrial environment. A short period of weathering preceded deposition of the overlying Abarungkwa Sandstone; however, the distinctly high volume of immature rhyolite rubble around the dome(s) indicates a short period between dome emplacement and burial. The preservation of the domes in this and other formations of similar age is testimony to the small repose period between dome emplacement and incision, as well as to the rapid deposition of proximal sediments.

Abarungkwa Sandstone (Eea)
This fluvialite sandstone-conglomerate unit typically forms rugged, bare rocky ridges and coastal cliffs on the northern half of Bickerton Island (Plate 2) and on Bustard Island. The rocks are pseudokarstically weathered and have a white phototone.

The reference locality for the Abarungkwa Sandstone, newly defined herein (see APPENDIX), occupies the isthmus between North and South Bay on Bickerton Island. The most complete section, estimated to be 100-150 m thick, is represented here. The sandstone and conglomerate of the Abarungkwa Sandstone were included in the ‘Bickerton Volcanics’ of Plumb & Roberts (1992). This unit has been formally recognised because it represents a significant fluvial episode during emplacement of the Erringkarri and Bickerton Rhyolites.

Along the shoreline of North Bay the Abarungkwa Sandstone overlies the Erringkarri Rhyolite with an erosional contact (Plate 3), and further to the northeast unconformably overlies the Grindall Formation. Near South Bay the unit is apparently overlain by the Bickerton Rhyolite although the contact is not exposed. Further to the north the unit is disconformably overlain by valley-fill boulder conglomerate of the Milyakburra Formation. On Bustard Island it is intruded by the Bickerton Rhyolite.

The main rock type is typically white to grey, coarse- to very coarse-grained sandstone which grades into granule conglomerate, particularly near the base. Pebbles, cobbles and rarely, boulders are scattered throughout, becoming more abundant and of larger average size near the base. Discrete horizons of poorly sorted pebble and cobble conglomerate occur throughout the unit. Silicified pink, medium-grained, moderately to well sorted sandstone forms rare intervals in the middle and upper levels of the formation. Overall the sand- and granule-size grains in this formation are angular and poorly sorted, while pebbles and cobbles are angular to well rounded.

The rocks are typically very thickly bedded, with sedimentary structures dominated by large - to very large-scale trough cross-beds (Plate 4). Small-scale trough cross-beds are rare and together with flat-bedding are confined to the finer- and thinner-bedded intervals. An isolated massive and very poorly sorted conglomeratic horizon near the base may represent a debris flow.

Plate 4 Trough cross-beds in coarse-grained Abarungkwa Sandstone. Hammer (centre left) 40 cm long. GR 2E262794, North Bay, Bickerton Island.
Figure 5 Palaeocurrent map for formations of the Groote Eylandt Group
The sandstone and granule conglomerate are quartz rich, typically with a white clay matrix. Exceptionally, the rocks immediately above the contact with the Erringkarri Rhyolite include abundant rhyolite granules. Here the colour of the rocks is dark red and pink and may be mottled and banded. Pebbles and cobbles are of more diverse composition including quartz, quartzite, fine-grained sandstone and mudstone (typical of the Grindall Formation), quartz-mica and quartz-tourmaline rocks probably of pegmatitic origin, schist, fine-grained tourmalinite, granite and white chert. Clasts of porphyritic rhyolite are abundant near erosional contacts with the Erringkarri Rhyolite, but their abundance decreases rapidly up-section, and they are relatively rare elsewhere.

The Abarungkwa Sandstone is a high-energy braided fluvialite unit throughout, with the most proximal facies near the base. The consistency and duration of the fluvial cycle on Bickerton Island suggests that the area did not subside significantly and that magmatic activity did not retrace between emplacement of the Erringkarri Rhyolite and the Bickerton Rhyolite. Palaeocurrent directions measured from cross-beds indicate consistent flow from north to northwest (Figure 5).

**Bickerton Rhyolite (Pei)**

The Bickerton Rhyolite forms low outcrop and scattered boulders of dark purple porphyritic felsic volcanic rock around the margins of South Bay on Bickerton Island and on the southern part of Bustard Island. The ‘Bickerton Volcanics’ were first mapped by Plumb & Roberts (1965) and formally defined by Plumb & Roberts (1992). The redefined Bickerton Rhyolite is equivalent to the upper part of the ‘Bickerton Volcanics’ at its designated type locality (around the shores of South Bay). On Bustard Island the Bickerton Rhyolite intrudes the Abarungkwa Sandstone. On Bickerton Island the Bickerton Rhyolite is inferred to locally lie between the Abarungkwa Sandstone and the Milyakburra Formation. Here only the upper contact with the Milyakburra Formation is exposed, and the maximum thickness of the unit is estimated to be 150-250 m.

The porphyritic felsic volcanic rocks are rhyolitic to rhyodacitic in composition, with phenocrysts averaging 2 mm diameter, mainly of K-feldspar and minor ferromag-nesian minerals, but locally with rare quartz. The K-feldspar is typically altered to sericite and green and pink clay. The groundmass is commonly ferruginised (purple to red colour) or altered to grey and white clays. On Bickerton Island the rhyolite is massive to locally flow foliated, however on Bustard Island flow banding is spectacular and often contorted (Plate 5). Large rafts of sandstone (up to 5 m across) are contained within the mass of the rhyolite on the tip of Bustard Island. The sandstone was lithified when intruded. Some of the flow banding within the rhyolite and contacts with the sandstone body are oriented almost vertically, suggesting that this locality is near a vent.

Immature ferruginous volcaniclastic sandstone often forms irregularly shaped bodies within the outcrop; these possibly represent volcanic detritus locally reworked into voids and crevasses. This sandstone may represent part of an overlying sedimentary unit subsequently removed by erosion.

The Bickerton Rhyolite and Erringkarri Rhyolite are very similar both compositionally and in appearance. Minor differences noted in the field are the presence of more quartz phenocrysts in the Erringkarri Rhyolite, while the Bickerton Rhyolite has generally larger K-feldspar phenocrysts which tend to be more euhedral. Presumably, both units were drawn from the same source, a sporadically active silicic magma chamber at shallow depth. The age of the magmatic activity is well constrained by the U-Pb zircon age of 1814±8 Ma (Pietsch et al. 1994).

As for the Erringkarri Rhyolite, it is envisaged that the Bickerton Rhyolite formed large lava domes and coulees in a dry terrestrial environment. The assorted scree and talus deposits at the dome margins were subsequently incorporated into very immature fluvialite deposits flanking the rhyolite body.
Milyakburra Formation (Ecm)
Outcrops of the newly defined Milyakburra Formation (see APPENDIX) are dominated by cobble and boulder conglomerate, locally interbedded with granule conglomerate and coarse lithic sandstone. Typically these exposures are virtually devoid of vegetation and display pale tones on aerial photographs.

The formation is distributed in two areas on Bickerton Island. South of Milyakburra community, rocks of this unit overlie the Bickerton Rhyolite and form domal or mesa-like rocky ridges. In this area an erosional contact with the Bickerton Rhyolite is inferred from the abundance of rhyolite clasts in basal conglomerate units of the Milyakburra Formation. At the type locality immediately south of the community a maximum thickness of about 40 m is exposed in incomplete sections.

In the northern part of the island, scattered outcrops fill depressions and valleys incised into Abarungkwa Sandstone (Plate 6), with the interformational boundary marked by erosive channelling. Here the Bickerton Rhyolite was either removed by erosion or more likely was never present. No contact with overlying units is exposed.

Where the Milyakburra Formation overlies the Bickerton Rhyolite it comprises granule conglomerate and very coarse-grained sandstone with scattered pebbles, cobbles and boulders, interbedded with horizons of cobble and boulder conglomerate and minor medium- to coarse-grained cobbly sandstone. Rhyolite (Bickerton Rhyolite) and quartz are the most common clast types in the finer fraction. Larger clasts include silicified coarse-grained quartz-rich pebbly sandstone and granule conglomerate (Abarungkwa Sandstone), porphyritic rhyolite (Bickerton Rhyolite), sandstone and mudstone (probably Grindall Formation), quartz and various metamorphic rock types. Rhyolite may be dominant near the base of the unit, but clasts derived from the Abarungkwa Sandstone become dominant stratigraphically higher in the formation. Finer components are angular, while larger clasts (up to 1 m in diameter) may be angular to well rounded.

Sandstone intervals within the formation are poorly sorted to unsorted, usually weakly stratified and very thick bedded with large to very large trough cross-beds and large-scale channels containing basal boulder lags.

Unstratified clast-supported, poorly sorted cobble and boulder conglomerate in the basal Milyakburra Formation overlies the Abarungkwa Sandstone. This basal interval is dominated by subangular to rounded clasts of coarse-grained pebbly sandstone and granule conglomerate derived from the underlying formation, together with some volcaniclastic rocks, rhyolite and rocks derived from the Grindall Formation. This facies is also represented as intermittent sheets toward the top of the formation in the southern outcrop area, overlying the Bickerton Rhyolite.

These rocks are probably the product of deposition in high-energy fluviatile and alluvial fan environments sourced from elevated areas to the west and north (Figure 5). The facies probably represent a mixture of debris-flow, talus and channel-base deposits.

Milyema Formation (Eel)
Rugged, joint-controlled outcrops of conglomerate and coarse pebbly sandstone of the Milyema Formation, newly defined herein (see APPENDIX), are exposed on the northern extremities of Groote Eylandt and islands immediately offshore between Chasm Island and Jagged Head. The most continuous section, nominated as the upper boundary stratotype, lies along the north coast of Chasm Island where approximately 50 m of the unit is exposed. The thickness is probably significantly greater in the North Point Island area.

The base of the formation is not exposed, but the abundance of porphyritic rhyolite and probable Grindall Formation clasts in the lowest exposed beds indicates close proximity to these units either vertically or laterally. The upper contact with the overlying Alyinga Sandstone is erosional, but not angular. Magnetic (probably mafic) dykes are interpreted to intrude the Milyema Formation.
The Milyema Formation can be divided into a lower and an upper unit on the basis of grain size and compositional maturity. The lower unit has a dark red phototone which readily distinguishes it from the upper pale orange unit on aerial photographs.

The lower unit consists of very coarse pebbly lithic sandstone with distinct layers of matrix-supported granule to cobble conglomerate. Its typically dark red colour is due to distinctive red-pink-brown motling and the ferruginous nature of some beds. The larger clasts include red porphyritic rhyolite (very similar to the Bickerton Rhyolite), fine-grained sandstone and mudstone (Grindall Formation), coarse silicified pebbly sandstone (Milyema Formation), quartz, quartzite and various schistose rocks. The granule matrix to the conglomerate layers is dominantly rhyolite and quartz fragments. Pebbles and cobbles are scattered throughout the sandstone and sorting is very poor. Sedimentary structures include large-scale trough cross-beds and minor flat-beding.

The upper unit is dominated by medium-grained sandstone containing some fine- and coarse-grained horizons and rare granule trains and disseminated pebbles. Compositionally, rocks of this unit are quartz-rich and more mature in comparison to the underlying very coarse clastic rocks. The sandstone (quartzarenite) is moderately to well sorted, clean and silicified. It is very thick bedded and contains small to very large trough and tabular cross-beds and flat-bedding. Soft-sediment deformation (Plate 7), wave and current ripples and ripple cross-laminations are locally present.

The coarse clastics in the lower unit were deposited in a high-energy braided fluvialite environment, and may include some low-gradient alluvial fan-edge deposits. The presence of common cross-bedding argues against any outcrops representing proximal alluvial-fan deposits despite the large clast size. The unit was clearly deposited quite close to source, an area of at least moderate relief consisting of exposed rhyolite, Grindall Formation, metamorphic rocks and minor quartz-rich sandstone/granule conglomerate. Palaeocurrents indicate that the orientation of drainage was normal to that of contributing fans and actual clast source areas.

The upper unit may also be partly fluvialite, but the much greater spread of palaeocurrent directions at this level (Figure 5), the presence of wave ripples and the greater textural and mineralogical maturity suggest some shallow marine influence, at least for easternmost exposures.

The Milyema Formation is correlated with the Milyakburra Formation on Bickerton Island on the basis of similarity of rock types, facies and stratigraphic position. This is consistent with the similar lithology and proximity of an underlying unexposed rhyolite source. Rhyolite clasts in this formation compare well with those in the Milyakburra Formation. The Milyema and Milyakburra Formations also contain similar clasts of coarse silicified sandstone, which appear to be derived from underlying Abarungkwa Sandstone. The only other clasts present in the assemblage are clearly derived from the granitic and metasedimentary ‘basement’ sources (Grindall Formation, Bradshaw Complex and Bukudal Granite), indicating no other local sandstone source units for either formation.

The critical difference between the probable equivalent sedimentary sequences on Groote Eylandt (Milyema Formation) and Bickerton Island (Milyakburra Formation) is the greater dominance of marine sandstone toward the top of the succession on Groote Eylandt. This suggests an earlier and more definitive marine transgression in this area. Conversely, on Bickerton Island, this transgression is either absent or not exposed, suggesting that the subaerial (terrestrial) palaeotopography was maintained here. It is likely that magmatism and dome-building phases within this sedimentary-dominated succession represent an important palaeoenvironmental influence determining rate and duration of uplift and subsequent subsidence, and consequently affecting distribution, lithofacies and thickness of units. In areas of greatest magmatic activity, sedimentary intervals are typically fluvialite, while in areas of negligible magmatic activity such intervals are generally marine.
Importantly, the thinning of the overlying Alyinga Sandstone and Bartalumba Basalt in the direction of Bickerton Island suggests that subsequent sedimentation was more active in the Groote Eylandt area while contemporaneously waning in the Bickerton Island area. Thickness, facies and palaeocurrent variations all indicate a depocentre to the south of Groote Eylandt (Figure 5). This situation may have also been influenced by the continued subsurface activity of the feeder system to the rhyolite bodies.

STATHERIAN

ALYANGULA SUBGROUP

Interbedded sandstone and basaltic rock of the Alyangula Subgroup comprise most of Groote Eylandt, Connexion Island and southeastern Bickerton Island. This subgroup also constitutes the greater part of the stratigraphic thickness of the Groote Eylandt Group.

On Groote Eylandt the base of the lowest constituent formation (Alyinga Sandstone) consists of thick units of cobble sandstone and conglomerate which contain clasts from the underlying sandstone units. The base of the Alyinga Sandstone is erosive with a sharp contact but no evident angular unconformity. Elsewhere the base of the Alyangula Subgroup is represented by the Woodah Sandstone which unconformably overlies Grindall Formation. In BLUE MUD BAY the Woodah Sandstone is also unconformable on Bukudal Granite, Bradshaw Complex and porphyritic felsic dykes near Coast Range. The top of the subgroup is eroded.

Rocks of the Alyangula Subgroup have a close lithological and sequence-stratigraphic correlation with those in the lower part of the Tawallah Group in the southern McArthur Basin. On this basis the unconformity at the base of the Alyangula Subgroup is interpreted to represent the base of the McArthur Basin sequence.

Woodah Sandstone (Pew)

The Woodah Sandstone, newly named and defined herein (see APPENDIX), is a variable unit of conglomerate, sandstone and mudstone which is restricted to the Blue Mud Bay area. Within GROOTE EYLANDT REGION it is exposed in joint-controlled, bare rocky outcrops on northeastern Bickerton Island and smaller islands to the north and northeast. A maximum thickness of 50-60 m is preserved at the lower boundary stratotype locality on Morgan Island immediately north of GROOTE EYLANDT REGION in adjoining BLUE MUD BAY.

Relationships with other units of the Groote Eylandt Group are inferred. On Bickerton Island the contact of the Woodah Sandstone with the Milyakburra Formation and Abarungkwa Sandstone is obscured by younger cover and complicated by faulting. The basal conglomerate of the formation on islands to the north of Bickerton Island contains clasts interpreted as derived from the Abarungkwa Sandstone. On two of these islands, Burney Island and Wedge Rock, the formation unconformably overlies the Grindall Formation. On Morgan Island in BLUE MUD BAY (Haines et al. 1997), it unconformably overlies Grindall Formation and Bukudal Granite. On Bickerton Island the Woodah Sandstone is inferred to underlie the Bartalumba Basalt. Elsewhere in GROOTE EYLANDT REGION the top is always eroded and Cretaceous rocks and Cainozoic soil and laterite are the only cover.

Sections of Woodah Sandstone exposed in GROOTE EYLANDT REGION are thin and incomplete, but a more complete section is available at the lower boundary stratotype locality on Morgan Island, immediately to the north of the map sheet area. There, a 1-3 m-thick, white to reddish, pebble to cobble conglomerate forms the base of the formation. Clasts include indurated sandstone and foliated siltstone (Grindall Formation), quartz, quartz-rich pebbly coarse-grained lithic sandstone and granule conglomerate (Abarungkwa Sandstone) and rare granite in a matrix of unsorted coarse-grained sandstone. The conglomerate is overlain by a 20-30 m-thick interval of thin- to medium-bedded, fine- to medium-grained, ferruginous pebbly sandstone interbedded with red mudstone. The sandstone displays small-scale trough cross-bedding. The upper part of the section comprises blocky, medium- to thick-bedded, white to pink quartz sandstone. This sandstone is medium- to coarse-grained and contains disseminated rounded white quartz pebbles.

On Isle Woodah, Burney Island and Wedge Rock the Woodah Sandstone is represented by a lenticular, basal pebble to boulder conglomerate overlain by fine- to medium-grained quartz sandstone. Clasts within the conglomerate are predominantly foliated sandstone (Grindall Formation), felsic igneous rocks and minor pebbly sandstone (?Abarungkwa Sandstone) supported in a very coarse quartz-feldspar sand matrix. The sandstone is thin- to medium-bedded with planar cross-beds.

Plate 8 Woodah Sandstone. Thinly interbedded sandstone, granule conglomerate and red ferruginous micaceous mudstone. Hammer 40 cm long. GR PE407810, Bickerton Island.
Beneath Cretaceous rocks and laterite on Cape Barrow, exposure of the Woodah Sandstone is confined to one outcrop of white, coarse-grained pebbly sandstone. The pebbles are mainly massive quartz with minor fine-grained silicified sandstone (Grindall Formation) and rare cherty fragments. The sandstone is thick bedded with trough cross-beds.

On the northeastern coast of Bickerton Island a localised facies of the Woodah Sandstone comprises medium- to coarse-grained sandstone and granule conglomerate interbedded with red, ferruginous micaceous mudstone. These rock types are interbedded on a thin to very thin scale and display sedimentary structures that include climbing ripple laminations, desiccation cracks and flaser bedding (Plate 8). The remainder of the Woodah Sandstone in this area is medium grained quartz sandstone very similar to that on Isle Woodah to the north. The sandstone-mudstone interval is like that exposed on Grindall Point and at the lower boundary stratotype locality on Morgan Island in BLUE MUD BAY.

In GROOTE EYLANDT REGION the Woodah Sandstone was probably deposited mainly in a braided fluvial system. The localised desiccation-cracked mudstone facies probably represents flood deposits accumulated in an out-of-channel or cut-off-channel locale within the system.

Alyinga Sandstone (Eey)

The newly named Alyinga Sandstone (see APPENDIX) consists mainly of medium-grained quartz sandstone which forms rugged, sparsely vegetated, joint-controlled outcrops. Exposure is confined to northern Groote Eylandt, northern Winchelsea Island, North East Isles and adjacent islands. No complete section is exposed. A composite section comprising the lower boundary stratotype and reference localities (see APPENDIX) is estimated to be about 300 m thick. The unconformity with the underlying Milyema Formation is marked by a sharp erosional contact, and lithified clasts of upper Milyema Formation are present in the Alyinga Sandstone basal conglomerate (Plate 9).

Regional disconformity is also implied by the presence of associated foliated quartzite, sandstone and mudstone clasts (Grindall Formation), minor metamorphic and pegmatite clasts, and sandstone clasts probably derived from the Abarungkwa Sandstone. Although the upper contact is not exposed, it is inferred that Bartalumba Basalt concordantly overlies the Alyinga Sandstone.

The basal part of the formation is represented by a discontinuous unit of polymict granule to boulder conglomerate and coarse-grained pebbly or cobbly sandstone. Clasts in the conglomerate are angular to rounded and include coarse-grained pebbly sandstone and generally quartz-rich granule conglomerate (derived from Milyema Formation and probably also Abarungkwa Sandstone); quartz; indurated, foliated mudstone and fine-grained sandstone (Grindall Formation); and rare metamorphic and possible felsic volcanic rocks. Individual conglomerate beds are lenticular and discontinuous, and usually several metres thick. These beds often grade upward from clast- through matrix-supported conglomerate to quartz-pebble sandstone and may be repeated as several distinct cycles.

Where the conglomerate beds are absent the basal interval comprises up to 40 m of coarse- to very coarse-grained pebbly sandstone. The sandstone is lithic, immature and poorly sorted, with some cobbles beds as lag deposits at the base of trough cross-beds. The cobbles and pebbles are mainly massive quartz with subordinate amounts of foliated mudstone and fine-grained sandstone derived from the Grindall Formation, fine-grained sandstone derived from the Milyema Formation substratum, and minor amounts of various metamorphic rock types. Locally this sandstone is ferruginous, especially toward the top of this interval.

The basal facies grades upward into a thicker unit of mainly medium-grained, moderately to well sorted, white, quartz sandstone with scattered pebbles, and lenses of granule conglomerate. This unit is characterised by large trough cross-beds and prominent large-scale joints which control the topography (Plate 10). On Chasm Island, trough cross-beds have troughs up to 130 m wide with foresets up
to 20 m thick (Plate 11). At GR PE837880, in addition to the large trough cross-beds, planar to curved tabular cross-beds, flat-bedding and ripple cross-lamination are also present. The top of this unit on Chasm Island and an adjacent small island has a distinct purple colour due to patchy ferruginisation.

Outcrops on Winchelsea Island are stratigraphically higher and coarser grained than those on Chasm Island. Here the formation consists of white to pink, and in places brownish and reddish, coarse-grained pebbly sandstone which grades into thin horizons of granule conglomerate. The sandstone comprises poorly to moderately sorted, angular to subangular grains with pebbles both randomly distributed and locally as thin lag deposits at the base of trough cross-beds. Minor medium-grained sandstone beds are also present; these are quartz-rich with a minor clay matrix. Granules and pebbles consist mainly of quartz, with subordinate chert, silicified mudstone, sandstone and felsic volcanic rock. Sedimentary structures are dominated by large- to very large-scale trough cross-beds and minor tabular cross-beds.

The sandstone in the top of the exposed part of the formation is both medium- and coarse-grained and more mature than underlying units. Grains are well rounded, generally well sorted and of bimodal grainsize. Bedding is well defined and sedimentary structures include large trough and tabular cross-beds and wave and current ripples. These upper beds are silicified and overlain by laterite which may have formed from a weathered basalt parent rock.

The erosive contact at the base of the Alyinga Sandstone, which is not noticeably angular, is probably the result of a reactivation of the fluvial system, either relating to sea-level fall or more likely to renewed uplift (tectonic and/or intrusion related) in the source area. The lithology, sedimentary structures and palaeocurrent patterns (Figure 5) suggest a high-energy braided fluvial environment for much of the unit. The clean, well-sorted beds containing common wave ripples near the top of the formation may
reflect a marginal marine influence at this level. Overall, this pattern suggests a repeat of the Milyema Formation uplift-subidence cycle.

**Bartalumba Basalt (Peb)**
The Bartalumba Basalt, newly named and defined herein (see APPENDIX), is a very poorly exposed unit usually represented by weathered outcrop with fresh cores, or by moderately fresh boulders and cobbles in creek beds. Outcrops are small, isolated and located beneath scarps of Dalumbu Sandstone between the Bluff Hill area (eastern Groote Eylandt) and the east coast of Bickerton Island. The upper boundary stratotype for the Bartalumba Basalt is in the Bluff Hill area, at GR PE877535. Aeromagnetic data suggest that these outcrops form part of a continuous tabular body extending near surface from the southeastern tip of Groote Eylandt northwest to the unnamed bay on the central-eastern shore of Bickerton Island and dipping gently southeast and south. The presence of the unit beneath Mesozoic and Cainozoic cover is believed to be responsible for the broad corridor lacking in situ Proterozoic outcrop across northern Groote Eylandt.

The thickness of the Bartalumba Basalt cannot be accurately determined as the base of the formation is not exposed, but is inferred to be in the order of 200-400 m in northern Groote Eylandt. The decreasing intensity of magnetic anomalies towards Bickerton Island suggests a decreasing thickness in that direction.

On Groote Eylandt the Bartalumba Basalt crops out as red and black, vesicular and amygdaloidal basalt and microdolerite. Vugs of diameter 5-10 mm constitute up to 60% of the rock volume and are filled with quartz, chalcedony, agate, K-feldspar, chlorite and celadonite. There are also numerous very large (200 mm diameter) vugs filled with agate/chalcedony. Pipelike vesicles, which probably represent gas-escape structures, are evident at GR PE730658 (Plate 12). These vesicles consist of a series of parallel chalcedony-filled, partly branching pipes about 100 mm long, aligned subperpendicular to local bedding. On Bickerton Island, the top 10 m of the formation is represented by massive microdolerite overlain by vesicular amygdaloidal basalt.

The lower contact with the Alynga Sandstone is not exposed. The upper contact is also concealed, but the formation appears to be concordant with the overlying Dalumbu Sandstone.

Based on the absence of subaqueous emplacement features, a subaerial environment of emplacement is interpreted for the basalt.

**Dalumbu Sandstone (Peb)**
The dominantly coarse-grained pebbly sandstone exposed in central and southern Groote Eylandt, Connexion Island and southeastern Bickerton Island is attributed to the newly defined Dalumbu Sandstone (see APPENDIX). Typically this sandstone forms sparsely vegetated low hills and scarps, often with joint-controlled topographic expression. Vague bedding trends, more prevalent near the base of the formation, are evident on aerial photographs.

Due to its very gentle dips, no single section can represent the formation. Rather, all of the main body of continuous outcrop of the unit on Groote Eylandt constitutes the reference area. The Dalumbu Sandstone conformably overlies the Bartalumba Basalt. On Bickerton Island the basal portion of the formation comprises approximately 5 m of ferruginous sandstone and mudstone, in turn overlain by coarse pebbly sandstone. On Groote Eylandt, the basal contact is not exposed, but the ferruginous sandstone and mudstone unit is apparently absent. The top of the formation is eroded and overlain unconformably by Cretaceous rocks and Cainozoic sediments; hence the full thickness cannot be determined. A minimum estimated thickness in the order of 500-1000 m is exposed on Groote Eylandt, assuming that the regional dip is constant between one and two degrees.

The Dalumbu Sandstone is dominated by pebbly sandstone containing interbeds of finer-grained non-pebbly sandstone, and includes a thin layer of basalt which drapes large ridges of sandstone near the formation base. The pebbly sandstone is white to locally pink, quartz-rich and coarse-grained with horizons of granule conglomerate. Most

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**Plate 12** Gas-escape structures in Bartalumba Basalt. Pen (left) for scale. GR PE730658, central Groote Eylandt.
quartz grains are angular and poorly sorted. In contrast, pebbles and less abundant cobbles are generally rounded to well rounded. These are predominantly white quartz, but a few may be composed of quartzite and sandstone (Grindall Formation) and chert, and very rarely of felsic igneous and metamorphic rocks. The sandstone is thick- to very thick-bedded and contains abundant trough and less common tabular cross-beds with very large foresets. White to pink, more mature, medium-grained sandstone forms thin- to medium-bedded horizons up to about 10 m thick within the pebbly sandstone; this sandstone is quartz-rich with well rounded and sorted grains, and internally laminated with small- to medium-scale trough cross-beds.

Between Central Hill and Yillyangumana Point (GR PE950492) a distinct facies of parallel linear ridges is present about 40 m above the base of the formation. These distinct northeast-oriented linear ridges are in the order of 10 m high, at least 1.5 km long and typically spaced about 300 m apart, although the separation ranges from 200 m to 1000 m. The distinctly reddish-brown ridge-forming sandstone is medium to coarse grained and varies from well to poorly sorted. Cross-beds of various scales are represented by large low-angle foresets which contain smaller-scale trough cross-beds and low-angle tabular foresets. The presence of foresets oriented in opposing directions is in contrast to the unidirectional palaeocurrent orientation in the underlying pebbly sandstone.

A thin, weathered and ferruginised basalt unit (Red.) drapes the underlying ridge-forming sandstone. Up to 15 m of basalt may be preserved in troughs but the unit decreases in thickness or pinches out over ridge tops.

Large, up to decametre-size boulders of Dalumbu Sandstone (Red.) occur intermittently in the area north of the scarp defining the Bartalumba Basalt-Dalumbu Sandstone contact, between Yillyangumana Point (GR PE950492) and the mouth of Anarrama Creek (GR PE693710). The boulders may be arranged chaotically or form ring structures with no preferred bedding orientation. These boulders are interpreted as the collapsed remnants of scarpsretreat, a process in which the underlying basalt was eroded, perhaps by marine incursion during Cretaceous time.

The predominantly pebbly sandstones represent deposition in a braided fluvial environment in rivers that flowed southeast on Bickerton Island and more southerly on Groote Eylandt (Figure 5). The sand ridge facies most likely represents deposition on a shallow shelf during a brief marine incursion across a coastal alluvial plain. A thin sheet of basalt preserved these ridges from later reworking by the next fluvial episode.

UNDIFFERENTIATED PROTEROZOIC

Dolerite dykes (Edd)

Red and brown, massive or vaguely banded limonite rocks form thin dykes penetrating the Bartalumba Basalt and Dalumbu Sandstone. In places white, lathlike specks within the limonite betray a dolerite-like texture and the limonite is thus interpreted as an alteration product of dolerite and basalt. There is significant evidence for intrusion, including a discordant relationship with and the ferruginisation of adjacent sandstone. The dykes may locally represent feeders to an overlying extensively ferruginised thin basalt unit within the Dalumbu Sandstone.

Some of these dykes correspond to strong linear magnetic features which bear a striking resemblance to the magnetic signature of weathered basalt dykes in the Mitchell Ranges in ARNHEM BAY-GOVE and BLUE MUD BAY. The presence of two distinct sets of negative and positive, crosscutting linear magnetic features indicates that these dykes have intruded at different times during the Mesoproterozoic.

CARPENTARIA BASIN

MESOZOIC

CRETACEOUS

Early to Middle Cretaceous sediments were deposited unconformably over deeply dissected rocks of the Groote Eylandt Group. On the western extremity of Groote Eylandt, the more widespread major northwest-trending faults and joints within the Groote Eylandt Group have been instrumental in the development of discrete northwesttrending ridges over which Cretaceous sediments drape.

The thickness of Cretaceous sedimentary rocks probably exceeds 100 m on the western coast of Groote Eylandt, where they dip shallowly toward the west. In the vicinity of palaeocoastal basement highs, however, dip directions range from northeasterly and northwesterly to the more common westerly and southwesterly as the Cretaceous rocks drape over these basement ridges.

An approximate age of 95 Ma was obtained from K-Ar dating of glauconite within these rocks, which have been correlated with the late Albian to early Cenomanian Normanton Formation of the southern Carpentaria Basin (Bolton et al. 1990).

Two discrete sub-basins have been recognised on the western coast of Groote Eylandt (Figure 6). The northern sub-basin consists of locally derived, unfossiliferous quartz sandstone overlain conformably by shallow marine glauconitic claystone of late Albian age (Bolton et al. 1990). The upper portion of this sequence hosts the primary pisolithic manganese ores. In the southern sub-basin, minor manganese-cemented sandstone occurs in an interval of locally calcareous sandy siltstones. Minor occurrences of a manganese carbonate oolite have been reported from this sub-basin (Slee 1980).

In central Groote Eylandt, flat-lying sandstone and claystone infill palaeovalleys incised in Dalumbu Sandstone to a maximum elevation of 100 m. The basal Cretaceous sandstone is red-brown, mottled, medium to very coarse grained and quartz rich, with a variable amount of matrix-forming clay. Claystone intraclasts are common and quartz and sandstone pebble- and cobble-rich beds are locally developed. Quartz-granule lenses define weak bedding including both large and small cross-beds in which vertical and oblique barrows have been preserved. Remnant outcrops of white to mottled clayey sandstone and claystone overlying the basal sandstone are locally preserved.

Cretaceous rocks in the northern part of the island are exposed as multicoloured, mottled claystone, siltstone and clayey sandstone in road cuttings and boulder outcrop at low hills. Most sedimentary features have been overprinted
Figure 6  Distribution of manganese mineralisation in Cretaceous rocks on Groote Eylandt. Modified after Bolton et al. (1990).
by intense lateritisation, but thin bedding laminations and vertical to subvertical burrows are evident in places.

The basal Cretaceous sandstone is unfossiliferous, but the presence of burrows may indicate a shallow marine depositional environment. According to Bolton et al. (1990) the overlying glauconitic mudstone was deposited in a shallow-marine environment.

CAINOZOIC
Cainozoic deposits are concentrated around the periphery of Groote Eylandt. On most smaller islands and in the central part of Groote Eylandt where elevated rugged topography dominates, these deposits are sparse. On the mapface, Cainozoic deposits have been subdivided into genetically distinct units as identified on aerial photographs.

PALAEOGENE-NEOGENE-QUATERNARY
Intense chemical weathering during the Cainozoic led to the formation of pisolith and massive ferricrete and laterite (Czj). Typically the laterites consist of ferruginous to kaolinitic mottled clays and sandy clays. Lateritisation of the Cretaceous manganese oxide ores has important economic implications in that this supergene alteration in part converted loose pisolithic ore to competent lumpy ore.

Various locally derived sedimentary units have been deposited above Cretaceous rocks on the western side of Groote Eylandt. These units and others too minor to represent on the mapface have been included in a unit of undifferentiated Cainozoic deposits (Cz) which is dominantly sandy to gravelly soils. A major component unit recognised within the GEMCO mine area (mainly around C Quarry - see Figure 2) is a smectite clay unit immediately overlying the manganese ore horizon. Smectite clays can absorb and retain large amounts of water within their lattice and thus pose an operational problem for heavy machinery during the wet season. Also included are small river channel deposits with conglomeratic bases which locally incise the upper portion of the manganese ore. These are especially common immediately adjacent to the palaeoshoreline.

QUATERNARY
Extensive coastal aeolian dune fields (Qd) dominate the eastern and southern fringes of Groote Eylandt. The morphology and chronostratigraphy of the dune fields has been described by Shulmeister & Lees (1992), Shulmeister et al. (1993) and Shulmeister & Head (1993). Using the coarse-fraction thermonudmirencence dating technique, several phases of dune activity were identified by Shulmeister & Lees (1992). The oldest phase, a basal aeolianite (Qd.) was emplaced prior to 100 000 yrs BP. This unit has been identified on the seaward fringe of the northeast coast as indurated erosional remnants with a grey calcareous cement. Subsequent dunes (Qd) all formed during the Holocene, between 6 000 yrs BP and the present. Those that stabilised between about 6 000 yrs and 1 000 yrs BP are entirely siliceous, but modern dunes additionally include either a shell or a carbonate content.

Active and recently active cheniers and beach ridges (Qr) consist of shelly sand. These ridges are scattered along the coastline, and in ARNHEM BAY-GOVE to the north form on the seaward fringes of the older dune systems. Active deposits of intertidal and supratidal sediments (Qc) are forming on coastal flats and in tidal channels. These deposits are largely unvegetated, apart from stands of mangroves. They consist of unconsolidated grey clayey, silty and sandy sediments with common entrained shell debris. A thin salt dusting forms on the surface of supratidal flats when not inundated. Qc is often rimmed by slightly elevated grassy black soil plains (Qb) which are interpreted as old coastal deposits stranded by slow regression of the coastline. Some of these areas are slowly accreting by addition of flood-plain silts.

Active channels, flood plains and outwash sheet deposits (Qa) are sites of alluvial gravel, sand, silt and clay deposition. Fine-grained deposits formed in local depressions are included in this category. Areas of Qa flanking major rivers and creeks fan laterally toward the coastal zone where they intermingle with coastal sediments.

STRUCTURE
Rocks of the Grindall Formation were deformed during the Barramundi Orogeny at about 1870 Ma to produce tight folding about moderately plunging, northeast-trending axes. The exposed folds display wavelengths of up to several hundred of metres. An axial-plane cleavage is poorly to well developed in lutitic rocks and, within arenites, weakly developed only at fold hinges.

In GROOTE EYLANDT REGION, post-orogenic rocks, represented mainly by those of the McArthur Basin, are only mildly deformed. Regionally the architecture of the McArthur Basin is dominated by the meridionally-trending Batten (south) and Walker (north) Fault Zones, which are bounded by considerably less deformed regions referred to as shelves by Plumb (1994). The fault zones record a long history of substantial block faulting and reactivation. Bedding may be moderately dipping and usually only broadly folded, but steeply dipping in extensively faulted areas.

GROOTE EYLANDT REGION is located on the Caledon Shelf, east of the Walker Fault Zone (Figure 3). Rocks in this area are tilted at less than 5°. Faulting, which is uncommon, is mainly observed on Bickerton Island, where vertical displacement may be in the order of several hundred metres.

The sandstone units of the region display well developed conjugate joint sets trending mainly northnorthwest to northwest and east to northeast. Prominent linear features trending northeast to northnorthwest correlate with linear magnetic features which from limited outcrop relationships are interpreted as dolerite dykes.

GEOPHYSICS
Airborne magnetic and radiometric surveys were flown over GROOTE EYLANDT REGION for the NTGS in 1993 as part of an ongoing regional airborne geophysical survey of the McArthur Basin. Data were acquired at a mean ground clearance of 100 m along 300 m-spaced east-west flight lines. The results of this survey are available as 1:100 000-scale maps of total magnetic intensity (TMI) contours, TMI stacked profiles, flight paths and ground clearance. Results are also available as located, corrected digital data on 1600 BPI magnetic tape.
Gravity
The gravity data presented (Figure 7) as a Bouguer anomaly contour map are those collected by the Bureau of Mineral Resources at stations on an approximately 11 km-centre grid. No interpretation is offered herein, as small-scale features are not discernible from the broadly based data in this restricted area.

Magnetics
Magnetic features of GROOTE EYLANDT REGION are represented here as a grey-scale image (Figure 8) and as a coloured image on the mapface.

In the present interpretation four types of features have been outlined: lineaments, short-wavelength patterns, areas of high TMI and areas of low TMI.

Lineaments These are short-wavelength, magnetically positive and negative linear features which are common and widespread in eastern Arnhem Land. Many of these lineaments model as vertical to subvertical planar bodies (dykes) which in places may coincide with exposed dolerite dykes. The variation in remanent magnetism, responsible for the positive and negative responses, indicates that there have been at least two generations of intrusion. Other linear features may not be dykes, but boundary effects caused by the juxtaposition of two rock bodies of differing magnetic character, resulting for example from faulting. On a regional basis these linear magnetic features display pronounced northeaster to northeast to northwest to northnorthwest orientations and parallel the principal fault directions in the McArthur Basin, as described by Plumb (1994).

Short-wavelength patterns The designated pattern (Area I in Figure 8) is readily distinguished by its irregular pattern of short-wavelength, medium- to high-intensity magnetic features. The short-wavelength magnetic response indicates a near-surface source. The most likely sources are the Bartalumba Basalt and a thin unnamed basalt unit in the Dalumbu Sandstone. This association is confirmed by the fact that the restricted outcrops of basalt coincide with this magnetic feature and the response fades in definition downdip, to the southwest, as depth increases.

Areas of high TMI These (Areas II in Figure 8) are regionally large-wavelength features of high magnetic intensity that display steep bounding gradients. Superimposed on these features are short-wavelength responses from a surface or near-surface source. On a regional basis these magnetic features display similarities to those coinciding with the Bukudal and Garrthalara Granites located to the north on ARNHEM BAY-GOVE and BLUE MUD BAY. On this basis it may be interpreted that these areas in GROOTE EYLANDT REGION are underlain by similar magnetic granite. On the west side of Bickerton Island, however, this magnetic feature coincides with exposures of the Bickerton and Erringkari Rhyolites and a possible northerly continuation of rhyolite beneath the sea under Cape Barrow. This relationship suggests that rhyolite bodies may be the magnetic source for these areas of high TMI.

Areas of low TMI Northern Groote Eylandt, northeastern Bickerton Island and the nearby small islands consist of Grindall Formation or units that are stratigraphically close to the contact with the pre-orogenic basement. On this basis it is inferred that the remainder of this broad area of low TMI (Area III in Figure 8) is predominantly underlain by pre-orogenic rocks of the Arnhem Inlier (Grindall Formation and Bradshaw Complex). Small, isolated anomalous areas of higher magnetic intensity may have a rhyolite source (as
of higher magnetic intensity may have a rhyolite source (as for example over Bustard Island). Other weakly patterned, locally higher areas may be sourced by thin sedimentary units of the Bustard Subgroup.

Radiometrics
The radiometric data (Figure 9) are presented as a total count grey-scale image. In general the most readily identifiable radiometric patterns are those of high background value that coincide with well-developed lateritic soils and those of very low values (in potassium, thorium and uranium channels) coinciding with large areas of sand dunes on the eastern and southern sides of Groote Eylandt.

Both thorium and uranium channels exhibit very similar responses to all units. An exception is the strong response to some exposures of the Erringkarri Rhyolite in the thorium channel.

High potassium responses are recorded over basalt and rhyolite, and over sedimentary units that contain substantial rhyolite detritus. In a similar manner to the other two channels, responses are strong over well-developed laterite areas. Potassium responses are also very strong over pits which contain manganese.

GEOLOGICAL HISTORY
Turbidites of the Grindall Formation were deposited in the region, probably contemporaneously with the deposition of similar rock types in the Pine Creek Inlier at about ~1900 Ma. Deformation and high-temperature low-pressure metamorphism peaked at ~1870 Ma during the ‘Barramundi Orogeny’, interpreted by Rawlings et al. (1997) as an episode of zonal thermal metamorphism. Rocks of the Grindall Formation in GROOTE EYLANDT REGION were tightly folded, but remained essentially unmetamorphosed during this event. To the north of the map sheet area, the development of a continuum of deformed paragneiss, migmatisitic granite gneiss and granite resulted, with apparent rapid gradation to essentially unmetamorphosed remnant protolith (Grindall Formation). Shallow granite plutons, exposed mainly to the north of GROOTE EYLANDT REGION, were intruded at about 1840 Ma following substantial uplift and erosion.

Further uplift and erosion preceded deposition of post-orogenic felsic volcanic and related immature fluviatile sediments of the Bustard Subgroup at about 1815 Ma (Pietzsch et al. 1994). Following a brief hiatus, fluviatile and
shallow marine sandstones and mafic volcanics of the Alyangula Subgroup (basal units of the McArthur Basin) were deposited. Mafic dykes of various ages were intruded, probably both during and after deposition of the McArthur Basin. These dykes include possible feeders to the mafic volcanics and the structurally controlled dyke sets delineated by linear magnetic features.

A marine incursion during early to mid-Cretaceous time resulted in deposition of a thin veneer of shallow marine sediments over all but areas of the highest elevation. Erosion dominated during the Cainozoic when terrestrial conditions allowed widespread regolith and laterite development.

**ECONOMIC GEOLOGY**

One of the world’s largest economic manganese resources is located on the western coastal plain of Groote Eylandt. This deposit is within flat-lying Cretaceous sedimentary rocks mantled by a relatively thin succession of clay, sand and lateritic material.

In 1964 the Broken Hill Proprietary Company Limited (BHP) established a wholly owned subsidiary, Groote Eylandt Mining Company (GEMCO), to mine, process and market manganese ore from this deposit.

Manganese is primarily used in steelmaking, which utilises 95% of production. It serves to harden the steel and to improve its capacity to be worked into sheets, coils, slabs and other commonly used shapes.

It also has significant use in battery production and in particular in small dry-cell batteries. Manganese for batteries must have the ability to store charge, and this may be generated in two ways:

1) natural manganese dioxide (NMD): this is a naturally occurring form which can store charge; such ore is present in small quantities on Groote Eylandt (e.g. F4 Quarry) and has been sold for that purpose;

2) electrolytic manganese dioxide (EMD): manganese ore that is not naturally capable of storing charge may be electrolytically converted to impart this capacity. BHP operates an EMD plant at Newcastle, NSW, which uses only Groote Eylandt ore.

Other markets for manganese include the pigments, ceramics and chemicals industries; there are numerous other applications.
Manganese ores
The Groote Eylandt manganese orebody extends 22 km north-south and is up to 6 km wide and 9 m thick (average 3 m) - one of the largest single accumulations of economic manganese in the world. The deposit is centred around the Aboriginal community of Angurugu. Significant effort has been put into the investigation and description of the ore deposits on Groote Eylandt. Major descriptive and genetic studies have been made by Smith & Gebert (1970), Slee (1980), Ostwald (1980, 1988), Pracejus et al. (1988), Bolton et al. (1988) and Bolton et al. (1990). As well, the detailed unpublished works of numerous GEMCO geologists over the past 25 years have added enormously to the understanding of the geology and genesis of this world-class ore deposit.

The ores are present as manganese oxides, the chief minerals being pyrolusite and cryptomelane. Also present in minor amounts are romanechite, todorokite and traces of vernadite, braunite, lithiophorite, birnessite and chalcopyhanite (Ostwald 1988). Gangue minerals include kaolinite as the main clay within the ore horizon; detrital quartz grains are common below the ore horizon and are present within the secondary silicic ore zone. Quartz acts as the nucleus of some ooliths or pisoliths.

The ore minerals represent a variety of textural types, the most distinctive being the oolitic/pisolithic. In this ore type, component ooliths and pisoliths are variably cemented and in areas of extreme secondary cementation lose their primary textural identity. Locally, massive to concretionary textures are now developed where no primary pisoliths formed, both above and below the pisolithic ore.

The ore horizon can be subdivided into several stratigraphic units. The combined effects of an irregular primary depositional surface and widespread but variable post-depositional diagenetic, supergene and pedogenic processes have resulted in complex vertical and lateral distribution of units (Bolton et al. 1990).

A generalised stratigraphy is shown in Figure 10. The oldest pisolithic unit is now generally ferruginous; this was originally a manganiferous pisolite unit which underwent secondary iron replacement. Overall, the entire pisolithic succession was deposited in a shallow marine environment. Various cycles of reverse and normally graded pisoliths and ooliths are present and these are especially well preserved in the thick, uncemented ore of G Quarry. Pisoliths range up to 25 mm in diameter. Trough cross-bedding and hardground aggregates are also present in places (Bolton et al. 1990).

Ore genesis
Understanding of the probable genesis of the Groote Eylandt manganese deposits has improved significantly over the past thirty years. Early workers noted that the deposits were derived from anomalously manganese-rich rocks in the hinterland of the western Carpentaria Basin (Smith & Gebert 1970). Slee (1980) proposed that the deposits were formed through migration of Mn-rich fluids derived from slightly older Cretaceous rocks containing manganiferous calcareous siltstone in the southern basin of the west coast of Groote Eylandt.

Subsequent work by Frakes & Bolton (1984) and Bolton et al. (1988) suggested that manganese concentration occurred during an Albian marine transgression in anoxic, organic-rich waters of the western Carpentaria Basin; manganese oxides were later deposited during episodes of marine regression. The distinctive oolitic and pisolithic textures formed as the nucleating manganese oxides were gently rolled around near wave base. Frakes & Bolton (1984) proposed that manganese deposits could be sourced from a large hinterland west of the Carpentaria Basin that included basin-margin rocks containing manganese at average values.

A major marine regression during the early Cenomanian terminated deposition of manganese oxides, and local smectite clays were deposited over the manganese ores. Subsequent remobilisation of manganese occurred during
the Tertiary and this has played an important role in converting loose pisolitic manganese deposits into the competent lumpy ore sought by steelmakers. Recent work based on K-Ar dating of potassium-bearing manganese ores (Dammé et al. in press) suggests that primary mineralisation of Late Cretaceous age (i.e. younger than 95.4 Ma glauconite dates) was subjected to three periods of weathering in the Eocene to form the secondary manganese ores found throughout this large manganese deposit.

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**APPENDIX**

**DEFINITIONS OF NEW AND REDEFINITIONS OF EXISTING STRATIGRAPHIC UNITS**

The definitions below have been approved by the Commonwealth Territories Subcommittee of the Stratigraphic Names Committee and have been filed with the Central Register of Stratigraphic Names. Requirements and procedures for new definitions are set out in Staines (1985).


*Derivation of name:* Grindall Point (GR PFI130280) and nearby Mount Grindall and Grindall Bay in BLUE MUD BAY.

*Synonymy:* ‘Grindall Metamorphics’ (Plumb and Roberts, 1965, 1992). Note that outcrops near Grindall Point mapped as ‘Grindall Metamorphics’ by Plumb and Roberts (1965) are now assigned to the Bradshaw Complex.

*Distribution:* Eastern BLUE MUD BAY, particularly eastern flank of Coast Range, Morgan Island, Burney Island, northern Bickerton Island and small islands to the north of Bickerton Island.

*Type locality:* Plumb and Roberts (1992) nominate the eastern end of Morgan Island (lat. 13°28’S, long. 136°06’E; GR PFI195103) as the type locality. Here the unit is folded and mostly steeply dipping. A short distance to the west it is intruded by Bukudal Granite and overlain unconformably by flat-lying Woohad Sandstone (Groote Eylandt Group).

*Thickness:* Unknown as the unit is tightly folded and no stratigraphic base or top can be identified. Probably in excess of 1000 m thick.

*Lithology:* Red-brown to grey-green, fine- to medium-grained, thin- to thick-bedded, lithic sandstone generally interbedded with mudstone. Discrete sandstone beds are typically sharp-based and often graded. Schist, phyllite and metasedimentary rocks also present in Coast Range area.

*Depositional environment:* Considered to be, at least in part, a turbidite succession.

*Geomorphic expression:* Low rubbly hills, wave-cut platforms and cliffs along coasts.

*Relationships and boundary criteria:* Oldest known constituent of the Arnhem Inlier. No base exposed. Contact with younger units clearly marked by distinct angular unconformity and commonly succeeded by a basal conglomerate. Overlain unconformably by various units of the Groote Eylandt Group and locally by Jalarma Formation and unnamed volcanic rocks along Coast Range. Intruded by Bradshaw Complex, Bukudal Granite and various mafic and felsic dykes.

*Age:* Probably Palaeoprotorozoic, but constrained only by the minimum age of 1870 Ma provided by the oldest known intrusives, the Bradshaw Complex (Pietsch et al. 1994). Pietsch et al. (1994) indicate that it was deposited pre-Barramundi Orogeny (1885-1870 Ma).

*Correlatives:* May correlate with other pre-McArthur Basin sedimentary and metasedimentary successions in Pine Creek Inlier, Mirarrmima Complex and Murphy Inlier.

*Comments:* The change of name from ‘Grindall Metamorphics’ is considered necessary to reflect the predominant
lithology of the unit. Although locally metamorphosed, most outcrops do not warrant being termed metamorphic.

**GROOTE EYLANDT GROUP** (P.W. Haines, D.J. Rawlings and B.A. Pietsch, name redefined and modified after Plumb and Roberts, 1965)

*Derivation of name:* Groote Eylandt, Northern Territory (lat. 14°00'S, long. 136°30'E).

*Synonymy:* Largely comprised of the former ‘Groote Eylandt beds’ (Plumb and Roberts, 1965, 1992) with the addition of the old ‘Bickerton Volcanics’, most outcrops of which are now termed Bickerton Rhyolite.

*Distribution:* Groote Eylandt, Bickerton Island and adjacent smaller islands in Blue Mud Bay and minor occurrences on nearby mainland coastal areas in BLUE MUD BAY, PORT LANGDON, CAPE BEATRICE and ROPER RIVER.

*Constituent units:* Subdivided into two subgroups and nine formations. Listed below in stratigraphic order up the page. Alyangula Subgroup:

- Dalumbu Sandstone
- Bartalumba Basalt
- Alyinga Sandstone = Woodah Sandstone (possible lateral equivalents)

Bustard Subgroup:

- Milyakburra Formation = Milyema Formation (possible lateral equivalents)
- Bickerton Rhyolite
- Abarungkwa Sandstone
- Erringkarri Rhyolite

*Type sections/localities:* As for each component formation.

*Thickness:* The composite maximum thickness is about 1650 m.

*Lithology:* Volumetrically dominated by siliciclastic sedimentary rocks ranging from sandstone to boulder conglomerate. Interbedded with localised porphyritic rhyolite in the Bustard Subgroup and more consistent basaltic rocks in the Alyangula Subgroup.

*Depositional environments:* Predominantly fluvialite sedimentary components with subaerial volcanics. Some shallow marine intervals.

*Relationships and boundary criteria:* The group unconformably overlies the Grindall Formation and ~1840 Ma granites. The top of the unit is eroded and unconformably overlain by Cretaceous and Cainozoic rocks and sediments. Intruded by mafic dykes.

*Age:* Palaeoproterozoic.


**ERRINGKARRI RHYOLITE** (D.J. Rawlings, P.W. Haines and B.A. Pietsch)

*Derivation of name:* Erringkarri (GR PE2480), an Aboriginal place name located on North Bay, Bickerton Island, BLUE MUD BAY.

*Synonymy:* Formerly mapped as part of the now abandoned ‘Bickerton Volcanics’ (Plumb and Roberts, 1965, 1992).

*Distribution:* Outcrop restricted to shore of North Bay on Bickerton Island, BLUE MUD BAY.

*Upper boundary stratotype:* Southern shoreline of North Bay on Bickerton Island (lat. 13°45'S, long. 136°10'E; GR PE260790), where approximately 20 m of section is exposed.

*Thickness:* Known outcrops are about 20 m thick; the base is not exposed.

*Lithology:* Dark red, variably porphyritic (K-feldspar) rhyolite.

*Environment:* Terrestrial, probably formed large domes and coulées.

*Geomorphic expression:* Wave-cut platforms and cliffs along the coast beneath Abarungkwa Sandstone.


*Age:* Probably Orosirian (Palaeoproterozoic). The similar Bickerton Rhyolite, a little higher in the succession, has been dated at ~1815 Ma (Pietsch et al. 1994).

*Correlatives:* Considered to correlate with the ~1800-1840 Ma felsic volcanic suite widespread in northern Australia (Rawlings, 1994).

**BUSTARD SUBGROUP** (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

*Derivation of name:* Bustard Island (GR PE500850) in BLUE MUD BAY.

*Synonymy:* Formerly mapped as part of the now abandoned ‘Groote Eylandt beds’ (Plumb and Roberts, 1965, 1992).

*Distribution:* Bickerton Island, Bustard Island and northern-most islands north of Groote Eylandt.

**ABARUNGKWA SANDSTONE** (D.J. Rawlings, P.W. Haines and B.A. Pietsch)

*Derivation of name:* Abarungkwa (GR PE355875), an Aboriginal place name located on Bickerton Island, BLUE MUD BAY.

*Synonymy:* Formerly mapped as part of the now abandoned ‘Groote Eylandt beds’ (Plumb and Roberts, 1965, 1992).
**Distribution:** Northern half of Bickerton Island and on Bustard Island, BLUE MUD BAY.

**Lower boundary stratotype:** Southern shoreline of North Bay on Bickerton Island (lat. 13°45'S, long. 136°10'E; GR PE260790); approximately 12 m of section exposed.

**Upper boundary stratotype:** Covered interval at 13°46'S, long. 136°09'E (GR PE250775).

**Reference locality:** Isthmus between North Bay and South Bay on Bickerton Island, between lat. 13°45'00"S, long. 136°10'E and lat. 13°45'45"S, long. 136°10'E (GR PE260790 to PE260780).

**Thickness:** Most complete section at reference locality where it is estimated to be 100-150 m thick.

**Lithology:** White, coarse- to very coarse-grained, cross-bedded, pebbly, quartz-rich (lithic at base) sandstone; quartz-rich granule conglomerate; polymict pebble and cobble conglomerate; minor medium-grained quartz sandstone.

**Depositional environment:** High-energy braided fluvialite.

**Geomorphological expression:** Rugged, bare rocky ridges and coastal cliffs.

**Relationships and boundary criteria:** Lies unconformably on Grindall Formation. Locally overlies Eringkarri Rhylolite with erosional contact; overlain by Bickerton Rhyolite in South Bay area. Where Bickerton Rhyolite is absent the present unit is disconformably overlain by valley-fill conglomerate of the Milyakburra Formation. On Bustard Island it is intruded by Bickerton Rhyolite.

**Age:** Probably Orosirian (Palaeoproterozoic). The overlying Bickerton Rhyolite has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

**Correlatives:** Considered to correlate with the ~1800-1840 Ma felsic volcanic suite widespread in northern Australia (Rawlings, 1994).

**BICKERTON RHYOLITE** (D.J. Rawlings, P.W. Haines and B.A. Pietsch; name modified after Plumb and Roberts, 1965)

**Derivation of name:** Bickerton Island in BLUE MUD BAY.

**Synonymy:** Outcrops at type area previously mapped as the now abandoned ‘Bickerton Volcanics’ (Plumb and Roberts, 1965, 1992). Some other outcrops previously mapped as ‘Bickerton Volcanics’ are now assigned to other units.

**Distribution:** Bickerton Island and southern part of Bustard Island, BLUE MUD BAY.

**Type locality:** Northern edge of South Bay on Bickerton Island, lat. 13°46'30"S, long. 136°09'30"E (GR PE250770).

**Lower boundary stratotype:** Covered interval at lat. 13°46'S, long. 136°09'30"E (GR PE250775).

**Upper boundary stratotype:** Covered interval on eastern side of South Bay at lat. 13°48'30"S, long. 136°12'E (GR PE297735).

**Thickness:** Estimated maximum exposed thickness of 150-250 m.

**Lithology:** Red, porphyritic (K-feldspar) rhyolite.

**Environment:** Terrestrial, probably formed large domes and coulees.

**Geomorphological expression:** Low boulder-strewn hills.

**Relationships and boundary criteria:** On Bustard Island this unit intrudes the Abarungkwa Sandstone. On Bickerton Island it is inferred to locally overlie the Abarungkwa Sandstone and is overlain by the Milyakburra Formation.

**Age:** Orosirian (Palaeoproterozoic). Dated by SHRIMP single-zircon U-Pb techniques at ~1814 ± 8 Ma (Pietsch et al. 1994).

**Correlatives:** Considered to correlate with the ~1800-1840 Ma felsic volcanic suite widespread in northern Australia (Rawlings, 1994).

**MILYAKBURRA FORMATION** (D.J. Rawlings, P.W. Haines and B.A. Pietsch)

**Derivation of name:** Milyakburra community (GR PE290760), Bickerton Island in BLUE MUD BAY.

**Synonymy:** Formerly mapped as part of the now abandoned ‘Groote Eylandt beds’ (Plumb and Roberts, 1965, 1992).

**Distribution:** Bickerton Island, BLUE MUD BAY.

**Lower boundary stratotype:** Eastern side of South Bay (lat. 13°48'30"S, long. 136°12'E; GR PE297735).

**Reference locality:** South of Milyakburra community, on eastern side of South Bay, Bickerton Island (lat. 13°48'S, long. 136°12'E (GR PE297540).

**Thickness:** A maximum thickness of 40 m exposed in incomplete sections.

**Lithology:** Matrix- to clast-supported, polymict, coarse sand- to granule-matrix cobble and boulder conglomerate which is massive to cross-bedded; locally interbedded with granule conglomerate and medium- to very coarse-grained lithic sandstone.

**Depositional environment:** High-energy fluvial and alluvial fan environment. The facies probably represent a mixture of debris flow, talus and channel-base deposits.

**Geomorphological expression:** Prominent joint-controlled, bare rocky outcrops, commonly forming domal or mesa-like rocky ridges.

**Relationships and boundary criteria:** Erosional contact with underlying Bickerton Rhyolite and Abarungkwa Sandstone. No contact with overlying units is exposed.

**Age:** Probably Orosirian (Palaeoproterozoic). The underlying Bickerton Rhyolite has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

**Correlatives:** Considered to correlate with the ~1800-1840 Ma felsic volcanic suite widespread in northern Australia (Rawlings, 1994).

**MILYEMA FORMATION** (D.J. Rawlings, P.W. Haines and B.A. Pietsch)

**Derivation of name:** Milyema Island (GR PE720872), north of Groote Eylandt in PORT LANDINGON.

**Synonymy:** Formerly mapped as part of the now abandoned ‘Groote Eylandt beds’ (Plumb and Roberts, 1965, 1992).

**Distribution:** Northern extremities of Groote Eylandt, including Chasm Island, Jagged Head and adjacent small islands, BLUE MUD BAY.

**Upper boundary stratotype:** North coast of Chasm Island, lat. 13°39'30"S, long. 136°35'E (GR PE715898); includes 50 m of upper part of formation.

**Upper boundary reference locality:** Jagged Head (lat. 13°42'S, long. 136°45'E; GR PE890852).
Thickness: Exposed thickness of 50 m at boundary stratotype, probably significantly greater at some other localities. Lithology: Polymict basal granule to boulder conglomerate and interbedded coarse-grained pebbly lithic sandstone; pink, predominantly medium-grained sandstone with minor granule lenses.

Depositional environment: Lower units deposited in high-energy braided fluvialite and probably low-gradient alluvial fan-edge environments. Upper unit partly fluvialite and possibly shallow marine.

Geomorphic expression: Prominent rugged, joint-controlled, bare rocky outcrops.

Relationships and boundary criteria: Base not exposed, but abundance of porphyritic rhyolite and Grindall Formation clasts in lowest beds indicates close vertical or lateral proximity of these units. The upper contact with the overlying Alyangula Sandstone is erosional, but not angular.

Age: Probably Orosirian (Palaeoproterozoic). The underlying Bickerton Rhyolite has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

Correlatives: Considered to correlate with the ~1800-1840 Ma felsic volcanic suite widespread in northern Australia (Rawlings, 1994).

**Alyangula Subgroup** (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

**Derivation of name:** Alyangula community, Groote Eylandt (GR PE530675), in BLUE MUD BAY.

**Synonymy:** Formerly mapped as part of the now abandoned 'Groote Eylandt beds' (Plumb and Roberts, 1965, 1992).

**Distribution:** Groote Eylandt and closely associated islands of Blue Mud Bay (BLUE MUD BAY, PORT LANGLEY, CAPE BEATRICE and ROPER RIVER). Minor exposure of Woodah Sandstone on nearby mainland coastal areas.

**Constituent units:** In ascending order Alyangula Sandstone, Bartalumba Basalt and Dalumuba Sandstone on and around Groote Eylandt. The Woodah Sandstone on other islands and on the mainland is also included in the subgroup and is probably a lateral equivalent of the Alyangula Sandstone.

**Type sections/localities:** As for each component formation.

**Thickness:** Maximum thickness is developed on Groote Eylandt, where the estimated composite thickness is 1100 m.

**Lithology:** Predominantly sandstone and pebbly sandstone with minor pebble and cobble conglomerate, interbedded with basalt and dolerite (Bartalumba Basalt and thin basaltic unit in Dalumuba Sandstone).

**Relationships and boundary criteria:** The Alyangula Sandstone lies disconformably on the Milyenma Formation of the Bystard Subgroup. The Woodah Sandstone lies unconformably on the Grindall Formation and its intrusives, and is locally (Bickerton Island) inferred to overlie the Bystard Subgroup (contact not exposed). There is no exposed stratigraphic top to the subgroup (the youngest rocks of the Dalumuba Sandstone dip beneath the sea). Cretaceous and Cainozoic rocks and sediments lie unconformably over the subgroup in places.

**Age:** Probably Statherian (Palaeoproterozoic). The Bickerton Rhyolite in the underlying Bystard Subgroup has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

**Correlatives:** Possibly correlates with the lower Tawallah Group of the southern MacArthur Basin.

**Woodah Sandstone** (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

**Derivation of name:** Woodah Island (lat. 13°30'S, long. 136°09'E), BLUE MUD BAY.

**Synonymy:** Formerly mapped as part of the now abandoned 'Groote Eylandt beds' (Plumb and Roberts, 1965).

**Distribution:** Eastern BLUE MUD BAY. Main outcrops on Morgan, Burney and northern Bickerton Islands, Isle Woodah, Grindall Point and near Cape Barrow.

**Lower boundary stratotype:** Western side of Morgan Island, lat. 13°28'S, long. 136°05'E (GR PF183105).

**Thickness:** Thickest exposure is 50-60 m at Morgan Island, where the top is eroded.

**Lithology:** Isle Woodah- sandstone: pink and white, medium-grained, medium- to thick-bedded, flat- to cross-bedded, quartz rich.

Burney Island- basal cobble to boulder conglomerate: polymict, interbedded with coarse- to very coarse-grained, pebbly sandstone.

Bickerton Island- lower unit of mudstone: red-brown, micaceous, interbedded with medium- to coarse-grained sandstone, thin-bedded, ripples, desiccation crack. Upper unit of sandstone: white to pink, medium-grained, quartz-rich.

Cape Barrow- sandstone: coarse-grained and pebbly, grades into conglomerate: medium-bedded, cross-bedded, quartz-rich matrix, larger clasts polymict.

**Geomorphic expression:** Prominent joint-controlled, bare rocky outcrops.

**Relationships and boundary criteria:** Assigned to the base of the Alyangula Subgroup of the Groote Eylandt Group. Lies unconformably on Grindall Formation and its intrusives (Bradshaw Complex and Bukudal Granite). Outcrops tentatively identified as Woodah Sandstone are inferred to be overlain by Bartalumba Basalt on eastern Bickerton Island, although the contact is not exposed.

**Age:** Probably Statherian (Palaeoproterozoic), but not well constrained. A maximum constraint is provided by the ~1815 Ma age of the Bickerton Rhyolite (Pietsch et al. 1994), near the base of the underlying Bystard Subgroup.

**Correlatives:** Considered to be a lateral equivalent of the Alyangula Sandstone.

**Alyinga Sandstone** (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

**Derivation of name:** Alyinga Island (GR PE670817) in PORT LANGLEY.

**Synonymy:** Formerly mapped as part of the now abandoned 'Groote Eylandt beds' (Plumb and Roberts, 1965, 1992).

**Distribution:** Outcrops on northern Groote Eylandt, northern Winchelsea Island, North East Isles and on smaller islands to the immediate north and northeast, PORT LANGLEY and BLUE MUD BAY.
Lower boundary stratotype: Northern Groote Eylandt (north of Yirrmulanga at lat. 13°41'S, long. 136°35'E; GR PE715862).

Reference localities: Outcrop on a small island at lat. 13°41'30"S, long. 136°31'45"E (GR PE655857) and the northwestern part of Winchelsea Island thought to include the upper part of the formation (lat 13°44'S, long. 136°29'E; GR PE603807).

Thickness: Estimated to be of the order of 300 m thick.

Lithology: Thin basal polymict granule to boulder conglomerate and pebbly and cobbly sandstone; white, medium- to coarse-grained, locally pebbly, quartz-rich sandstone with very large trough cross-beds.

Depositional environment: High-energy braided fluviatile for most of the formation, changing to marginal marine near the top.

Geomorphic expression: Joint-controlled, bare rocky outcrops.

Relationships and boundary criteria: Disconformably overlies the Milyema Formation. Inferred to be overlain by Bartalumba Basalt, although there is a considerable covered interval at this level. Based on aeromagnetic evidence, it is intruded by magnetic (probably mafic) dykes.

Age: Probably Statherian (Palaeooproterozoic). The Bickerton Ryholite in the underlying Bustard Subgroup has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

Correlatives: Possibly correlates with the Yiuyintyi Sandstone of the Tawallah Group.

BARTALUMBA BASALT (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

Derivation of name: Bartalumba Bay on northern side of Groote Eylandt, BLUE MUD BAY.

Synonymy: Where previously differentiated it was mapped as the now abandoned ‘Bickerton Volcanics’ (Groote Eylandt) or as unnamed dolerite (Bickerton Island) by Plumb and Roberts (1965, 1992).

Distribution: Scattered small outcrops across northern Groote Eylandt. One small outcrop on eastern coast of Bickerton Island (PORT LANGDON and BLUE MUD BAY).

Upper boundary stratotype: Bluff Hill area (lat. 13°59'S, long. 136°44'E; GR PE877535); 20 m of rubbly section contiguous with contact.

Thickness: Cannot be accurately determined as base is not exposed, but a thickness in the order of 200-400 m can be inferred for northern Groote Eylandt. Probably thins to the west towards Bickerton Island.

Lithology: Amygdaloidal basalt.

Depositional environment: Subaerial flows.

Geomorphic expression: Very recessive. Top of unit crops out locally where protected by overlying scarps of Dalumbu Sandstone.

Relationships and boundary criteria: Part of the Alyangula Subgroup of the Groote Eylandt Group. Inferred to overlie Alyinga Sandstone. Overlain with structural concordance by Dalumbu Sandstone, but contact is not exposed.

Age: Probably Statherian (Palaeooproterozoic). The Bickerton Ryholite in the underlying Bustard Subgroup has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

Correlatives: May correlate with the Sly Creek Sandstone of the Tawallah Group.

DALUMBU SANDSTONE (P.W. Haines, D.J. Rawlings and B.A. Pietsch)

Derivation of name: Dalumbu Bay on southeastern side of Groote Eylandt, CAPE BEATRICE.


Distribution: Most outcrops on central and southern parts of Groote Eylandt. Also exposed on Connexion Island and southeastern Bickerton Island (PORT LANGDON, CAPE BEATRICE, BLUE MUD BAY and ROPER RIVER).

Lower boundary stratotype: Bluff Hill area (lat. 13°59'S, long. 136°44'E; GR PE877535), where the unit overlies Bartalumba Basalt. Approximately 80 m of sandstone above the boundary.

Reference area: Because of very gentle dips no single section through the formation exists. The nominated reference area comprises the main body of continuous outcrop of the unit on Groote Eylandt, an area of approximately 900 km², centred at about lat. 14°05'S, long. 136°35'E.

Thickness: Minimum thickness of ~500-1000 m exposed on Groote Eylandt. No stratigraphic top has been recognised.

Lithology: White to pink, medium- to coarse-grained, cross-bedded, quartz-rich, pebbly (mainly quartz) sandstones with granule lenses; very weathered, ferruginous basalt lava.

Depositional environment: Predominantly a braided fluviatile environment. Sand ridges preserved by a thin (<15 m) basalt flow probably represent deposition on a shallow shelf during a brief marine incursion across a coastal plain.

Geomorphic expression: Dissected plateau of joint-controlled, bare rocky outcrops.

Relationships and boundary criteria: Concordantly overlies Bartalumba Basalt, although contact is not exposed. The top of the unit is eroded and overlain unconformably by Cretaceous and Cainozoic rocks and sediments. Based on aeromagnetic evidence, it is intruded by magnetic (probably mafic) dykes.

Age: Probably Statherian (Palaeooproterozoic). The Bickerton Ryholite, low in the Groote Eylandt Group, has been dated by SHRIMP single-zircon U-Pb techniques at ~1815 Ma (Pietsch et al. 1994).

Correlatives: May correlate with the Sly Creek Sandstone of the Tawallah Group.