EXPLANATORY NOTES

BLUE MUD BAY SD53-7

P.W. HAINES\(^1\), D.J. RAWLINGS\(^1\), I.P. SWEET\(^2\), B.A. PIETSCH\(^1\), K.A. PLUMB\(^2\), T.L. MADIGAN\(^1\) and A.A. KRASSAY\(^2\)

1. Northern Territory Geological Survey
2. Australian Geological Survey Organisation
Haines, P. W. (Peter Wyatt)
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ABSTRACT

The BLUE MUD BAY* 1:250 000 scale mapsheet covers part of the eastern coastal region of Arnhem Land and adjacent islands in the Gulf of Carpentaria, including the northwestern corner of Groote Eylandt, in the Northern Territory. This is a largely undeveloped and sparsely populated area with a warm monsoonal climate, characterised by heavy seasonal rainfall. The entire area lies within the Arnhem Land Aboriginal Reserve.

BLUE MUD BAY covers several geological domains including the Palaeoproterozoic Arnhem Inlier and the Palaeo- to Mesoproterozoic McArthur Basin, representing ‘basement’ and ‘platform cover’ of the North Australia Craton respectively. Outliers of the Mesozoic Carpentaria Basin mantle the older rocks in places.

In the east, the Arnhem Inlier comprises the folded and locally metamorphosed turbiditic succession of the Grindall Formation, intruded by deformed granitoid and migmatite of the 1870 Ma Bradshaw Complex. A similar association occurs in the poorly exposed Mirarrmina Complex in the northwest. These assemblages are considered to have been tectonically amalgamated during the Baramundi Orogeny, with post-orogenic igneous activity represented by minor unmaled volcanics and the 1836 Ma Bukudal Granite.

The Arnhem Inlier is unconformably overlain by the Groote Eylandt Group and Coast Range Sandstone in the east, and by the Donydi Group in the northwest, each representing the local base of the McArthur Basin succession in their respective areas. The lower Groote Eylandt Group (Bustard Subgroup) contains siliciclastic rocks and rhyolite dated at 1814 Ma suggesting correlation with the younger ‘Transition phase’ volcanics elsewhere in northern Australia. The conformably overlying siliciclastic and mafic igneous rocks of the upper Groote Eylandt Group (Alyangula Subgroup) probably correlate with the lower Donydi Group. This group also correlates with the lower Tawallah and Katherine River Groups elsewhere in the basin. The Fagan Volcanics of the upper Donydi Group are dated at 1710 Ma, correlating with a widespread phase of igneous activity throughout the basin, which may also be represented by rhyolite dykes in the east of BLUE MUD BAY.

The Fagan Volcanics are conformably overlain by the Parsons Range Group, which crops out extensively in the Parsons Range and southern Mitchell Ranges. The group reaches 5-6 km in thickness and is dominated by quartzarenite, although minor mudstone and carbonate rocks are also present. Isolated outcrops assigned to the Coast Range Sandstone and Jakma Formation in the eastern part of the mapsheet may represent attenuated equivalents of the Parsons Range Group, but could be younger.

The conformably overlying Balma Group has a maximum composite thickness of 4.5 km. The group is comprised of mudstone, stromatolitic and evaporitic carbonates, sandstone and minor conglomerate. It is correlated with the McArthur Group of the southern McArthur Basin and the Hahgood Group in ARNHEM BAY-GOVE to the north. Outcrop is generally poor and the rocks are strongly altered by surface leaching and silicification. Dates of 1621 Ma and 1600 Ma have been obtained from tuffaceous rocks in the upper part of the group.

Scattered silicified outcrop of the Balbirini Dolomite of the Nathan Group is found in the southwestern corner of BLUE MUD BAY and west of Coast Range. Minor outcrop of the laterally equivalent Dook Creek Formation of the Mount Rigg Group is found in the northwest.

The clastic-dominated Roper Group forms the youngest succession of the McArthur Basin, unconformably overlying the Nathan and Mount Rigg Groups near the western margin of the sheet. This cyclic marine succession is relatively thin in BLUE MUD BAY in comparison to areas further south. The Roper Group was intruded by thick mafic sills prior to the final deformation of the McArthur Basin during the late Mesoproterozoic or Neoproterozoic.

Relatively thin and predominantly flat-lying marine and terrestrial Cretaceous strata occur as scattered erosional relics mantling older rocks across the mapsheet. The most extensive exposures occur as dissected plateaux between Parsons and Bath Ranges.

Cainozoic deposits cover about 50% of the land area of BLUE MUD BAY. These include older ferricrete and laterite deposits that are currently being dissected, as well as active alluvium and extensive active and relic coastal deposits.

Structurally, BLUE MUD BAY is dominated by the north-south trending Walker Fault Zone, major components of which were apparently periodically active during deposition of the McArthur Basin succession, at times creating shifting depocentres within the ‘Walker Trough’. Goyder impact structure, of post McArthur Basin age, lies within the Roper Group in the western part of the sheet.

The only economic mineral occurrence known in BLUE MUD BAY is the Cretaceous psilite sedimentary manganese deposit on Groote Eylandt in the far southeast of the sheet. This world-class deposit has been mined since 1967.

* Names of 1:250 000 and 1:100 000 scale mapsheet areas are given in large and small capitals respectively, e.g. BLUE MUD BAY, Koolatong.
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MAP

1:250 000 Geological Map of BLUE MUD BAY (SD53-7) in pocket
INTRODUCTION
By P.W. Haines

These explanatory notes describe the geology, geophysics and mineral resources of BLUE MUD BAY, a 1:250 000 scale mapsheet bounded by latitudes 13°00’S and 14°00’S, and longitudes 135°00’E and 136°30’E in the Northern Territory (Figure 1). The associated geological map includes a segment of the PORT LANGDON sheet (western half of Grey) appended to the northeast corner. In combination, it covers an area of about 13 500 km² on the east coast of Arnhem Land and adjacent islands, with about one third of the sheet area covered by sea of the western Gulf of Carpentaria. The remainder of the PORT LANGDON sheet is presented separately as part of the GROOTE EYLANDT REGION geological map (Pietsch and others, 1997), which overlaps the southeastern corner of BLUE MUD BAY.

The first edition geological map and explanatory notes of BLUE MUD BAY—PORT LANGDON was published in 1965 (Plumb and Roberts, 1965) following field mapping by the Bureau of Mineral Resources (BMR) in 1962. Geological mapping for this edition was undertaken by geologists from Northern Territory Geological Survey (NTGS) and Australian Geological Survey Organisation (AGSO, formerly BMR) under a National Geoscience Mapping Accord (NGMA) objective to geologically re-map the northern McArthur Basin. Field mapping was largely undertaken during the 1991 and 1992 dry seasons simultaneous with mapping of ARNHEM BAY—GOVE and GROOTE EYLANDT to the north and southeast. Minor additional mapping in the Groote Eylandt and Bicketton Island areas was carried out by NTGS in 1993.

Airborne magnetic and radiometric data (500 m line spacing, 100 m terrain clearance) were obtained over almost the entire sheet in surveys undertaken in 1989, 1990 and 1993. This data can be obtained from NTGS in digital format or as contour maps.

References to specific locations utilise Australian Map Grid coordinates. Such grid references are prefixed by letters GR (eg GR NF050100).

Habitation, access and land use

BLUE MUD BAY lies within the Arnhem Land Aboriginal Reserve. Human habitation is restricted to Alyangula and Angurugu townships which are linked by a sealed road and are serviced by regular commercial air flights. Other roads in the area are unsealed and generally passable only during the dry season. Airstrips at outlying communities are unsealed and are seasonably inoperable. On the mainland, the main access road runs across the middle of BLUE MUD BAY, linking Numbulwar, Ngukurr and Roper Bar to the south, with the Stuart Highway and Nhulunbuy, which lies to the north in ARNHEM BAY. Outstations on the mainland are linked to this access route, with the exception of those in the northeast which are linked directly to the main Nhulunbuy access road. Old exploration tracks have generally not been maintained but still provide limited four-wheel-drive access to some areas; however much of BLUE MUD BAY is essentially inaccessible to normal vehicular travel. During mapping helicopters were used for remote regions. The main industries are manganese mining on Groote Eylandt and commercial fishing in the Gulf of Carpentaria.

Climate and vegetation

BLUE MUD BAY has a humid monsoonal climate, with a distinct wet season from November to April, during which most of the annual rainfall occurs and unsealed roads are generally impassable. The dry season lasts from May to October. The area is at risk to tropical cyclones during the wet season. Long-term meteorological records have been kept at Angurugu, from 1921. The following statistics are summarised from the Bureau of Meteorology (1988). Angurugu has a mean annual rainfall of 1300 mm with an average of 84 raindays per year. January, February and March are the wettest months. Relative humidity remains high all year round. The daily maximum temperature varies from an average of 34.5°C in December to 28.4°C in July, while the average daily minimum ranges from 24.3°C in January and February to 14.4°C in July. The influence of southeast trade winds blowing across the Gulf of Carpentaria maintains high humidity and rainfall along the east coast of Arnhem Land well into the dry season in comparison to other areas in the northern part of Northern Territory. This influence decreases inland and does not appear to extend beyond Parsons Range. Most water courses are seasonal, with scattered water holes remaining during the dry season, but larger rivers such as Goyder, Koolatong, Mata Murta and Walker, flow year round.

Vegetation reflects the seasonal monsoonal climate, but pronounced geological control is also evident. Lowland areas are covered by open Eucalyptus woodland, with stands of native pine (Callitris sp) near the ranges. Flood plains and soils developed over recessive argillaceous formations and dolerite are covered by dense annual grass and pockets of scrub, but are relatively sparse in larger trees. Major watercourses are lined by tall eucalypts and paperbarks (Melaleuca sp). The coastal belt comprises unvegetated (apart from stands of mangroves in intertidal areas) tidal and supratidal flats flanked in part by grassy black-soil plains. Rocky sandstone hills and ranges such as Parsons Range support pockets of spinifex grass (Triodia sp), low shrubs and sparse trees between bare rocky outcrops. Perennial species are generally fire resistant and much of the annual growth, particularly near communities and roads, is burnt by Aboriginal fire practices during the dry season.

Physiography

The mainland areas of BLUE MUD BAY contain portions of three major physiographic subdivisions, the Arafura Fall, the Gulf Fall and the Coastal Plain (Plumb and Roberts, 1965; 1992: Figure 2). Parsons and Mitchell Ranges lie along the major drainage divide separating the Arafura Fall (dissected hilly country with drainage towards the Arafura Sea) from the Gulf Fall - similar terrain with drainage towards the Gulf of Carpentaria, including the rocky islands off shore. The coastal Plain comprises low relief areas adjacent to the coast but extends up to 90km inland along the southern edge of the
The Parsons and contiguous Mitchell Ranges form the major topographic relief. The bevelled tops of the ranges are relatively uniform height, with the highest measured point being 342 m above sea level (GR NF495398). The islands are generally rugged with relief to 100 m above sea level. The Bath Range forms a smaller dissected plateau with elevations to 190 m. Steep cliffs form along its western and northeastern margins, but to the southwest it merges gently with the Yarrawirrie Plains.

Most major watercourses originate in the Parsons and Mitchell Ranges. The Goyder River and its tributaries drain the Aratula Fall, while the Koolatong, Walker and Rose River systems and Harris Creek drain the Gulf Fall. Smaller creeks and rivers drain the Coastal Plain. Tidal water may extend 15 km inland in the case of Walker River.

### Terminology and rock classification

The terminology for rock-types follows the scheme for ARNHEM BAY–GOVE (Rawlings and others, 1997) and MOUNT YOUNG (Haines and others, 1993). Field classification of siliciclastic sedimentary rocks is based essentially on grainsize and composition (e.g., medium-grained lithic sandstone). Petrological classification follows Folk (1974) (e.g., sublitharenite).

Carbonate rock terminology is based on grainsize. Dolomutite is composed of mud-size dolomite grains, dolarenite of sand-size dolomite grains and dolorudite of dolomite grains larger than 2 mm. The modifier ‘siliciclastic’ refers to small (5-25%) quantities of sand- and mud-sized siliciclastic (mainly quartz) components. Oligomudstone. On the map, the modifiers ‘sandy’ and ‘muddy’ indicate this same siliciclastic component, but specify a grainsize range (e.g., muddy dolomitite). Dolostone is a general term for rock composed mainly of the mineral dolomite and is not necessarily of intraclastic origin. Because many surface outliers of carbonate rocks are leached and/or silicified, it is often not possible to determine the primary composition (whether dolostone or limestone). In these cases, the nonspecific term ‘carbonate’ is used.

Definition and classification of volcanic rocks follow the scheme set down by the International Union of Geological Sciences (Le Maitre, 1989). The terms basalt, microdolerite and dolerite are used in a non-genetic sense and do not imply extrusive or intrusive origins. The terms flow, dyke and sill are used to infer origins. Description and classification of volcanic and volcanogenic deposits follows the schemes of McPhie and others (1993) and Cas and Wright (1987). The Proterozoic geological timescale proposed by the IUGS (Plumb, 1991) is used for chronostratigraphy.

The term ‘supersequence’ conforms to usage in ARNHEM BAY–GOVE and is applied informally and non-genetically. Each nominated supersequence refers to groups from various parts of the McArthur Basin, which are considered to be spatial or temporal correlatives, even though they may be widely separated. For instance, Supersequence 3 incorporates
the contemporaneous McArthur Group and the Balma and Habgood Groups in the southern and northern McArthur Basin respectively. This simplifies clumsy references to this package, and avoids the need for a formal sequence stratigraphic nomenclature at this time. As used here, 'supersequences' are not necessarily unconformity bound (cf. Krabez, 1996), although they commonly are, and do not imply periodicity or relationship with plate tectonic and supercontinent cycles (cf. Krabez, 1997; Winter, 1989; Haq and others, 1988). Only Supersequence 1 has been further subdivided (Supersequence 1A to D), each of which is constrained between sequence boundaries and is characterised by a strict internal lithofacies coherence. These may each comprise one or more formations.

The term 'rift' accords with the American Geological Institute glossary definition of "a long narrow continental trough bounded by normal faults". Furthermore, it is a zone of subsidence into which a relatively thick sequence was deposited. We do not imply a genetic model or a tectonic setting in using this term.

Previous geoscientific investigations and mineral exploration in BLUE MUD BAY are summarised in Table 1.

**REGIONAL GEOLOGIC SETTING**

By P.W. Haines and D.J. Rawlings

The regional geologic setting of BLUE MUD BAY with respect to immediately surrounding sheets is depicted in Figure 3. Three principal tectonostratigraphic components – the Arnhem Inlier (Palaeoproterozoic), and the McArthur (Palaeo-Mesoproterozoic) and Carpentaria (Cretaceous) Basins – are represented. The Neoproterozoic-Palaeozoic Arfakura Basin lies just to the north of the sheet. Arnhem Inlier and McArthur Basin comprise respectively the ‘basement’ and ‘platform cover’ of the Palaeo- to Mesoproterozoic North Australia Craton (Plumb, 1979) in BLUE MUD BAY.

The Arnhem Inlier, which has limited exposure in BLUE MUD BAY, comprises deformed Palaeoproterozoic sedimentary, metamorphic and igneous rocks which were affected by the 1870 Ma Barramundi Orogeny (Page and Williams, 1988). The inlier is probably continuous with similar rocks of the Pirie Creek Inlier to the west and the Murphy Inlier to the south, as well as some other basement terrains of northern Australia. The Barramundi Orogeny involved high-temperature-low pressure metamorphism and localised anatexis, with rapid gradation into unmetamorphosed rocks (Rawlings and others, 1997). Post-orogenic 1860-1810 Ma shallow-level granite batholiths with distinctive I- and A-type chemistry, and associated extrusive and epipelagic rocks, were emplaced into and overlie the various Barramundi terrains throughout the North Australian Craton (Wyborn and others, 1987). In BLUE MUD BAY these are represented by the 1840 Ma Bukudal Granite.
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<td>Matthew Flinders makes general geological notes around the BLUE MUD BAY coast.</td>
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<td>1818</td>
<td>P. King makes general geological notes around the BLUE MUD BAY coast.</td>
<td>King, 1826</td>
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<td>W. H. Fitton provides descriptions of samples (including Manganese ore from Groote Eylandt) collected by Flinders and King.</td>
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<td>H. Y. L. Brown visits Groote Eylandt and notes Manganese occurrence.</td>
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<td>W. F. Murphy leads a prospecting party and makes geological notes.</td>
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<td>Jensen, 1914</td>
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<td>Frome-Broken Hill Co. visit Groote Eylandt and makes geological observations.</td>
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<td>1960</td>
<td>P. R. Dunn (BMR) notes manganese at Anguraga</td>
<td>Plumb and Roberts, 1965</td>
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<td>1962</td>
<td>Reconnaissance aeromagnetic survey of Gulf of Carpentaria by Delhi Australian Petroleum Ltd includes part of BLUE MUD BAY.</td>
<td>Hartman, 1962</td>
</tr>
<tr>
<td>1962</td>
<td>Photogeology map of BLUE MUD BAY produced by BMR.</td>
<td>Ruker, 1962</td>
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<td>1962</td>
<td>BLUE MUD BAY mapped geologically by BMR.</td>
<td>Plumb and Roberts, 1965</td>
</tr>
<tr>
<td>1965</td>
<td>Publication of 1st edition of BLUE MUD BAY geological map sheet and explanatory notes by BMR.</td>
<td>Plumb and Roberts, 1965</td>
</tr>
<tr>
<td>late 1960's-1974</td>
<td>BHP exploration</td>
<td>BHP, 1972a, b; 1973; 1974</td>
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<tr>
<td>1967</td>
<td>BMR gravity survey of BLUE MUD BAY.</td>
<td>Whitworth, 1970</td>
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<td>1978</td>
<td>BMR aeromagnetic and radiometric survey of BLUE MUD BAY.</td>
<td>BMR, 1978</td>
</tr>
<tr>
<td>1992</td>
<td>Publication of Geology of Arnhem Land, Northern Territory by BMR, a summary of field data collected in the 1960's.</td>
<td>Plumb and Roberts, 1992</td>
</tr>
<tr>
<td>1991-1993</td>
<td>Field work in BLUE MUD BAY by the NGMA party.</td>
<td>This report</td>
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<tr>
<td></td>
<td>Detailed aeromagnetic and radiometric survey over BLUE MUD BAY by NTGS.</td>
<td>This report</td>
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and minor undifferentiated intrusives and unnamed extrusives in the Coast Range area. Extrusives from the youngest part of this phase are present within the basal McArthur Basin succession of the lower Groote Eylandt Group (Bustard Subgroup).

BLUE MUD BAY straddles the eastern margin of the northern McArthur Basin, an extensive cover sequence that unconformably overlies the Arnheim Inlier and its lateral equivalents. Basinal rocks cover an area of 180,000 km² in a northwest trend from the Queensland-Northern Territory border, along the west coast of the Gulf of Carpentaria, to the north coast of Arnhem Land. Its subsurface extent beneath younger cover sequences is poorly known and it is almost certainly continuous with other platform covers in northern Australia. Regional geology of the McArthur Basin is summarised by Plumb and others (1990), who also suggest correlations with other Proterozoic basins. The geology of the southern McArthur Basin is detailed in Jackson and others (1987), Pietsch and others (1991) and Haines and others (1993). Geology of the northern part of the basin is summarised in Plumb and Roberts (1992). Recent amendments to regional basin stratigraphy are provided by Pietsch and others (1994).

The main tectonic elements of the McArthur Basin (Figure 4) were defined by Plumb and Derrick (1975) and refined by Plumb and others (1980, 1981, 1990) and Plumb and Wellman (1987). The 50-80 km wide Batten (south) and Walker (north) Fault Zones lie serially in a north orientation through the centre of the outcropping McArthur Basin succession, and are separated by the east trending Urapunga Fault Zone. Plumb and others (1980, 1981) interpreted the north trending fault zones as sites of former syn-depositional graben or half graben, the Batten and Walker Troughs respectively. More stable regions, generally preserving attenuated successions, flank the fault zones. These are the Bauhinia (west) and Wearyan (east) Shelves, in the southern McArthur Basin, and the Arnhem (west) and Caledon (east) Shelves in the north. BLUE MUD BAY contains parts of the southern Arnhem and Caledon Shelves separated by the southern Walker Fault Zone.

The McArthur Basin comprises a thick (10-12 km in the troughs: Plumb and Wellman, 1987) succession of largely unmetamorphosed sedimentary and lesser volcanic rocks, deposits in a variety of intracratonic shallow-marine, lacustrine, fluvial and aeolian settings. It can be subdivided into five depositional phases, and may be better considered a composite of several superimposed basins with different tectonic controls and different depocentres. Rawlings and others (1997) have referred to these depositional phases informally as supersequence 1-5 (see note under 'Terminology and rock classification'). All of these supersequences are represented in BLUE MUD BAY.

Supersequence 1 (1815-1710 Ma) comprises the Donydi and Groote Eylandt Groups in BLUE MUD BAY. Elsewhere it includes the Spencer Creek Group of the Caledon Shelf in ARNHEM BAY–GOVE, Katherine River Group of the Arnhem Shelf to the west and Tawallah Group of the southern McArthur Basin. This succession, locally up to 6 km thick, is characterised by fluvial to shallow-marine siliciclastic rocks, minor carbonate rocks and intercalated felsic and mafic volcanic sequences and their intrusive equivalents. Rawlings and others (1997) further subdivide the package into supersequence 1A-1D.

The oldest, supersequence 1A, comprises the 1815 Ma fluvial and felsic volcanic succession of the Bustard Subgroup in BLUE MUD BAY. The age equates these rocks with the similar Edith River Group, which is exposed in western McArthur Basin and previously was considered part of the basement. In BLUE MUD BAY, there is only a minor stratigraphic break between this succession and similar overlying rocks assigned to supersequence 1B. For this reason, the Bustard Subgroup is considered part of the McArthur Basin.

Supersequence 1B comprises the lower two thirds of the Tawallah and Katherine River Groups, and in BLUE MUD BAY is represented by the Alyangula Subgroup. It is characterised by basal fluvial siliciclastic rocks grading up into a shallow-water mixed siliciclastic and carbonate succession. Widespread flood basalts are present and are represented by Bartlamba Basalt in BLUE MUD BAY.

Supersequence 1C is a thinner transgressive succession of mudstone, carbonate and sandstone, comprising the middle to upper parts of Tawallah and Katherine River Groups. In BLUE MUD BAY, the Dhunganda Formation of the lower Donydi Group probably belongs to supersequence 1C, as does the lower Spencer Creek Group of ARNHEM BAY–GOVE.

Supersequence 1D includes a mixed package of coarse to fine lithic siliciclastic rocks associated with felsic and mafic volcanic rocks and their intrusive equivalents. This supersequence forms the top of the Tawallah and Katherine River Groups and the upper volcanic part of the Spencer Creek Group. In BLUE MUD BAY, it is represented by Ritarango Formation and Fagan Volcanics of the medial to upper Donydi Group, and probably by the Gadabara Volcanics and unnamed felsic dykes in the Coast Range area. The volcanic components were typically emplaced at around 1710-1725 Ma.

Supersequence 2 comprises the 5-6 km thick siliciclastic Parsons Range Group which is only known from the Walker Fault Zone in BLUE MUD BAY and ARNHEM BAY–GOVE. Coast Range Sandstone (BLUE MUD BAY) and Rorrurwuy Sandstone (ARNHEM BAY–GOVE) may represent attenuated rift–margin equivalents. Contacts above and below appear to be formable, but elsewhere in the basin this interval is represented by a significant hiatus commonly with evidence of considerable uplift and erosion.

Supersequence 3 is essentially restricted to Walker and Batten Troughs and includes Balma Habgood Groups in the north and McArthur Group of the southern McArthur Basin. Only Balma Group is represented in BLUE MUD BAY, although the thin Jalma Formation is probably a trough-
margin equivalent. These groups, which comprise up to 5 km of evaporite carbonates, mudstone and sandstone facies, were apparently deposited in tectonically active graben. Evidence of syndepositional faulting is common in all areas and may be responsible for the generation of local and regional hiatuses within the package. Tuffaceous rocks are commonly present and ages of 1640 to 1600 Ma have been obtained from the medial and upper parts of supersequence 3.

Supersequence 4 comprises the widespread Nathan Group (over most of the McArthur Basin) and Mount Rigg Group (Arnhem Shelf) typically 1 km thick or less. These successions display similar facies to supersequence 3, but are more widely distributed, having been deposited in a sag-basin setting. In most areas, there is a well developed hiatus at the base of supersequence 4, which is overlain by a transgressive siliciclastic unit. However, in southern BLUE MUD BAY it is possible that a conformable relationship exists with Balma Group.

The youngest tectonostratigraphic package of the McArthur Basin is supersequence 5, consisting of the Roper Group in all areas. This cyclic succession of marine mudstone and sandstone varies significantly in thickness, but has a constant stratigraphy across the basin, apparently representing another sag-basin phase. It is always unconformable on older
rocks - usually supersequence 4. Post-depositional mafic sills and dykes have been emplaced into supersequence 5 and older units in most parts of the basin and are well represented in BLUE MUD BAY. However, outcrop is uncommon and distribution of these intrusions is inferred from geophysics. These were emplaced during a regional extensional event prior to the Post-Roper Inversion; a major period of shortening which uplifted and deformed the entire McArthur Basin. The age of this inversion is not well constrained but preceded late Neoproterozoic sedimentation in areas beyond BLUE MUD BAY.

Late Neoproterozoic to Palaeozoic successions fill a number of basins and occur as scattered outliers across northern Australia. None are recognised in BLUE MUD BAY, the nearest being represented by the Arafura Basin which unconformably overlies McArthur Basin rocks just to the north in ARNHEM BAY–GOVE (Rawlings and others, 1997). There is no depositional record between early Palaeozoic and Cretaceous anywhere in the McArthur Basin region.

Relatively thin marine and terrestrial Cretaceous deposits are widespread across northern Australia. Such deposits in BLUE MUD BAY represent erosional outliers of the Carpentaria Basin, which contains thicker successions offshore beneath the Gulf of Carpentaria. Deep weathering profiles and regolith are a widespread feature of the basal Cretaceous unconformity, which is partly responsible for much near-surface weathering in the region. Cainozoic laterite, sand and soil, including active alluvium and coastal deposits form a widespread veneer on older rocks throughout Arnhem Land. These constitute about 50% of the land area of BLUE MUD BAY.

STRATIGRAPHY

The stratigraphy of BLUE MUD BAY is divided into three principal tectonostratigraphic units – Arnhem Inlier, McArthur Basin and Carpentaria Basin – each of which is described below.

ARNHEM INLIER

The Arnhem Inlier is a composite of older (1870 Ma) sedimentary, metamorphic and anatetic rocks (Grindall Formation, Bradshaw and Mirarrmina Complexes), a younger (1840 Ma) batholith of shallow-level granites (Bukudal, Giddy, Garrthalala and Dhalinybuy Granites), and minor undifferentiated volcanic and intrusive rocks. The Grindall Formation, which is thought to be at least a partial protolith for the Bradshaw Complex, is only exposed in BLUE MUD BAY. The Bradshaw Complex and 1840 Ma granite plutons are sporadically exposed along the eastern coast of Arnhem Land from Gove Peninsula (ARNHEM BAY–GOVE) to the mouth of Koolatong River (BLUE MUD BAY). Only Bukudal Granite is exposed in this mapsheet. The Mirarrmina Complex is restricted to a small meridional-oriented block on the western margin of Mitchell Ranges. Lithology and stratigraphic relationships of these components are summarised in Table 2 and described below.

PALAEOPROTEROZOIC–OROSIRIAN

Grindall Formation (2w)

By P.W. Haines

The Grindall Formation, a deformed and locally metamorphosed sequence of interbedded sandstone and mudstone, is the oldest rock unit known in BLUE MUD BAY. Outcrop is restricted to the eastern flank of Coast Range and to small areas around Morgan, Burney and Bickerton Islands, and other small islands in this vicinity. However, the abundance and widespread occurrence of Grindall-derived clasts in the Groote Eylandt Group suggests that Grindall Formation represents the principal basement over much of eastern BLUE MUD BAY. It is unconformably overlain by various units of Groote Eylandt Group, Coast Range Sandstone and locally by Jalma Formation and unnamed volcanics along the southern Coast Range. Grindall Formation is intruded by granite of the Bradshaw Complex, but is thought to be a partial protolith for, and hence be contiguous with, the metamorphic component of the complex. It is also intruded by Bukudal Granite and felsic and mafic dykes of various ages.

Originally termed ‘Grindall Metamorphics’ (Plumb and Roberts, 1965; 1992), the unit was renamed Grindall Formation by Pietsch and others (1997) when it was recognised that metamorphism is a localised feature of the sequence. Plumb and Roberts (1992) nominated a type section at the eastern end of Morgan Island (around GR PF195103). Here the sequence is folded, mostly steeply dipping (Plate 1), and to the immediate west of the section is intruded by Bukudal Granite and unconformably overlain by flat-lying Woodah Sandstone. As no stratigraphic base or top can be defined, no reliable thickness can be estimated, but the formation probably exceeds 1000 m.

The Grindall Formation is well exposed on the wave cut shores of the above-specified islands. Outcrop is dominated by discrete beds of thin- to medium-bedded (occasionally thick-bedded), fine- to medium-grained, micaceous sandstone, rhythmically intercalated with mudstone. When fresh, the sequence varies from grey-green to reddish-brown. Sandstone beds are generally sharp-based and tend to exhibit a degree of grading as well as transitional contact with overlying mudstone. The lower part of individual sandstone beds is generally massive, while planar- and cross-lamination is present in the finer tops. Thick- to very thick-bedded massive sandstone with closely spaced, sub-parallel, water escape structures has been observed in places. Outcrops on the islands exhibit tight to open folding and, in some places have a notable cleavage, but have not been metamorphosed.

In contrast, outcrops along the Coast Range display low grade regional and local contact metamorphism. Metasandstone is interbedded with phyllite and quartz-sericite schist in the northern part of Coast Range. Small altered
<table>
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<tr>
<th>UNIT and MAP SYMBOL</th>
<th>LITHOLOGY</th>
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<th>STRATIGRAPHIC RELATIONSHIPS</th>
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<tr>
<td>Bukudal Granite (Pgk)</td>
<td>Granite, massive, white to pink, equigranular, medium- to coarse-grained; composed of quartz, K-feldspar, plagioclase, biotite and fayalite; locally sheared.</td>
<td>Fayalite-bearing; reddened spherical inclusions.</td>
<td>Intrudes Brashaw Complex and Grindall Formation. Intruded by 71710 Ma rhyolite dykes. Unconformably overlain by Woodah Sandstone.</td>
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<tr>
<td>Undifferentiated Volcanics (Px)</td>
<td>Rhyolite, grey, porphyritic, sugary, contact-metamorphosed; phenocrysts of quartz, plagioclase, K-feldspar and pyroxene.</td>
<td>Sugary texture in hand specimen; in outcrop resembles intrusive microgranite.</td>
<td>Probably unconformable on Grindall Formation. Unconformably overlain by Coast Range Sandstone. Probably intruded by Bukudal Granite.</td>
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<tr>
<td>Mirrminna Complex (Py)</td>
<td>‘Older’ component: Gneiss, metasedimentary rocks, granite, migmatite; commonly foliated. ‘Younger’ component: rhyolite, porphyritic microgranite and dolerite dykes.</td>
<td>Amphibolite facies garnet-dominated assemblages; retrogressed along shear zones to greenschist facies.</td>
<td>‘Older’ high-grade metamorphic and anatectic rocks intrude metasedimentary rocks. ‘Younger’ felsic and mafic dykes intrude these ‘older’ units. Unconformably overlain by Donydi Group.</td>
</tr>
<tr>
<td>Grindall Formation (Pw)</td>
<td>Sandstone, red-brown to grey-green, fine- to medium-grained, thin- to thick-bedded, graded; interbedded with red-brown to grey-green mudstone.</td>
<td>A deformed and locally metamorphosed turbidite sequence.</td>
<td>Oldest known component of the Arnhem Inlier. No base exposed. Intruded by granites of Brashaw Complex and Bukudal Granite, and by various mafic and felsic dykes. Apparently contiguous with metamorphics of Brashaw Complex. Overlain unconformably by various units of the Groote Eylandt Group, Coast Range Sandstone, Jalma Formation and undifferentiated volcanics.</td>
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Porphyroblasts, possibly originally andalusite, are present in the schist. Most of the sequence is red-brown, and somewhat ferruginous, but pale green quartz-rich schist is observed in places. Outcrop is too poor to accurately determine the scale of bedding or to trace marker units, but structural measurements suggest that the sequence is tightly folded. Pelitic rocks have developed a steeply dipping northwest trending foliation. Quartz veins are common throughout the sequence. The average grain size of the sandstone (medium- to coarse-grained) appears to be coarser than that on the islands and beds are probably much thicker or occur in amalgamated packets. East-trending spurs along the flank of Coast Range are composed of the more resistant metasandstone, while the valleys are cut into units dominated by pelitic rocks.

At the southern end of Coast Range, the original fabric has been largely destroyed by contact metamorphism adjacent to the Brashaw Complex. Though more psammitic and pelitic facies can be identified the rocks are massive and all contacts are diffuse. Small haematitic spots are common in these purple-grey to green-grey rocks.

Due to poor exposure and a lack of datable rocks, the age and stratigraphic relationships of the Grindall Formation are largely unresolved. Currently, a minimum age of 1870 Ma is constrained by granite of the Brashaw Complex (U-Pb SHRIMP zircon; Rawlings and others, 1997), which intrude the formation. As the base of the unit has not been identified and no detrital geochronological studies have been carried out, there is no maximum age available for the Grindall Formation. Based on lithofacies and structural comparisons,
correlation is suggested between Grindall Formation and sedimentary and metasedimentary rocks of Mirarrmina Complex, and Pine Creek and Murphy Inliers. An inferred age of 1885–1870 Ma for the Grindall Formation is derived by tenuous correlation with the lithologically similar Burrell Creek Formation of the Pine Creek Inlier. This latter formation lies conformably on the tuffaceous Gerowie Tuff (1885±2 Ma; Needham and others, 1988) and was metamorphosed during the Barramundi Orogeny (1870–1890 Ma; Page and William, 1988).

Grindall Formation is considered to represent a turbidite sequence probably deposited in a rapidly subsiding basin prior to the Barramundi Orogeny. Although the sequence along Coast Range is too poorly exposed and altered for any detailed sedimentological analysis, it would appear from grain size and thickness trends to be more proximal than outcrop on the islands.

Bradshaw Complex (P.x)

By P.W. Haines and T.L. Madigan

The term Bradshaw Complex was first used by Dunnet (1965) for a complex of deformed granite, granitic gneiss, migmatite and paragneiss in eastern ARNHEM BAY–GOVE. The name was later formalised by Plumb and Roberts (1992). Plumb and Roberts (1992) and Madigan and Rawlings (1994) recognised several informal subdivisions, while Rawlings and others (1997) have simplified and formalised the subunit classification, defining the Melville Bay Metamorphics and Drimmie Head Granite.

Bradshaw Complex has not previously been recognised in BLUE MUD BAY. Outcrop now assigned to Bradshaw Complex is generally included in the old ‘Grindall Metamorphics’ by Plumb and Roberts (1965), except for minor outcrop on Round Hill Island, which is included in the old ‘Bickerton Volcanics’. Outcrop is restricted to small areas along the southern Coast Range near Mount Grindall and on Round Hill Island. The formal subdivisions in ARNHEM BAY–GOVE have not been recognised in BLUE MUD BAY and consequently Bradshaw Complex remains undivided.

Granitic and gneissic rocks near the southern end of Coast Range comprise several distinct phases, only the older of which may represent true Bradshaw Complex. However, due to the small size of the area, no attempt has been made to differentiate it at map scale and it is all mapped as undivided Bradshaw Complex. Rocks at the northern end around GR NF862023 are gneissic and contain a metamorphic assemblage of sillimanite-andalusite–cordierite–hercynite spinel suggesting upper amphibolite metamorphism. The exposure consists of weathered bare and dolomitic outcrop beneath the unconformably overlying Coast Range Sandstone. The rocks show a weak foliation and are cut by several generations of aplite veins. To the south, relatively small outcrops of garnet- and olivine-bearing, fine- to medium-grained, biotite granite may represent an equivalent of Bukudal Granite and are probably intrusive into Bradshaw Complex.

Further south (near GR NF860015), a weathered pink granitoid has apparently intruded the biotite granite. This situation may be analogous to the Garrthalala Granite, which intrudes Bradshaw Complex and probably Bukudal Granite in ARNHEM BAY–GOVE (Rawlings and others, 1997). Bradshaw Complex and probable younger intrusives are surrounded by outcrops of Grindall Formation. To the north, the contact with low grade metamorphic Grindall Formation, which crops out 1.5 km beyond the northern-most gneissic exposure, has not been observed. To the south around GR NF860010, a complex and poorly exposed contact between granitic and pegmatitic rocks and contact metamorphosed Grindall Formation occurs. The contact involves chaotic pegmatitic and metasedimentary lithologies and it is uncertain if it involves true Bradshaw Complex or the inferred later intrusive phases.

Outcrop around Mount Grindall and Round Hill Island is composed of rounded boulders of equigranular, massive to banded, biotite-quartz-K-feldspar-garnet rock, interpreted to be granite and migmatite. Banding appears to take two forms;
as relict sedimentary layering and lamination; and widely
spaced (10-100 cm) segregations of refractory and non-
refractory minerals. Sporadic small discordant pods of quartz-
K-feldspar pegmatite probably represent locally mobilised
metamorphic melts. These outcrops are unconformably
overlain by Coast Range Sandstone and probable Woodah
Sandstone. The outcrop on Round Hill Island is intruded by
Gadabara Volcanics.

In ARNHEM BAY-GOVE, garnet-bearing granite within
the Bradshaw Complex has been dated at 1867±12 Ma using
SHRIMP U-Pb single zircon techniques (R. Page, pers.
comm.; Rawlings and others, 1997). This date indicates
affinity with the Barramundi Orogeny (Page and Williams,
1988).

The Bradshaw Complex is thought to be the result of
varying degrees of in situ partial melting of a metasedimentary
protolith that generated inhomogeneous partial melts
(pegmatite) through to heterogeneous granite. In ARNHEM
BAY-GOVE, Rawlings and others (1997) consider that the
Melville Bay Metamorphics and the enclaves within both
Drimmie Head Granite and undivided Bradshaw Complex
represent metamorphosed equivalents of this sedimentary
protolith. Metamorphics of Bradshaw Complex appear to be
laterally contiguous with Grindall Formation, which as a
result, may represent the partial protolith.

Mirarrmina Complex (Ey)

By K.A. Plumb and D.J. Rawlings

The Mirarrmina Complex is a composite of structurally-
amalgamated stratigraphic blocks of various age and lithology,
which cannot be resolved at the map scale. It comprises four
main components: metamorphic and anatectic granitoid
basement rocks; intrusive equivalents of the Donydji Group;
structurally intercalated strips of Donydji and probable Parsons
Range Groups; and younger dolerite dykes. The Mirarrmina
Complex outcrops poorly over a small area (<450 km²) along
the western margin of Mitchell Ranges, centred on the aboriginal
community of Donydji. Its main area of outcrop occurs in
southern ARNHEM BAY-GOVE, but a small portion extends
into northern BLUE MUD BAY.

The complex occupies the sole thrust zone of the Mitchell-
Flinders Thrust Belt and all components of the complex, except
the younger dolerite dykes, are overprinted by deformation
related to the Post-Nathan Shortening event. Deformational
products range from weak to intense cataclasite or mylonite;
almost all primary fabrics have been destroyed. The magnetic
expression of the complex is dominated by faults and lineaments
of the thrust belt. The age range of Mirarrmina Complex has
been confirmed by SHRIMP U-Pb geochronological analysis
of individual zircon grains by R. Page (pers. comm., 1996).
The metamorphic and anatectic basement rocks are 1870 Ma,
similar to the Bradshaw Complex, while younger felsic
intrusives are 1710 Ma, similar to the Fagan Volcanics.

The unit was originally named the Mirarrmina Complex by
Dunnet (1965), after Mirarrmina Creek which flows westwards
from the complex. This followed informal use of the now invalid
term 'McClaren Complex' by Crohn (1956). Plumb and Roberts
(1992) formally defined the unit and nominated the entire
mapped area as the type locality. Despite the new mapping,
poor outcrop and structural complexity inhibit the interpretation
of its geological framework and it thus remains a 'complex'.
The following description is drawn from Plumb and Roberts

The Mirarrmina Complex is typically recessive, and areas
of outcrop and subcrop display dark red and brown aerial
phototones. In ARNHEM BAY-GOVE, much of the outcrop
comprises discrete areas of metasedimentary and granitoid
basement. However, high-level mafic and felsic intrusive
rocks, which relate to adjacent Donydji Group, occupy
extensive areas, particularly in the north. The complex also
incorporates structurally imbricated sedimentary and volcanic
rocks from the adjacent Donydji and Parsons Range Groups.
These imbricated zones could not be resolved at the scale of
mapping. Contacts between the Mirarrmina Complex and
Donydji Group in the Mitchell Ranges are not exposed, but
the Donydji Group is presumed to unconformably overlie
this unit (Rawlings and others, 1997). The boundary appears
to have been reactivated as a thrust or decollement.

Basement comprises metasedimentary rocks and
garnet gneiss. Metasedimentary rocks are abundant in the
north and northeast, from about Donydji outstation
northwards, and granite gneiss is the dominant rock-type
from Donydji south.

The principal metasedimentary rock is amphibolite-
grade granofels that has been locally retrogressed to
greenschist-grade quartz-sericite schist and phyllonite
along shear-zones associated with Post-Nathan
Shortening. These low-grade rocks are not metamorphic
equivalents of the granofels, as suggested by Plumb and

The least altered granofels have assemblages such as
garnet-orthoclase-biotite-plagioclase-cordierite-quartz,
garnet-microcline-albite-quartz-biotite-sericite, and
muscovite-biotite-quartz-sericite-plagioclase. Fabrics are
granofelsic, with a weak foliation. Most minerals show
minor retrogression to sericite, chlorite and epidote, and
cordierite is entirely altered to pinitie. These assemblages
are consistent with those of the Bradshaw Complex, which
are interpreted to reflect aluminous sedimentary protoliths.

Retrogressed equivalents include quartz-sericite schist
and phyllonite, in which relict traces of sillimanite, garnet,
muscovite, feldspar, and pinitised cordierite attest to
retrogression. An early relic penetrative foliation is
defined by trails of opaques. Pods of crushed quartz and
feldspar with sericite are strung out in a second non-
penetrative cleavage. Fold axes plunge steeply 015°,
sub-parallel to a near-vertical axial-plane cleavage, which is
in turn parallel to, and indistinguishable from, the regional
cleavage of the Mitchell–Flinders Thrust Belt.

Granite gneiss comprises porphyroblastic
garnetiferous gneissic granite, augen gneiss, banded gneiss
and migmatite, and minor adammellite and granodiorite. Relationships between phases are ambiguous because of poor outcrop. Small bodies of even-grained granite intrude augen gneiss. Pelite and quartzite inclusions up to 2 m long are common. The garnetiferous gneissic granite is distinctly S-type and resembles the coeval Bradshaw Complex, particularly in the Mount Alexander-Port Bradshaw area (ARNHEM BAY-GOVE).

Gneiss and granite are compositionally uniform, comprising microperthitic K-feldspar, generally albite but occasionally oligoclase/andesine, quartz, biotite and garnet. Fabrics range from massive to foliated, even-grained to porphyroblastic and grain size varies from medium to coarse. Foliated rocks contain feldspar augen, with schistosity defined by mica and oriented megacrysts. These grade into banded gneiss and migmatite, in which intensely folded lithologic layering is defined by variations in composition (primarily mica content) and grain size. Equigranular micaceous gneiss grades into augen gneiss into massive porphyroblastic granite. Quartzite inclusions lie within schistosity, and lithologic layering is axial plane to root-folded in quartzite inclusions. Schistosity varies in orientation from sub-planar, sub-vertical and northerly-striking, to intensely and irregularly folded without obvious symmetry.

The younger intrusive units include porphyritic rhyolite, megacrystic microgranite and dolerite/gabbro. Rhyolite and microgranite make up the more resistant outcrop of the Mirralla Complex and tend to crop out along meridional trends as vertical dykes. Better outcrops comprise rounded weathered tors and exfoliating boulders of white to grey porphyritic rhyolite and megacrystic microgranite. These are made up of pink to white ovoid K-feldspar megacrysts, up to 4 cm in diameter, and lesser smaller quartz, set in a grey to green fine- to medium-grained equigranular or granophyric quartz-K-feldspar-plagioclase-biotite groundmass. They range between massive, foliated and cataclastic in texture, and are altered. Felspar and quartz phenocrysts are commonly resorbed and embayed. Rounded elongate xenoliths of metasedimentary rock, quartz-feldspar-biotite gneiss and amphibolite/gabbro up to 20 cm in length are common. Micaceous schlieren are present locally.

Dolerite and gabbro occur as isolated lenticular intrusions up to 6 km by 1.5 km, elongate parallel to the structural trend of the Mirralla Complex. These were encountered regularly during exploratory drilling in the late 1960s (McGregor, 1969; Hogan and Goode, 1971; BHP, 1972a). They are composed principally of ophitic to intergranular clinopyroxene and plagioclase, and are variably altered.

Unusual hybrid rocks are developed where bodies of porphyritic rhyolite and dolerite are in contact, and mafic xenoliths are abundant within rhyolite. Both rock-types are locally recrystallised to hornfels. K-feldspar phenocrysts within rhyolite have micrographic reaction rims, fracture-controlled replacements or cores of albite. The groundmass locally comprises hornblende, epidote, chlorite, biotite and albite. Similarly, the groundmass of mafic xenoliths is a mosaic of quartz and K-feldspar in symplectic intergrowth with skeletal hornblende. Mafic phenocrysts are replaced by deccussate biotite, and plagioclase is sericitised. Relationships are typical of coeval emplacement of bimodal magmas.

A geochronological, petrological and geochemical similarity exists between some of the younger intrusive rocks and the felsic and mafic igneous rocks of the nearby Fagan Volcanics.

The youngest rocks of the complex are dykes of massive, medium-grained, subophitic pyritic dolerite, composed of partly altered labradorite and augite with amphibole reaction rims. These dykes cut the rhyolite bodies and have not been affected by cataclasis associated with the Mitchell–Flinders Thrust Belt.

Most rocks within Mirralla Complex are foliated to varying degrees. While lithologic layering and folded schistosity of the granite gneiss are syn-metamorphic, the more planar schistosity is sub-parallel to, and difficult to separate from, the younger cataclastic overprint of the Mitchell–Flinders Thrust Belt. This later cataclastic cleavage occurs in all rocks of the complex except the youngest dolerite dykes. It cuts earlier lithologic layering obliquely, and deforms micaceous inclusions. The cleavage strikes 015° to 030° and dips steeply east, sub-parallel to cleavage that predominates in the adjacent Mitchell Ranges. Younger shear zones also strike 060°, on trend with cross-faults in Mitchell Ranges. Rotational features around K-feldspar and quartz megacrysts (augen) are common within the 1710 Ma porphyritic intrusives. Cataclasis increases in localised shear zones, with progressive crushing and granulation of grains down to microcrystalline mylonite or ultracataclasites. Intimate imbrication of the various components of the complex characterises shear zones in the north.

The basement metasedimentary and granitoid rocks are interpreted to be the metamorphic and anatectic products of amphibolite-grade metamorphism and granitisation at 1870 Ma (Barraamundi Orogeny; Etheridge and others, 1987). This event was concurrent with metamorphism of Bradshaw Complex to the east. Protoliths for these rocks are inferred to include spatial and temporal equivalents of sedimentary and perhaps igneous units of Grindall Formation (to the southeast) and Pine Creek succession (to the west). SHRIMP U-Pb zircon geochronological studies of garnet-biotite granite (R. Page, pers. comm., 1996) have confirmed the age of peak metamorphism of Mirralla Complex to be 1870±8 Ma, indistinguishable from that of Bradshaw Complex.

Younger rhyolite and dolerite bodies were emplaced into the metamorphic basement at shallow crustal levels, and are probably feeders to the adjacent Fagan Volcanics (R. Page (pers. comm., 1996)) confirmed this relationship, obtaining a SHRIMP U-Pb zircon date of 1705±10 Ma for one of the porphyritic microgranite dykes.

High-grade basement rocks were retrogressed to greenschist facies, and both basement and younger intrusive units were intensely sheared and cataclastically deformed,
within the sole zone of the Mitchell–Flinders Thrust Belt during the high-level Post-Nathan Shortening. The young dolerite dykes are correlated with the Post-Roper Extension and Dykes event, discussed in TECTONICS AND STRUCTURE.

Undifferentiated Volcanics (Pz)

By D.J. Rawlings

This unit is a thin (<100 m) unconformity-bounded sliver of porphyritic rhyolite exposed along the eastern side of Coast Range near GR NF886096. It probably lies unconformably over metamorphosed sandstone and mudstone of Grindall Formation and is overlain unconformably by Coast Range Sandstone. It is probably intruded by Proterozoic rhyolite dykes and Bukudal Granite.

The only fresh rock found are numerous small core-stones of dark grey-black, fine-grained, porphyritic quartz-feldspar-biotite rock. It contains rare xenoliths and mafic clots and in outcrop resembles intrusive microgranite. Phenocrysts of plagioclase (35%), pyroxene (5%), and minor K-feldspar, quartz and opaque oxide are set in a groundmass of quartz and lesser K-feldspar (total 50%). Metamorphic biotite is common (5%) as poikilitic masses in both the phenocryst and groundmass domains.

Plagioclase phenocrysts appear to range dramatically in composition from calcic varieties (andesine) to sodic types (albite). Exsolution features are ubiquitous, and include blebs and irregularly sutured segments of albite, quartz or K-feldspar within larger plagioclase phenocrysts. Pyroxene phenocrysts are anhedral to subhedral and weakly pleochroic, suggesting orthopyroxene. Quartz phenocrysts are embayed and inclusion-free. Biotite contains numerous spherical poikilitic inclusions of quartz, oxide and feldspar. It has an obvious metamorphic origin, partly replacing pyroxene and opaque oxides. The groundmass has a distinct polygonal fabric and exhibits poikilitic or sutured boundaries with quartz and feldspar phenocrysts.

Mineralogy and texture are consistent with contact metamorphism possibly relating to nearby unexposed Bukudal Granite. Metamorphism has obscured primary textures and evidence of mode of emplacement. However, by comparison with the petrologically similar but unmetamorphosed Scrutton Volcanics in MOUNT YOUNG (Haines and others, 1993), a pyroclastic mode is inferred. Lithology, metamorphism, geochemistry and stratigraphic position suggest correlation with the 1870-1800 Ma ‘Transitional phase’ of Rawlings (1994). It is better constrained by the inferred intrusive relationship with Bukudal Granite (1840 Ma), which may represent a slightly younger comagmatic intrusive. This allows correlation with 1870-1850 Ma igneous suites elsewhere in the region, such as Scrutton Volcanics. Correlation with the younger 1810 Ma Bickerton Rhyolite, appears unlikely.

Bukudal Granite (Egk)

By T.L. Madigan and P.W. Haines

The main outcrop area for Bukudal Granite is in the northeast corner of BLUE MUD BAY, occupying an area of 35 x 25 km around Myaoola Bay. Small granite outcrops immediately south on Morgan Island are also mapped as this unit. A possible minor occurrence at GR NF862020 along the Coast Range is too small to differentiate on the map and has been included in the Bradshaw Complex. Much of the outcrop now assigned to Bukudal Granite was previously mapped as Myaoola Granite and thought to be of similar age to Bradshaw Complex (Plumb and Roberts, 1965). The northern-most exposures in the mapsheet, and those on Morgan Island, were previously mapped as Caledon Granite. Current mapping demonstrates that these outcrops are the same lithology and belong to a single partly-unroofed granite body. Therefore, all outcrops previously assigned to Myaoola or Caledon Granite in BLUE MUD BAY are now mapped collectively as Bukudal Granite, in line with mapping by Rawlings and others (1997) north of the mapsheet boundary. The type locality for this unit has been defined in ARNHEM BAY–GOVE by Rawlings and others (1997).

Bukudal Granite is characteristically white to pink, medium- to coarse-grained, equigranular and massive. The mineralogy consists of quartz, K-feldspar, plagioclase and biotite with minor fayalite, orthopyroxene, clinopyroxene, hornblende and rare garnet, and accessory fluorite, spinel, magnetite, zircon and rutile. Secondary minerals include sercite, muscovite, chlorite and epidote. Grain boundaries are consertal. Bukudal Granite contains diagnostic red spherical xenoliths (up to 10 cm) with mafic cores. Rare miarolitic cavities are filled by biotite in coarser grained granite. Bukudal Granite is relatively undeformed throughout. However, outcrops around GR PF570550 have large-scale joint sets, the principle joints trending north and west-northwest, and there is evidence of minor shearing.

Bukudal Granite intrudes metamorphic and granitic rocks of the Bradshaw Complex in ARNHEM BAY–GOVE and appears to be coeval with Garrthalala Granite. This relationship may also occur around GR NF862020 in BLUE MUD BAY where possible equivalents of Bukudal and Garrthalala Granites apparently intrude Bradshaw Complex along the Coast Range (see ‘Bradshaw Complex’). These outcrops are too small to differentiate on the map. In BLUE MUD BAY, Bukudal Granite intrudes sandstone and mudstone of Grindall Formation and a well-exposed contact of this relationship occurs on Morgan Island. The contact is very irregular but apparently joint-controlled. Blocks of sandstone have been incorporated into the granite adjacent to the contact and there is only mild and localised contact metamorphism. Bukudal Granite is unconformably overlain by Woodah and Coast Range Sandstones. It is intruded by aplitic dykes and veins which may be part of the 1710 Ma magmatic event.

Three samples of Bukudal Granite from separate locations have SHRIMP U-Pb zircon ages of 1835, 1836 and 1837 (all ±4) Ma (R. Page, pers. comm.; Rawlings and others, 1997).
Figure 5 Stratigraphic relationships of units in the northern McArthur Basin.
Samples were collected at GR PF716612, PF558462 and PF565522 respectively. These are considered equivalents of the granites intruding the Pine Creek Geosyncline. Although no mineralisation has been recognised, they assume similar mineralisation potential.

Bukudal Granite has an A-type affinity (cf. White and Chappell, 1977). Many A-type granites have a bimodal association with mafic rocks (Turner and others, 1991) but there are no known outcrops of mafic rock associated with the Bukudal Granite. However, a strong magnetic anomaly is associated with it, which suggests mafic bodies exist at depth. Bukudal Granite is probably comagmatic with Giddy, Garrthalala and Dhalinybuy Granites in ARNHEM BAY–GOVE based on geochronology, fabric, geochemistry and lithology (Rawlings and others, 1997).

MCARTHUR BASIN

Stratigraphic relationships of units in the northern McArthur Basin are shown in Figure 5.

PALAEOPROTEROZOIC – OROSIRIAN TO STATHERIAN

Groote Eylandt Group

By B.A. Pietsch

The Groote Eylandt Group is a sequence of gently dipping sandstone and conglomerate interbedded with felsic and mafic volcanic rocks. The group is subdivided into Bustard Subgroup and the overlying Alyangula Subgroup (Table 3). The preserved thickness is extremely variable, from a few tens of meters on some islands, to in excess of 1000 m on southern Groote Eylandt. The maximum composite thickness of the group in GROOTE EYLANDT REGION (Pietsch and others, 1997), where the top and bottom is not exposed, is 1650 m. However, not all units may be present in a single vertical section.

The Groote Eylandt Group unconformably overlies Grindall Formation and Bukudal Granite. The top is eroded and unconformably overlain by Cretaceous sedimentary rocks.

The name 'Groote Eylandt beds' was first used by Dunn (1963) and Plumb and Roberts (1965), and defined by Plumb and Roberts (1992). Under this usage, 'Groote Eylandt beds' was conceived as a single sandstone/conglomerate unit, locally overlying the felsic 'Bickerton Volcanics'. Formalisation to Groote Eylandt Group essentially encompasses the old 'Groote Eylandt beds', with minor modification. It is now interpreted that 'Bickerton Volcanics' at their nominated type area (South Bay, Bickerton Island; Plumb and Roberts, 1992) are interbedded within the sedimentary sequence. Renamed Bickerton Rhyolite, to reflect their mono-lithologic character, this unit is now included within the Groote Eylandt Group. Some rocks previously mapped as 'Bickerton Volcanics' are now recognised as belonging to separate units, that have been assigned new names.

Bustard Subgroup

The sandstone, conglomerate and felsic volcanics in the lower part of Groote Eylandt Group have been placed in the Bustard Subgroup. The rocks of this sequence are closely interrelated, having formed in a depositional environment dominated by rapid uplift related to shallow level felsic intrusion in which scree deposits at the margins of the rhyolite bodies were re-worked 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 is inferred to be disconformable. This inference is made because 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 the Bustard Subgroup is given by Bickerton Rhyolite, which has a U-Pb zircon age of 1814±8 Ma (Pietsch and others, 1997). Based on this age the rhyolite belongs to the younger suite (1800-1840 Ma) of the "Transitional phase" of Rawlings (1994). Bickerton Rhyolite and associated felsic volcanics and immature fluvial clastic rocks can be equated with similar rocks of the Edith River Group, which underlie the McArthur Basin on its northwestern margin.

Erringkarri Rhyolite (Pее)

Outcrop of Erringkarri Rhyolite is confined to the shoreline of North Bay on Bickerton Island. The outcrop forms the base of weathered cliff walls, and also consists of blocks and boulders of red to brown rhyolite. This unit is not shown on previous maps.

The type area for Erringkarri Rhyolite is centred on GR PE260790, Bickerton Island (Pietsch and others, 1997). There, about 20 m of the top part of Erringkarri Rhyolite is exposed and is erosively overlain by Abarungkwa Sandstone. Elsewhere, Erringkarri Rhyolite is absent, and Abarungkwa Sandstone unconformably overlies Grindall Formation. The lower part of the formation is always obscured by the sea, and relationships with underlying units cannot be established. The presence of clasts derived from Erringkarri Rhyolite, Grindall Formation and Bukudal Granite in the Abarungkwa Sandstone, suggests there is no concealed unit between Erringkarri Rhyolite and these two older units. Field relationships also suggest that Grindall Formation directly underlies Erringkarri Rhyolite at the type area (Rawlings and others, 1995).

Rhyolite is mainly cryptocrystalline and porphyritic but in places may be aphnitic. Most phenocrysts are relic K-feldspar, with minor ferromagnesian minerals, and rare quartz. K-feldspar averages 2 mm in diameter, but some anomalously larger (to 7 mm diameter) intricately embayed crystals are also recognised. Flow banding was not observed. Alteration and/or weathering are generally evident in outcrop, but are
### Table 3  Stratigraphy of the Groote Eylandt Group in BLUE MUD BAY

<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alyangula Subgroup</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dalumbu Sandstone (Pcd)</strong> 500-1000 m exposed on Groote Eylandt</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. Ped.: Basalt, very weathered and ferruginised.</td>
<td>Mostly braided fluvial, with minor marine incursion. Subaerial basalt: lava flow.</td>
<td>Conformably overlies Bartalumba Basalt. Unconformably overlain by Cretaceous rocks and Cainozoic sediments.</td>
</tr>
<tr>
<td><strong>Bartalumba Basalt (Peb)</strong> 200-400 m in northern part of Groote Eylandt</td>
<td>Basalt and microdolerite, massive to amygdaloidal.</td>
<td>Subaerial lava flows.</td>
<td>Lower contact not exposed, but no evidence of disconformity. Upper contact concordant with Dalumbu Sandstone.</td>
</tr>
<tr>
<td><strong>Alyinga Sandstone (Pcy)</strong> Approximately 300 m in type area</td>
<td>Sandstone, white, medium- to coarse-grained, locally pebbly, quartz-rich, very large trough cross-beds in lower part, interbedded ripple horizons at top. Thin basal polymict granule to boulder conglomerate and pebbly and cobbly sandstone.</td>
<td>Mostly high-energy braided fluvial, with minor marginal marine.</td>
<td>Apparently disconformable on Milyakburra Formation. Inferred concordant contact with overlying Bartalumba Basalt. Interpreted lateral equivalent of Woodah Sandstone.</td>
</tr>
</tbody>
</table>
| **Woodah Sandstone (Pew)** Maximum thickness 50-60 m exposed at type section | *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 cracks; 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. | Braided fluvial. | Unconformably overlies Grindall Formation and Bukudal Granite. Inferred to unconformably overlie Milyakburra Formation and Abarungkwa Sandstone and conformably underlie Bartalumba Basalt. Elsewhere the lap is eroded and unconformably overlain by Cretaceous rocks and Cainozoic sediments. Interpreted lateral equivalent of Alyinga Sandstone. |

Variable in intensity, resulting in replacement of feldspar components by green, yellow or white clay, sericite and muscovite. Locally however, the rocks are leached or ferruginous. A notable spheroidal weathering is visible in the main body of the unit and in volcanic rock clasts in the overlying sandstone unit.

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

*Abarungkwa Sandstone (Pca)*

This fluvial sandstone-conglomerate unit forms rugged, bare rocky ridges and coastal cliffs on the northern half of Bickerton Island and on Burney Island. The rocks are pseudokarstically weathered and have a white phototone.
### Table 3 (continued)

<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BUSTARD SUBGROUP</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Milyakburra Formation (Penn)</td>
<td>Cobble and boulder conglomerate, matrix- to clast-supported, polymict, coarse sand to gravel matrix, massive to cross-bedded; locally interbedded with granule conglomerate and medium- to very coarse-grained lithic sandstone.</td>
<td>High-energy fluvial and alluvial fan. Facies probably represent a mixture of debris flow, talus and channel base deposits.</td>
<td>Erosional contact with underlying Bickerton Volcanics. Elsewhere, unconformable on underlying Aburungkwa Sandstone. Contact with overlying Woohah Sandstone is obscured. Laterally correlated with Milyemna Formation.</td>
</tr>
<tr>
<td>Maximum of 40 m in incomplete sections</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bickerton Rhyolite (Rei)</td>
<td>Rhyolite, red, porphyritic (K-feldspar).</td>
<td>Large subaerial lava domes and coulees.</td>
<td>Localised unit. Intrudes and lies conformably on Aburungkwa Sandstone. Contact with overlying Milyakburra Formation is erosional.</td>
</tr>
<tr>
<td>Maximum estimated thickness 150-250 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aburungkwa Sandstone (Pea)</td>
<td>Sandstone, white, coarse- to very coarse-grained, cross-bedded, pebbly, quartz-rich (lithic at base); granule conglomerate, quartz-rich; pebble and cobble conglomerate, polymict; minor medium-grained quartz sandstone.</td>
<td>High-energy braided fluvial.</td>
<td>Overlies Erringkarri Rhyolite with an erosional contact and unconformably overlies Grindall Formation. Overlain conformably by Bickerton Rhyolite or unconformably by Milyakburra Formation.</td>
</tr>
<tr>
<td>Most complete section, estimated to be 100-150 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erringkarri Rhyolite (Peo)</td>
<td>Rhyolite, dark red, variably porphyritic (K-feldspar).</td>
<td>Large subaerial lava domes and coulees.</td>
<td>Localised unit. Inferred to unconformably overlie &quot;basement&quot; (Grindall Formation and granite). Overlain by Aburungkwa Sandstone with erosional contact.</td>
</tr>
<tr>
<td>+20 m</td>
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</table>

The type section for Aburungkwa Sandstone occupies the isthmus between North and South Bay on Bickerton Island, where the most complete section, estimated to be 100-150 m thick, is present. A definition is given in Pietsch and others (1997).

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

The main rock-type is white to grey, coarse- to very coarse-grained sandstone which grades into granule conglomerate, near the base. Pebbles, cobbles and rarely boulders are scattered throughout, and are 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 top levels of the sequence. Overall the sand and granule grains are angular and poorly sorted, while pebbles and cobbles are angular to well rounded.

The rocks are very thickly bedded, with sedimentary structures dominated by large- to very large-scale trough crossbeds. Small-scale trough crossbeds are rare and along with flat-bedding, are confined to the finer and thinner-bedded facies. An isolated massive and very poorly sorted conglomerate near the base may represent a debris flow.

The sandstone and granule conglomerate are quartz rich, with white clay matrix. An exception is the succession immediately above the contact with Erringkarri Rhyolite, where abundant rhyolite granules are present. Here, the colour is dark red and pink and may be mottled and banded. Pebbles and cobbles are of diverse composition, including quartz, quartzite, fine-grained sandstone and mudstone (typical of
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.

Abarungkwa Sandstone is a high-energy braided fluvial sequence 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 eruption of Erringkarri Rhyolite and Bickerton Rhyolite.

**Bickerton Rhyolite** (Pet)

Bickerton Rhyolite forms low outcrop and scattered boulders of dark purplish porphyritic rock around the margins of South Bay on Bickerton Island (Plate 2) and on the southern part of Bustard Island. The ‘Bickerton Volcanics’ were first mapped by Plumb and Roberts (1965) and formally defined by Plumb and Roberts (1992). The redefined Bickerton Rhyolite is equivalent to ‘Bickerton Volcanics’ at its designated type area (around the shores of South Bay). A formal redefinition is given in Pietsch and others (1997). On Bustard Island, Bickerton Rhyolite intrudes the Abarungkwa Sandstone. On Bickerton Island, Bickerton Rhyolite is inferred to locally lie between the Abarungkwa Sandstone and Milyakburra Formation. Here, only the upper contact with Milyakburra Formation is exposed, and the maximum thickness is estimated to be 150-250 m.

The porphyritic rocks are rhyolitic to rhyodacitic in composition, with phenocrysts of mainly K-feldspar, minor ferromagnesian minerals, and rare quartz. The K-feldspar is altered to sericite and green and pink clay minerals. The groundmass is commonlly ferruginised (purple to red colour) or altered to grey and white clays. On Bickerton Island the rhyolite is generally massive, but locally flow foliated, however, on Bustard Island contorted flow banding is spectacular.

Xenoliths and rafts of sandstone (up to 5 m) are contained within the mass of rhyolite on the tip of Bustard Island. The sandstone was lithified when intruded. Flow banding within the rhyolite and contacts with sandstone are oriented almost vertically (Plate 3) suggesting this locality is near a vent.

Immature ferruginous volcanioclastic sandstone forms irregular shaped bodies within the outcrop, which possibly represent volcanic detritus reworked into voids and crevasses. This sandstone may represent part of an overlying sandstone unit subsequently removed by erosion.

Bickerton and Erringkarri Rhyolites are similar compositionally and in appearance. Minor differences are more quartz phenocrysts in Erringkarri Rhyolite and Bickerton Rhyolite has larger, more euhedral K-feldspar phenocrysts. Presumably, both were drawn from the same source, a sporadically active silicic magmas chamber at shallow depth.

As for Erringkarri Rhyolite, it is envisaged that Bickerton Rhyolite formed large lava domes and coulces in a dry terrestrial environment. The assorted scree and talus deposits at the dome margins were subsequently incorporated into immature fluvial deposits flanking the rhyolite body.

Bickerton Rhyolite, has a U-Pb SHRIMP zircon age of 1814±8 Ma (Pietsch and others, 1994).

**Milyakburra Formation** (Eem)

Outcrops of Milyakburra Formation are dominated by cobble and boulder conglomerate, locally interbedded with granule conglomerate and coarse lithic sandstone. Typically, these exposures are devoid of most vegetation and display light tones on aerial photographs.

The formation is distributed in two areas on Bickerton Island. South of the Milyakburra Community this unit overlies Bickerton Rhyolite and forms domal and mesa-like rocky ridges. In the northern part of the island scattered outcrops fill depressions and valleys cut into Abarungkwa Sandstone. A maximum thickness of 40 m is exposed in incomplete sections, including the type area immediately south of Milyakburra Community. A definition is given in Pietsch and others (1997).

South of Milyakburra Community, an erosional contact with underlying Bickerton Volcanics is inferred from the abundance of rhyolite clasts in the basal conglomerate. In the northern part of the island, the unconformity between underlying Abarungkwa Sandstone and the scattered outcrops of Milyakburra Formation is marked by erosive channelling. Here Bickerton Rhyolite was either removed by erosion or more likely was never present. No contact with overlying units is exposed.

Where Milyakburra Formation overlies Bickerton Rhyolite it comprises granule conglomerate and very coarse-grained sandstone which contains scattered pebbles, cobbles and boulders, interbedded with cobble and boulder conglomerate and minor medium- to coarse-grained cobble sandstone (Plate 4). Rhyolite (Bickerton-derived) and quartz are the most common clasts types in the finer fraction. Larger clasts include silicified coarse-grained quartz-rich pebbly sandstone and granule conglomerate (Abarungkwa-derived), porphyritic rhyolite (Bickerton Rhyolite), sandstone and mudstone (?Grindall Formation), quartz, and various metamorphic rock-types. Rhyolite clasts may be dominant near the base of the unit, but clasts derived from Abarungkwa Sandstone become dominant upsequence. Finer components are angular while larger clasts (up to 1 m) may be angular to well rounded.

Units within this sequence are poorly sorted to unsorted, usually weakly stratified, and very thick bedded with large trough cross-beds and large-scale channels containing basal boulder lags.

Unstratified clast-supported, poorly sorted, cobble and boulder conglomerate overlies the Abarungkwa Sandstone.
In this situation, Milyakburra Formation is dominated by subangular to rounded clasts of coarse-grained pebbly sandstone and granule conglomerate, derived from Abarungkwa Sandstone. It does, however, contain some clasts of volcaniclastic rock and rhyolite ("Bickerton Rhyolite"), and sedimentary rock presumably from Grindall Formation. This facies is also represented as intermittent sheets toward the top of the sequence to the south, overlying Bickerton Rhyolite. This unit is probably the product of deposition in a high-energy fluvial and alluvial fan environment sourced from elevated areas to the west and north. The facies probably represents a mixture of debris flow, talus and channel base deposits.

**Alyangula Subgroup**

Interbedded sandstone and basaltic rocks of the Alyangula Subgroup form most of Groote Eylandt, Connexion Island and the southeastern part of Bickerton Island. This subgroup also constitutes the greater majority of the stratigraphic section of the Groote Eylandt Group.

On Groote Eylandt, the base of the lowest formation of Alyangula Subgroup (Alyinga Sandstone) consists of thick units of cobbly sandstone and conglomerate, which contain clasts from underlying sandstone. The base of Alyinga Sandstone is erosive with a sharp contact but no apparent unconformity. Elsewhere, the base of the Alyangula Subgroup is represented by Woodah Sandstone, which unconformably overlies Grindall Formation and is interpreted to disconformably overlie the Bustard Subgroup.

Alyangula Subgroup has a close lithological and sequence stratigraphic correlation with the lower part of the Tawallah Group, in the southern McArthur Basin. On this basis, the unconformity/disconformity at the base of the Alyangula Subgroup equates to the base of the McArthur Basin sequence elsewhere.
Woodah Sandstone (Pew)

Woodah Sandstone is a variable unit of conglomerate, sandstone and mudstone. It is exposed as joint-controlled, bare rocky outcrops mainly on northeast Bickerton Island and smaller islands to the north and northeast. A maximum thickness of 50-60 m is preserved at the type locality on Morgan Island (Plate 5). The formation is defined in Pretsch and others (1997).

Relationships with other units of the Groote Eylandt Group are inferred. On Bickerton Island the contact between Woodah Sandstone and Milyakburra Formation and Abarungkwa Sandstone is obscured by younger cover and complicated by faulting. The basal conglomerate of Woodah Sandstone on islands to the north of Bickerton Island contains clasts interpreted to be derived from Abarungkwa Sandstone. On two of these islands, Burney Island and Wedge Rock, the Woodah Sandstone unconformably overlies Grindall Formation. On Morgan Island, it unconformably overlies the Grindall Formation and Bukudal Granite. On Bickerton Island, Woodah Sandstone is inferred to underlie Bartalumba Basalt. Elsewhere the top is always eroded, and it is overlain by Cretaceous and Cainozoic sediments.

At the type locality a 1-3 m thick, white to reddish pebble to cobble conglomerate forms the base. 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. These are set in a matrix of unsorted coarse-grained sand. The conglomerate is overlain by medium- to thin-bedded, medium- to fine-grained ferruginous pebbly sandstone interbedded with red mudstone. The sandstone displays small-scale trough cross-bedding. This unit is estimated to be 20-30 m thick. The top of the sequence comprises blocky, medium- to thick bedded, white to pink quartz sandstone. The sandstone is medium- to coarse-ground 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-boulder conglomerate overlain by fine- to medium-
grained quartz sandstone. Clasts within the conglomerate are predominantly foliated sandstone (Grindall Formation) and felsic igneous rocks, and minor pebbly sandstone (?Abarungkwa Sandstone) which are supported by a coarse quartz-feldspar sand matrix. The sandstone is thin- to medium-bedded with planar cross-beds.

Under Cretaceous rocks and laterite on Cape Barrow, exposure of Woodah Sandstone is confined to one outcrop of white, coarse-grained pebbly sandstone. The pebbles comprise mainly massive quartz, with lesser fine-grained silicified sandstone (Grindall Formation) and rare chert. The sandstone is thick-bedded with trough cross-beds.

On the northeast coast of Bickerton Island, a localised facies of Woodah Sandstone comprises medium- to coarse-grained sandstone and granule conglomerate interbedded with red, ferruginous micaceous mudstone. These rocks are thinly interbedded and display sedimentary structures that include climbing ripple laminations, desiccation cracks and flaser bedding. The remainder of Woodah Sandstone in this area is medium-grained, quartz sandstone similar to that on Isle Woodah to the north. The sandstone-mudstone sequence is similar to that exposed on Grindall Point and at the type section on Morgan Island.

Woodah Sandstone was deposited mainly in a braided fluvial system. The localised desiccated mudstone facies represents flood deposits accumulated in an out-of-channel or cut-off-channel, within the fluvial sequence.

**Alynga Sandstone (Pey)**

Alynga Sandstone consists mainly of medium-grained quartz sandstone which forms rugged, sparsely vegetated, joint-controlled outcrops. A formal definition is given in Pietsch and others (1997). Exposure in BLUE MUD BAY is confined to the western side of Winchelsea Island. The bulk of the unit is distributed across the northern part of Groote Eylandt, northern Winchelsea Island, North East Isles and other small adjacent islands (see GROOTE EYLANDT REGION map). No complete sections are exposed. In the type area in GROOTE EYLANDT REGION, a composite section is estimated to be 300 m thick. The disconformity with underlying Milyema Formation (in the GROOTE EYLANDT REGION) is marked by a sharp erosional contact, and lithified clasts of upper Milyema Formation are present in the basal conglomerate. Regional disconformity is also implied from the presence of clasts of foliated quartzite, sandstone and mudstone of Grindall Formation, minor metamorphic and pegmatite clasts, and sandstone clasts probably derived from Abarungkwa Sandstone. Although the upper contact is not exposed, it is inferred that Bartalumba Basalt concordantly overlies Alynga Sandstone.

The basal part of the formation is a discontinuous unit of polymict granule to boulder conglomerate and coarse-grained pebbly or cobbley 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 ?Abarungkwa Sandstone), quartz, indurated foliated mudstone and fine-grained sandstone (Grindall Formation), and rare metamorphic and ?felsic volcanic rocks. Individual conglomerate beds are lenticular and discontinuous, and usually several metres thick. These beds grade upward from clast-supported to matrix-supported conglomerate to quartz-pebble sandstone and may be repeated in several cycles.

Where conglomerate beds are absent the basal part of the Alynga Sandstone comprises 40 m of coarse- to very coarse-grained pebbly sandstone. The sandstone is lithic immature and poorly sorted with some cobble 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 Grindall Formation, fine-grained sandstone derived from Milyema Formation substratum, and minor amounts of various metamorphic rocks. Locally this sandstone is ferruginous.

The basal facies grades upward into a thicker unit of mainly medium-grained, moderately to well sorted, white, quartz-rich sandstone which contains occasional scattered pebbles, and lenses of granule conglomerate. This horizon is characterised by huge trough cross-beds and prominent large-scale joints which control the topography. Outcrops on Winchelsea Island are stratigraphically higher and coarser grained and consist of white to pink, and in places brownish and reddish, coarse-grained pebbly sandstone which grades into thin beds of granule conglomerate. The sandstone comprises poorly to moderately sorted angular to subangular grains with pebbles both randomly distributed and in places as thin lag deposits at the base of trough cross-beds. Medium-grained sandstone beds are also present. The sandstone is quartz-rich with a clay matrix. The granules and pebbles consist mainly of quartz, with subordinate chert, silicified mudstone, sandstone and felsic volcanic rock. Sedimentary structures are dominated by large scale trough cross-beds and minor tabular cross-beds.

Sandstone exposed in the upper part of the formation is medium- to coarse-grained and more mature than underlying units. Grains are well rounded, generally bimodally sorted. 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 Alynga Sandstone is not noticeably angular and is probably the result of reactivation of the fluvial system. This either relates to sea level drop or, more likely, tectonic or intrusion related uplift in the source area. The lithology, sedimentary structures and palaeocurrent patterns suggest a high-energy braided fluvial environment. The clean, well-sorted beds containing wave ripples near the top of the formation may reflect a marginal marine influence at this level. This pattern suggests an overall repeat of the Milyema Formation uplift-subidence cycle.
Bartalumba Basalt is poorly exposed. Outcrops are small, isolated and located beneath scarps of Dalumbu Sandstone between Bluff Hill on eastern Groote Eylandt (see GROOTE EYLANDT REGION map) and the east coast of Bickerton Island. Exposures are deeply weathered, rarely with fresh cores. Moderately fresh boulders and cobbles may be found in creeks. Aeromagnetic data suggest these outcrops are part of a continuous tabular body extending near-surface from the southeastern tip of Groote Eylandt, northwest to the unnamed bay on the middle-eastern shore of Bickerton Island and dipping gently southeast. 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 type area for the Bartalumba Basalt is GR PE730660 (lat 13°52'S, long 136°36'E), northern Groote Eylandt.

The thickness cannot be determined accurately as the base is never exposed, but is inferred to be in the order of 200-400 m on northern Groote Eylandt. The decreasing intensity of magnetic anomalies towards Bickerton Island suggests decreasing thickness in that direction.

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

The lower contact with Alynga Sandstone is not exposed. The upper contact is also concealed, but a concordant relationship is evident with overlying Dalumbu Sandstone.

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

Dalumbu Sandstone (Eed, (Eed,)

The predominantly coarse-grained, pebbly sandstone exposed on the central and southern part of Groote Eylandt, Connexion Island and southeastern Bickerton Island, is part of the Dalumbu Sandstone. This unit crops out as sparsely vegetated hills and scarps, often with a joint-controlled topographic expression. Vague bedding trends, more prevalent near the base, are evident on airphotos.

Because of gentle dips, no single section can be considered representative. Instead, the entire body of continuous outcrop of Dalumbu Sandstone on Groote Eylandt (in GROOTE EYLANDT REGION) constitutes the type area. The unit is formally defined in Pietsch and others (1997). Dalumbu Sandstone conformably overlies Bartalumba Basalt. On Bickerton Island, the base of the formation comprises 5 m of ferruginous sandstone and mudstone, which is then 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 unit is eroded and overlain unconformably by Cretaceous and Cainozoic sediments. Because the top is eroded, the full thickness cannot be determined. A minimum estimated thickness of 500-1000 m is exposed on Groote Eylandt, based on the assumption that the regional dip is constant by one or two degrees.

Dalumbu Sandstone is dominated by pebbly sandstone that contains interbeds of finer-grained non-pebbly sandstone. It also includes a thin unit of weathered basalt, which drapes large ridges of sandstone near the formation base. The pebbly sandstone is white to pink, quartz-rich and coarse-grained with horizons of granule conglomerate. Most quartz grains are angular and poorly sorted. In contrast, pebbles and less abundant cobbles are generally rounded to well rounded. The pebbles and cobbles comprise predominantly white quartz, but a few are composed of quartzite and sandstone (possibly Grindall Formation) and chert, and very rarely 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 beds up to 10 m thick within the pebbly sandstone. The medium-grained sandstone is quartz-rich with well-rounded and well-sorted grains, and internally laminated with small- to medium-scale trough cross-beds.

Between Central Hill and Lugadamanja Point (in GROOTE EYLANDT REGION), a distinct facies of parallel linear ridges is present 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 300 m apart, but the separation can vary from 200 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, very weathered and ferruginised basalt (Eed,) drapes the underlying ridge-forming sandstone. This basalt is poorly exposed, but up to 15 m may be preserved in palaeodune troughs, while it pinches out over the palaeodune ridges.

The pebbly sandstone lithofacies of the Dalumbu Sandstone represents deposition in a braided fluvial environment in rivers that flowed southeast on Bickerton Island and more southerly on Groote Eylandt. The sand ridge facies represents deposition on a shallow shelf, during a brief marine incursion across a coastal alluvial plain. These ridges were preserved from later reworking by the next fluvial cycle and by a thin sheet of basalt lava.
PALAEOPROTEROZOIC – STATHERIAN

Donydji Group

By D.J. Rawlings

Donydji Group is a sequence of dominantly fluviatile to shallow-water coarse-grained siliclastic sedimentary rocks and bimodal (felsic-mafic) igneous rocks. It is inferred to unconformably overlie metamorphic and granitic rocks of the Mirrarrmina Complex and is in turn conformably overlain by the sandstone-dominated Parsons Range Group. A summary of internal stratigraphy is given in Table 4.

Outcrop is restricted to Mitchell Ranges, a narrow elongate meridional-trending belt of relatively deformed sandstone and igneous rocks, bordering ARNHEM BAY–GOVE and BLUE MUD BAY. These ranges are bounded on each side by major north-trending faults – the Bath Range, Mitchell Ranges, Dhunganda and Badalngarmirri Faults – and are internally complexly faulted in a similar north orientation. The overall structure of the Mitchell Ranges is a broad double-plunging synclinorium, culminating in the centre of the ranges at Ritarango Gap, in ARNHEM BAY–GOVE. Mitchell Ranges are the principal high-relief feature of the mapsheet, sharply abutting the surrounding Gulf Fall and Arafla Fall, and are deeply incised and relatively well exposed. Structural repetition of some formations has complicated the estimation of total thickness, which is probably of the 2000–3000 m. The maximum age of the Donydji Group is constrained by the 1870 Ma age of underlying Mirrarrmina Complex. Minimum age is constrained by 1710 Ma for concordant igneous units at the top of the group (Maidjunga and Dhupuwamirri Members).

The formations that now collectively make up the Donydji Group were informally referred to by Crohn (1956) as ‘Mitchell Range’ and ‘Cypress Creek Formations’. This sequence was later revised by Dunnet (1965) to include two new subdivisions, ‘Ritarango beds’ and Fagan Volcanics. These lithostratigraphic units were subsequently formalised by Plumb and Roberts (1992). The term ‘Ritarango beds’ referred to all clastic sedimentary rocks stratigraphically between the Mirrarrmina Complex and a major mid-sequence unconformity, marked also by the first significant igneous interval. The igneous-dominated succession above this was (and still is) referred to as Fagan Volcanics.

The current mapping has identified valid reasons to again revise these divisions. A significant break or unconformity between ‘Ritarango beds’ and Fagan Volcanics could not be confirmed, but a distinct depositional break (‘unconformity’) was identified lower in the succession. Large areas of poor outcrop from a similar level of the sequence, originally thought to be dykes and excluded from the sedimentary succession, have since been confirmed to be, at least in part, concordant volcanic units. For these reasons, it became necessary to introduce a three-fold subdivision of the group, including two new formations (defined in Rawlings and others, 1997). These are, in ascending stratigraphic order, Dhunganda and Ritarango Formations, and Fagan Volcanics. Rawlings (1994) informally referred to this new subdivision, suggesting important breaks between units that could be correlated regionally.

The lowermost two units, Dhunganda and Ritarango Formations, together make up the same interval that Plumb and Roberts (1992) referred to as ‘Ritarango beds’. A significant mid-sequence change in rock-type and structural characteristics has been recognised during the current mapping, instigating the new subdivision. The lower unit, Dhunganda Formation, comprises strongly deformed sandstone, and lesser felsic and mafic igneous rocks, volcanioclastic rocks and mudstone. The unconformably overlying Ritarango Formation comprises mildly deformed coarse-grained (partly conglomeratic) lithic sandstone with minor mudstone and volcanioclastic rocks. The ‘old’ Fagan Volcanics is retained but is subdivided into three units, Maidjunga, Sheridan and Dhupuwamirri Members (in ascending stratigraphic order). It comprises a sequence of variably deformed sandstone, mudstone, felsic and mafic igneous rocks, and minor conglomeratic and volcanioclastic rocks. Intrusive and extrusive phases of igneous activity are recognised.

Ductile and brittle deformation has modified the original fabrics of many Donydji Group rocks, imposing foliation, fracture cleavage, jointing, silicification and quartz veining. This deformation resulted from localised wrench faulting and thrusting, in which the Mitchell–Flinders Thrust Belt formed.

Dhunganda Formation (Eid, Eid,)

The Dhunganda Formation is a sequence of strongly deformed sandstone, and lesser felsic and mafic igneous rocks, volcanioclastic rocks and mudstone. It apparently unconformably overlies Mirrarrmina Complex and is in turn unconformably overlain by the siliciclastic Ritarango Formation. Outcrop is restricted to the core of Mitchell Ranges, largely in southern ARNHEM BAY–GOVE. Minor exposure is present along strike in northern BLUE MUD BAY but was not studied. Consequently, the following summaries are based on the work of Rawlings and others (1997) immediately north of the mapsheet boundary.

Dhunganda Formation comprises the lower half of the ‘Ritarango beds’ of Plumb and Roberts (1992). The need to subdivide ‘Ritarango beds’ followed the identification of significant mid-sequence changes in rock-type and structural characteristics, thought to be related to a sedimentological break and period of tectonism. The upper half of the ‘Ritarango beds’ has been redefined by Rawlings and others (1997) as Ritarango Formation. It comprises considerably coarser-grained and less mature siliciclastic rocks with a lower degree of deformation. Rawlings and others (1997) nominated a type section on the southwestern perimeter of Ritarango Gap, around lat 12°58'S, long 135°32'E (ARNHEM BAY–GOVE). No base or top to the formation were identified during the current mapping. Structural complications and poorly exposed contacts inhibit accurate measurement of thickness, however a minimum of 500 m is suggested by Rawlings and others (1997) for the area immediately north of the sheet boundary.
### Table 4 Stratigraphy of the Donydji Group and Gadabara Volcanics in BLUE MUD BAY

<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadabara Volcanics (Ev) 50 m</td>
<td>Felsic igneous rock, pink to brown, aphyric to sparsely porphyritic, coherent and banded, locally amygdaloidal; volcanic sandstone and breccia.</td>
<td>Lavas and talus deposited into shallow water to emergent environment.</td>
<td>Intrude and unconformably overlie Woodah Sandstone. Unconformably overlain by Coast Range Sandstone.</td>
</tr>
</tbody>
</table>

**DONYDJII GROUP**

2000-3000 m

**Fagan Volcanics (Eif)**

1000-1200 m

| Dhupuwamirri Member (Eiid) 450-550 m | Rhyolite, green to brown, porphyritic with phenocrysts of K-feldspar, quartz and albite, massive to flow banded; volcaniclastic mudstone, sandstone and breccia; dolerite, basalt and hybrid igneous rocks. | Sedimentary facies are shallow water low-energy ?delta-fan. Igneous rocks are extrusive and high-level intrusive. | Conformably overlies Sheridan Member and is conformably overlain by Mامتارمة Sandstone of the Parsons Range Group. |

| Sheridan Member (Eīb) 250-400 m | Sandstone, white, cross-bedded, medium- to coarse-grained, lithic; interbedded with mudstone, red-brown, ferruginous, micaceous; local volcaniclastic breccia, conglomerate and sandstone; locally sheared. | Shallow water, low- to moderate-energy setting (lacustrine or fan-delta). | Lies with conformity on the Maitjunga Member and with local disconformity on the Ritarango Formation. Overlain conformably by Dhupuwamirri Member. |

| Maitjunga Member (Eīfm) 150-250 m, locally removed | Rhyolite, brown and pink, coarsely porphyritic with phenocrysts of K-feldspar, quartz and albite; minor volcaniclastic sandstone and mudstone; locally foliated and sheared. | Sedimentary facies are shallow water fluvial to lacustrine. Igneous rocks are extrusive and high-level intrusive. | Lies with conformity or mild disconformity on the Ritarango Formation. Overlain conformably by Sheridan Member. |

| Ritarango Formation (Eir) 500-1500 m | Sandstone, maroon to white, fine- to very coarse-grained, locally pebbly or conglomeratic, lithic, cross-bedded; minor volcaniclastic sandstone; minor mudstone; locally foliated and sheared. | Mostly shallow water high-energy fluvial and lesser low-energy deltaic. | Possibly unconformably overlies Dhunganda Formation and is conformably to disconformably overlain by Fagan Volcanics. |

| Dhunganda Formation (Eid) >500 m | Eid Sandstone, silicified, white, fine- to coarse-grained, locally pebbly, quartzose, cross-bedded. Eid; Recessive intervals of mudstone and fine-grained sandstone, felsic-mafic-hybrid igneous rocks, volcaniclastic rocks, sheared rocks. | Lower sandstone rich package is fluvial to shallow water deltaic. Upper diverse package ranges from alluvial to moderately deep water lacustrine. | Overlies Mirarma Complex with apparent angular unconformity. Possibly unconformably overlain by Ritarango Formation. |

Two distinctly different types of outcrop are present in this formation: strongly resistant sandstone with white phototones (mapped as Eid); and recessive igneous, volcaniclastic and mudstone with dark brown tones (mapped as Eid). Each outcrop type also exhibits distinctive characteristics in magnetics, radiometrics and multi-spectral data (see Rawlings, 1995).
These two rock-types are interbedded on a 10 to 100 m scale in the upper half of Dhunganda Formation; the lower half is dominated by sandstone. The distinctive area of alternating resistant and recessive outcrop in Ritarango Gap is largely due to this interbedding, but is also complicated by fault-repetition, and by numerous felsic and mafic intrusions, many of which are concordant sills. On aerial photographs, it appears that the sequence has been attenuated and segmented by north oriented shear-zones, slightly askew to bedding. The lower sandstone-dominated part of the formation is tightly vegetated and steeply dipping, typically forming upstanding strike-vegitates. It exhibits a strong macroscopic joint or fracture pattern oriented north, presumably due to shearing. A characteristic feature is the large number of similarly oriented basaltic dykes and sills, which appear dark and vegetated on aerial photographs. These intrusive bodies are distinct from the sills mentioned above, as they are thin (< 5 m wide), non-magnetic, regularly transgress bedding, and appear to merge with the fracture pattern (see ‘Proterozoic dolerite dykes’).

In areas of least faulting, Dhunganda sandstone can be confused with other sandstone units on aerial photographs, such as those of Ritarango Formation or Parsons Range Group. However, they can be distinguished by their greater structural complexity (particularly the prominent north orientation) brightness of white phototones, and high frequency of sills and dykes.

The lower half of Dhunganda Formation comprises mainly white silicified, sheared, fine- to coarse-grained, quartzoze sandstone. It is locally pebbly, particularly near the base, and the sequence tends to fine-upwards. Thin intervals of mottled ferruginous mudstone and fine-grained sandstone are also recognised locally.

The lowest part comprises very coarse-grained, pebbly to cobbly, variably lithic sandstone. Most clasts are well-rounded massive quartz, some up to 10 cm in diameter. Pebbles occur in isolation and as pebble-trains in cross-beds. Sorting is poor to moderate and the rocks are medium- to very thick-bedded with trough cross-bedding. Overlying this is white fine- to medium-grained (some coarse-grained) moderate- to well-sorted, quartzose to slightly lithic sandstone. This is medium-to thick-bedded, with trough cross-bedding and flat-bedding, however, thin- to medium-bedded rippled intervals are locally present.

The upper half of Dhunganda Formation comprises interlayered (10 to 100 m scale) recessive and resistant intervals. Resistant intervals (Ed on the mapface) are composed of white fine- to medium-grained quartzoze and lithic sandstone. Recessive intervals (Ed.) comprise complicated intercalations of felsic and mafic igneous rock, volcaniclastic rocks and fine-grained ferruginous sandstone.

Quartzoze sandstone is fine- to medium-grained, well-sorted, with rare mudstone intraclasts. It is thickly-bedded, with trough crossbedding, with occasional thin rippled intervals. It is associated with lithic sandstone and volcaniclastic rocks in fining and maturing-upwards cycles, immediately above felsic volcanic units. A typical sequence above such a unit comprises (bottom to top): basal hyaloclastite and autoclastite breccia, redeposited hyaloclastite/autoclastite breccia, volcaniclastic pebbly sandstone and conglomerate; medium- to coarse-grained lithic sandstone; and finally fine-grained quartzoze sandstone. Mudclasts and possible evaporite casts are present in the lithic sandstone and it is clear that lithic material was derived from the underlying felsic volcanic unit.

Mudstone and fine to medium-grained sandstone intervals, presumably unrelated to igneous bodies, form coarsening-upwards intervals of approximately 50 mm thickness. There appear to be several such intervals in the formation, but there is also evidence for structural repetition. The base of each interval comprises mudstone and minor interbedded fine-grained sandstone. These are wavy-bedded, with abundant ripples, interference ripples, cross-lamination and small-scale hummocky cross-stratification. Higher up, fine-grained sandstone dominates over mudstone and medium-grained sandstone. They are flaggy and thin-bedded, slightly lithic with locally abundant mudstone intraclasts. Characteristic are small-scale cross-beds, soft-sediment deformation (including slumps and convolute bedding), occasional tool marks and ferruginous evaporite (?gypsum) casts.

Igneous rocks are mainly felsic, however, mafic and intermediate hybrids are also recognised. Field relationships suggest that most igneous bodies are extrusive, but some may be intrusive.

The most common rock is massive porphyritic rhyolite, with K-feldspar, quartz and plagioclase (albite) phenocrysts in a dark microcrystalline to cryptocrystalline groundmass. In thin-section, K-feldspar and quartz phenocrysts are embayed and resorbed, and average 0.5 mm diameter (quartz grains up to 0.7 cm and K-feldspar up to 2 cm). Patches of exsolved albite and microperthite are visible in K-feldspar. The groundmass comprises microgranophytic to cryptocrystalline quartz, feldspar, sercite and minor opaques. This rock has an unusually high magnetic susceptibility. Some rhyolite near the margins of bodies is phenocryst-poor, comprised of small euhedral K-feldspar and albite phenocrysts in black cryptocrystalline groundmass. This rock-type has a low magnetic susceptibility. Field relationships, facies associations and textural features favour a coherent volcanic origin for most of the felsic igneous bodies. Some rhyolitic rocks are thought to be pyroclastic (Rawlings and others, 1997).

Hyaloclastite and autoclastite breccia, some of which has clearly been redeposited by post-volcanic processes, is closely associated with rhyolite bodies. Primary non-transported deposits contain large angular clasts with no distinctive internal variation in texture. Breccia deposits form a continuum between closed-framework jigsaw-fit hyaloclastite, and open-framework weakly graded or bedded redeposited autoclastite/hyaloclastite. Volcaniclastic pebbly sandstone and conglomerate have undergone considerably more transport and comprise more rounded polmict clasts and texturally more mature matrix.

Mafic igneous rock comprises dark green dolerite and microdolerite. The coarse rock has skeletal texture, best
observed on weathered surfaces. They contain variably altered plagioclase and pyroxene with ophitic, subophitic and intergranular textures. Secondary minerals, including chlorite, opaques, sericite, epidote, quartz, K-feldspar, biotite and amphibole, are present in variable quantities, giving rise to variable magnetic susceptibilities. The fine-grained rocks have a much higher magnetic susceptibility when compared to the coarser dolerite. This appears to be a hydrothermal alteration feature rather than weathering.

Many exposures of dolerite and microdolerite are not assigned to a mappable unit because of uncertainties on their age and distribution. In many cases, it appears these equate to younger igneous phases, such as those of the bimodal Dhupwamirri Member of the Fagan Volcanics. They may even relate to younger magmatic events post-dating Parsons Range Group. However, there is evidence to suggest that some mafic rocks have both a spatial and temporal relationship with the felsic volcanic rocks of the Dhunganda Formation. This includes small occurrences of felsic-mafic hybrid rock, as described by Rawlings and others (1997).

Outcrop is foliated, fractured, brecciated, silicified and quartz-veined in many places, particularly adjacent to fault zones. Steep dips are frequent and bedding is locally overturned. Often the outcrop is so jointed and silicified that bedding is obscured. A close-spaced cleavage is noted in mudstone and igneous rocks around shear zones, whereas deformed sandstone has an indistinct widely-spaced fracture cleavage. Many igneous and coarse-grained sedimentary rocks from the central part of Mitchell Ranges exhibit phyllitic and gneissic fabrics (Rawlings and others, 1997).

The environment of deposition for the lower half of the formation is high-energy shallow water, fluvial or possibly deltaic. Conditions during formation of the upper half have been erratic and influenced by the presence of extrusive igneous bodies. Conditions are interpreted to range from moderately deep water to shallow and emergent.

The age of this formation is constrained by the underlying Mirarrmina Complex (1870 Ma) and the overlying Ritarango Formation and Fagan Volcanics (1710 Ma). A concordant relationship and close association with felsic volcanism suggest a temporal and spatial relationship with overlying formations and an age closer to 1720-1740 Ma. As discussed in ‘Regional Correlation’, this is consistent with the regional tectonostratigraphic framework.

Ritarango Formation (Rir)

Ritarango Formation is a succession of mildly deformed coarse-grained (partly conglomeratic) lithic sandstone with minor mudstone and volcanioclastic rocks. It lies unconformably above the Dhunganda Formation and conformably below the igneous and sedimentary Fagan Volcanics. Outcrop is restricted to Mitchell Ranges, in the northern part of BLUE MUD BAY, continuing onto the southern part of ARNHEM BAY. Extensive north oriented faults are superimposed on bedding in many areas, imposing a distinctive pseudo-bedding pattern. Plumb and Roberts (1992) believed that this faulting obscures macroscopic fold structures.

Ritarango Formation succeeds the name ‘Ritarango beds’, applied by Dunnet (1965) to the interval now collectively encompassed by Ritarango and Dhunganda Formations. Significant structural and lithological contrasts, and a probable unconformity, were identified at the contact of these two formations during the current mapping. This necessitated subdivision into a lower strongly deformed formation and an upper mildly deformed formation. The term Ritarango was retained by Rawlings and others (1997) and raised to formation status, but now only applies to the upper stratigraphic subdivision.

The entire Mitchell Ranges were nominated as a reference area for the ‘Ritarango beds’ by Plumb and Roberts (1992). Rawlings and others (1997) nominated an incomplete type section through the axis of a large syncline at the eastern margin of Mitchell Ranges between GR NF640772 and NF680840 (ARNHEM BAY–GOVE). A reference area was also nominated for a complete section along the Koolatong River near GR NF600530 in BLUE MUD BAY.

Incomplete and structurally repeated sequences are common, and the basal relationship with the Dhunganda Formation is not firmly established. In most areas, a minimum thickness of 500 m can be estimated. However, based on measured dips, it is probably thicker (perhaps 1500 m) in the vicinity of the type section in ARNHEM BAY–GOVE (Rawlings and others, 1997).

In outcrop, it is moderately resistant with white and grey-green phototones. Strata dip steeply, giving rise to upstanding ridges with a strong meridional macroscopic fracture pattern. Like the underlying Dhunganda Formation, it contains abundant rhyolite and basalt dykes and sills, which appear very dark and highly vegetated on aerial photographs. When flat-lying, this formation exhibits orthogonal joint patterns. It exhibits pseudo-karstic weathering, but outcrop is more commonly bouldery and rounded. In areas of least faulting, it can be confused with Mattamurra Sandstone or Dhunganda Formation on aerial photographs. It is distinguished from the former by its greater structural complexity, particularly in the prominent north orientation, and frequency of north oriented rhyolite/basalt sills and dykes. Similarly, Dhunganda Formation is distinguished because of its greater structural complexity and segmentation on aerial photographs and because it is whiter, more silicified and less vegetated.

Ritarango Formation is made up of white, maroon or pink, fine- to very coarse-grained lithic sandstone, with minor mudstone and volcanioclastic intervals. No volcanic intervals were identified, but they do appear likely given the immaturity and quantity of felsic igneous rock fragments present in some sandstone. The most common rock is coarse-grained lithic sandstone. This is moderately- to poorly-sorted, with rounded to angular clasts (granules, pebbles and rarely cobbles) of mainly massive quartz, with lesser lithified sandstone, quartzite, felsic volcanic rock and mudstone. The sandstone may also be feldspathic rather than lithic. It is thick-bedded
with large-scale trough cross-beds and rare ripples. The lithic component varies from negligible to significant in the volcaniclastic rocks. Sandstone with a high lithic content has a chalky and speckly appearance. Quartz grain maturity (sorting and rounding) is variable from place to place. Rare clasts include metamorphic micaceous mudstone and chert. At some localities, lithic sandstone is interbedded (on 1-10 m scale) with red-brown mudstone. Mudstone intraclasts are present in the enclosing sandstone. The sandstone becomes finer-grained, more quartzose and more mature to the south, suggesting a source area to the north.

In some areas, the sandstone is silicified to the extent where original texture has been obliterated. In others areas, silicification forms a hard carapace around friable clay and sand. Lithic and feldspathic sandstones weather to a soft structureless mass. Bedding is diffuse due to joints that are more prominent than bedding.

In thin-section, sandstone is generally submatute to immature, comprising quartz, lithic fragments and K-feldspar. It falls into the litharenite and sublitharenite fields of Folk (1974). There are two populations of quartz grains: the dominant has a silicic volcanic provenance, and the second population has a metamorphic-granite provenance. Rock fragments are mainly quartz-K-feldspar porphyry, and lesser micaceous mudstone, fine-grained matrix-rich sandstone and meta-mudstone/greywacke. K-feldspar is a minor component of most sandstone. It is clear from the dominance of felsic volcanic fragments in some specimens that the source must be very proximal and probably intraformational.

The contact between the Ritarango Formation and the underlying Dhunganda Formation is obscured by scree, but appears to have been intruded by a dolerite sill along much of its length. The boundary with the overlying Maidjunga Member of the Fagan Volcanics is conformable or weakly disconformable. The contact surface is sinuous, scalloped or crenulated in a north orientation on a scale of 10-100 m. This feature is most obvious on aerial photography. It has been ascribed to either: a manifestation of structural contrast between Ritarango sandstone and Maidjunga porphyritic rhyolite; syn-depositional loading; an irregular erosive (disconformity) surface; or preservation of primary depositional bedforms (megagripples) on the upper surface of Ritarango Formation. Examples of the latter have been described from Kombolgie Formation in western Arnhem Land by Nott and Ryan (1996). The cause of the irregular contact in Mitchell Ranges could not be resolved during fieldwork due to difficult access to critical areas. West of Sheridan Fault in BLUE MUD BAY, Maidjunga Member is absent and Ritarango Formation is disconformably overlain by Sheridan Member of Fagan Volcanics.

Sandstone is locally sheared, fractured, cleaved, brecciated, silicified and/or quartz-veined, particularly adjacent to fault zones. High angles of dip are common and there is occasional overturning of strata. There is also considerable evidence for stratigraphic repetition in many areas. Foliation in sandstone can be intense and destructive of primary fabric. This is particularly so in lithic, coarse-grained sandstone, which is the most readily foliated. It is suspected that this is facilitated by the breakdown of chemically unstable rock fragments during early diagenesis and alteration. Most grain fabrics have been modified during deformation, with the superimposition of undulose extinction, bohm lamellae, and, in the most severe cases, composite grain fabrics, fractures and stretched fabrics. Attenuated pebbles have been recorded in foliated sandstone in outcrop. In thin-section, quartz grain attenuation may reach 5:1.

A shallow-water fluvial environment appears most likely for the sandstone. Some of the finer-grained sediments may have deposited in a floodplain or delta, complementary to the coarser-grained higher-energy fluvial (?braided) sediments.

Ritarango Formation resembles Nyanantu Formation from southern McArthur Basin (Haines and others, 1993) in many respects. It is also similar in appearance to some intervals of Bustard Subgroup. Thin-sections suggest derivation from both felsic volcanic and metamorphic-granite (Mirarrmina Complex and later granite) sources. It is clear from the dominance of felsic igneous rock fragments in some specimens that the source must be very proximal and probably intraformational. Evidence suggests a source to the north.

Underlying Ritarango Formation are Dhunganda Formation (unknown age) and Mirarrmina Complex (1870 Ma), providing a maximum age of 1870 Ma. Ritarango Formation is conformably or weakly disconformably overlain by Maidjunga Member rhyolite, dated by single grain SHRIMP U-Pb techniques at 1710 Ma (R. Page, pers. comm., 1992).

Fagan Volcanics (Dif)

The Fagan Volcanics are the uppermost formation of the Donydi Group and are made up of felsic and mafic igneous rocks, sandstone, mudstone and minor conglomeratic and volcaniclastic rocks. They lie conformably on the coarse siliciclastic Ritarango Formation and are in turn conformably overlain by the quartzose Mattamurta Sandstone (Parsons Range Group). Outcrop is confined to Mitchell Ranges in the northern part of BLUE MUD BAY and southern ARNHEM BAY—GOVE. The individual successions in these two sheets are separated by the core of the ranges (30 km wide), made up of older units of the Donydi Group.

The main area of outcrop in BLUE MUD BAY is a broad southerly-plunging syncline at the border of Mitchell and Parsons Ranges. To the east, steeply-dipping Fagan Volcanics are terminated abruptly against upper Parsons Range and Balma Groups by the Mitchell Ranges Fault. The western limb of the syncline is bounded by the Badalangarmirri Fault and terminates against Mirarrmina Complex.

The thickness of the Fagan Volcanics in BLUE MUD BAY is 1000-1200 m. The bottom and top parts of the succession have been dated using U-Pb zircon SHRIMP geochronological techniques at 1707±12 and 1706±10 Ma respectively (R. Page, pers. comm., 1992).
The Fagan Volcanics were first mapped by Dunnet (1965), around Fagan Creek, a tributary of the Koolatong River in BLUE MUD BAY. The name was formalised by Plumb and Roberts (1992) and a type locality was nominated around the headwaters of Koolatong River*. Due to local structural complexity, a type section was not proposed. Stratigraphic relations with the enclosing formations were considered by Dunnet (1965) and Plumb and Roberts (1992) to be unconformable. The latter authors identified five informal members but these could not be mapped accurately due to lateral facies variation. They also pointed out the existence of intrusive phases.

Rawlings (1995) identified three units within the formation, which were subsequently formalised as members by Rawlings and others (1997). These are, in ascending stratigraphic order, the igneous-dominated Maidjunga Member, the exclusively sedimentary Sheridan Member, and the mixed sedimentary-igneous Dhupuwamiirr Member. Each has been assigned a type section distinct from that of the complete formation. Lithostratigraphic correlation of these members from ARNHEM BAY—GOVE to BLUE MUD BAY appears reasonable based on geochronology, geochemistry and petrography. However, owing to discontinuity of outcrop, the inherently transgressive nature of igneous units, strict chronostratigraphic correlation is not possible.

Stratigraphic relations with the enclosing formations have also been revised during the current mapping. The lower boundary with Ritarango Formation, interpreted by Dunnet (1965) to be an angular unconformity, is probably conformable. A convoluted and scalloped interface between these two units is discussed in the section on ‘Ritarango Formation’. In the area west of the Sheridan Fault, the lowermost member of Fagan Volcanics is missing and an erosional (disconformable) contact occurs between Ritarango Formation and Sheridan Member. The observation of Plumb and Roberts (1992) that Ritarango Formation is much more highly sheared and faulted suggests preservation of an earlier tectonic event that pre-dates Fagan Volcanics. However, we favour this being an apparent feature, resulting from a competency contrast.

The upper contact with the Mattamurra Sandstone was interpreted by Dunnet (1965) to be unconformable. Recent mapping indicates the contact is conformable in both ARNHEM BAY—GOVE and BLUE MUD BAY. Rawlings (1995) suggested this represents a sequence boundary in both mapsheets, which enables chronostratigraphic correlation. Further felsic igneous bodies are recognised in the lower part of the Mattamurra Sandstone, suggesting that ‘Fagan phase’ (Rawlings, 1994) magmatism continued spasmodically after deposition and emplacement of Fagan Volcanics.

Rawlings and others (1997) proposed a revised set of rock-types for the formation, including felsic and mafic igneous rock, mudstone, sandstone, and minor conglomeratic and volcanioclastic rocks. Sedimentary rocks are variable in maturity and grain-size, and individual units exhibit significant lateral facies variation. However, a crude stratigraphy exists, which is complicated by igneous units and structure. Igneous rocks are now thought to be principally cohesive (not pyroclastic) and of both intrusive and extrusive origin. Some shallow intrusive bodies appear to transgress the stratigraphy along strike to emerge as extrusive lava domes and flows.

A structural overprint is less obvious and variable in intensity compared to the underlying Donydji Group. Silicification, fracturing and quartz veins are widespread in all rock-types. A tectonic foliation in sandstone and volcanics, and a weak cleavage in mudstone, are only locally developed and confined to shear-zones.

**Maidjunga Member (Eifm)**

Maidjunga Member comprises mainly porphyritic rhyolite and minor volcanioclastic rocks. It lies with conformity or mild disconformity on the coarse-grained siliciclastic Ritarango Formation, and in turn is overlain conformably by the sandstone-mudstone succession of the Sheridan Member. Outcrop of this unit occurs in the northern and southern parts of Mitchell Ranges, in both ARNHEM BAY—GOVE and BLUE MUD BAY. The individual successions are separated by a considerable distance (30 km), and despite similarities, strict chronostratigraphic correlation is not possible.

The best sections of porphyritic rhyolite and associated volcanioclastics are in BLUE MUD BAY, where access is by helicopter only. A type section was nominated by Rawlings and others (1997) along the Koolatong River between GR NF589537 and NF581543. A volcanioclastic sequence exposed nearby at GR NF600600 was nominated as a reference area.

This unit is between 150 and 250 m thick and appears to maintain uniform thickness throughout Mitchell Ranges, consistent with a sheet-like form. Outcrop is typically recessive, with brown, yellow and grey phototones. Outcrop is generally comprised of small bare brown domes, separated by green phototones depicting vegetation.

The principal rock-type is porphyritic rhyolite, associated with minor volcanioclastics, and rare dolerite. Outcrops comprise blocks, rounded exfoliating boulders and low rubble rises of pink, green or brown rhyolite. In hand specimen (Plate 6), it comprises 30-45% phenocrysts/megacrysts of large pink ovoid K-feldspar up to 4 cm (average 1-1.5 cm), 0-10% quartz up to 1 cm (average 0.25 cm) and 5% green altered albite to 1 cm. These are set in a grey-brown-purple cryptocrystalline to microcrystalline quartzofeldspathic groundmass.

In thin-section, K-feldspar phenocrysts are characterised by embayments and skeletal texture, patchy albite exsolution or microperthite. Small euhedral plagioclase inclusions (?primitocrysts) also occur within K-feldspar megacrysts. Stubby lath-shaped albite phenocrysts are euhedral to subhedral. Quartz is strongly embayed and resorbed and characteristically exhibits a concavo-convex fracture pattern, thought to be induced by thermal shock during emplacement.

* The latitude/longitude for the type locality proposed by Plumb and Roberts (1992), given as lat 13°15'30"S, long 135°33'E contains a typographical error and should read lat 13°07'30"S, long 135°33'E
Also present are small pseudomorphs after primary Fe-Ti minerals.

Poor outcrop and overprinted structural fabrics inhibit the recognition of primary emplacement features. Undeformed rock is massive and featureless, with no upsequence lithological variation. Fiamme-like foliated inclusions (flattened vesiculated autolasts), chlorite-quartz-carbonate-filled amygdales and lithic fragments are noted. Tectonic foliations resemble eutaxitic textures (pyroclastic welding) in the field and in thin-section. Small exposures of coarse-grained altered dolerite also occur locally, but may be related to younger periods of magmatism.

A typical outcrop of this member is noted from the southeastern-most exposures near GR NF608430. It comprises weakly porphyritic K-feldspar-quartz rhyolite with rare flattened vesicular autolasts and lithic fragments. The northeastern-most exposures around GR NF605565 are also distinct, comprising albite-rich quartz-poor porphyritic rhyolite. K-feldspar (15%), albite (15%) and rare quartz phenocrysts occur with minor altered ferromagnesian minerals or mafic clots (5%), in a red to black cryptocrystalline groundmass. Albite phenocrysts are noticeably euhedral, forming stubby laths up to 3 mm (average 0.75 mm). Small round amygdales and included lithic fragments of chert and vein quartz, are present. The rock exhibits a weak tectonic foliation and contains occasional vesicular autolasts, which may easily be confused with eutaxitic foliation and fiamme respectively.

Small exposures of coarse-grained altered dolerite occur locally, but may be related to younger magmatic periods.

Volcaniclastic rocks are associated with, and in cases intermingled with, porphyritic rhyolite bodies. They are mainly of epiplectic origin, their constituent volcanic materials having been redeposited by sedimentary processes not directly related to volcanism. These include coarse-grained (granular or pebbly) lithic or feldspathic sandstone and beds of red-brown-blue ferruginous mudstone/fine-grained sandstone. Sedimentary structures range from thin- to thick-bedding, massive- to trough-cross-bedding, ripples, and cross-lamination. Some rocks are possibly pyroclastic or redeposited pyroclastic. These are poorly bedded and contain almost exclusively felsic igneous materials with a distinctly fragmental appearance, including angular fractured quartz, feldspar and rock fragments, with minor mudstone intraclasts. In some cases (eg around GR NF600600) volcaniclastic deposits become difficult to distinguish from adjacent coherent volcanic rocks. Flattened clasts of green pumice are locally abundant.

Thin (<5 m) lenses of volcaniclastic sandstone and mudstone interfinger with the rhyolite bodies. They comprise mainly dark ferruginous lithic fine- to medium-grained sandstone and red-brown mudstone with localised ripples and rhombic evaporite casts. In thin-section, some mudstone contains relict glass shards, indicating pyroclastic contribution to sedimentation. Finely laminated crystal-poor mudstone around GR NF605565 is speculated to be airfall tuff. At one locality (GR NF585538), a volcaniclastic lens has been disrupted by the overlying igneous body, which also contains similar clasts in its base.

As discussed earlier, the contact between Maidjunga Member and the underlying Ritango Formation is conformable or weakly disconformable. This contact surface is sinuous, scalloped or crenulated in a north orientation on a scale of 10-100 m, most obvious on aerial photography (see section on 'Ritango Formation'). In the area west of Sheridan Fault, the Maidjunga Member is missing and an erosional (disconformable) contact occurs between Ritango Formation and Sheridan Member. Local clast lithology suggests that Maidjunga Member and the basal part of Sheridan Member have been stripped and the eroded material redeposited.

The upper boundary with Sheridan Member in many areas takes the form of a conformable volcanic-epiclastic relationship, where porphyritic rhyolite is overlain by progressively more mature volcaniclastic sandstone.

Many exposures of porphyritic rhyolite are foliated, with the long axis of phenocrysts aligned parallel to the foliation. Some phenocrysts also exhibit rotational features, indicating displacive layer-parallel shear of probable tectonic origin. In the more deformed cases, phenocrysts are stretched or attenuated in the same orientation. In thin-section, quartz phenocrysts exhibit undulose extinction, deformation lamellae, mechanical rounding and fragmentation. However, tectonic foliation is not always recognisable. In some cases, the groundmass develops a distinct convoluted banding and phenocrysts can lack evidence of ductile or brittle deformation, or rotation. These rocks can be mistaken for welded ignimbrite with a cutaxitic texture (cf. Williams and Burr, 1994), even in thin-section.

Sedimentary facies of the Maidjunga Member are typical of fluvial to shallow-water (?) lacustrine) deposition. Most igneous bodies appear to be volcanic, but some may also intrude shallow levels of the sediment pile as sills, dykes and cryptodomes. The association with fluvialite to shallow-water sedimentary sequences favours a subaerial extrusive setting. The widespread sheet nature of the deposits and the uniformity of rock-type are anomalous for a cohesive origin. Deposits of this type generally result from voluminous high-temperature pyroclastic flows (rhemorphic ignimbrite). The absence of pyroclastic textures and phenocryst fragmentation, and the local presence of autolasts, favour a low-viscosity effusive eruptive mechanism. This does not preclude the presence of associated intrusions and small isolated domes and coales, which probably involved eruption of high-viscosity magma.

Rhyolite porphyry from the Maidjunga Member in ARNH EM BAY-GOVE produced a SHRIMP single zircon U-Pb age of 1707±12 Ma (R. Page pers. comm., Rawlings and others, 1997).
**Sheridan Member (Elfs)**

The Sheridan Member is a sandstone-mudstone succession which lies conformably between the rhyolite Maidjunga Member and the mixed igneous-sedimentary Dhupuwamirri Member. Outcrop is restricted to two areas in the northern and southern parts of Mitchell Ranges. These two areas comprise distinct sedimentary successions that are separated by approximately 30 km of older Donydji Group rocks. For this reason, they are correlated by lithostratigraphy, not strict chronostratigraphy.

The Sheridan Member was adapted by Rawlings and others (1997) from the now redundant ‘Sheridan Formation’, originally mapped by Plumb and Roberts (1965) in BLUE MUD BAY. ‘Sheridan Formation’ included small outcrops of conglomerate on the western side of Mattamurra Fault, near GR NF480510. The term was formalised by Plumb and Roberts (1992) and a reference area defined at lat 13°06’S, long 135°24’30”E. Its stratigraphic relationships were poorly understood, as it was seen to unconformably overlie ‘Ritarango beds’ and Fagan Volcanics, yet be older than Parsons Range Group. During the current mapping, unconformable relationship with Ritarango Formation and conformable relationship with Dhupuwamirri Member were established. A broad correlation, based on facies characteristics, was also made between these conglomeratic rocks and the mudstone-sandstone sequence in the middle Fagan Volcanics to the east. They have both been subsequently mapped as Sheridan Member of Fagan Volcanics, and the name ‘Sheridan Formation’ abandoned.

The most complete and representative sections of this unit are in BLUE MUD BAY, where access is feasible by helicopter only. A type section for the sandstone-mudstone lithofacies was nominated by Rawlings and others (1997) for exposures between GR NF592490 and NF586486. For ease of access, incomplete exposures adjacent to the Central Arnhem Road around GR NF680960 (ARNHEM BAY-GOVE) were nominated as a reference area. The localised sandstone-mudstone-conglomerate lithofacies recognised only in BLUE MUD BAY, (‘Sheridan Formation’ of Plumb and Roberts 1965), is best exposed west of the Sheridan Fault. Their original reference area near GR NF480510 was retained by Rawlings and others (1997).

In BLUE MUD BAY, the thickness of this member varies from east to west across several major faults. East of the Mattamurra Fault, the unit is uniformly 250 m thick where sandstone and mudstone make up the succession. West of Mattamurra Fault, the anomalously thick sandstone-mudstone-conglomerate lithofacies may be more than 400 m thick.

This unit is characterised by variable erosional resistance and dark brown aerial phototones. Prominently banded strike ridges are caused by interbedding (on a 20 m scale) of mudstone and sandstone.

As mentioned earlier, the individual successions in ARNHEM BAY-GOVE and BLUE MUD BAY are correlated lithostratigraphically. In both areas the unit consists of sandstone and mudstone, with a localised conglomerate restricted to BLUE MUD BAY.

In BLUE MUD BAY, the Sheridan Member comprises mainly sandstone and mudstone interbedded on scales ranging from 5 cm to 50 m, but mostly in the order of 20 m. West of Mattamurra Fault, a thicker sequence is evident and mudstone/sandstone are interbedded on a 30–40 m scale. Beds of pebbly and conglomeratic sandstone also become prominent in the sequence.

The sandstone is generally fine- to medium-grained (locally coarse), and variably quartzose, lithic or feldspathic. There is an apparent overall trend of the sandstone becoming cleaner and coarser upsequence. Quartz grains are angular to well-rounded and poorly- to well-sorted. Colour varies from white, pink, grey, red and maroon. Outcrop is thin- to very thick-bedded, commonly with low-angle trough cross-bedding. Mudclasts, mudclast impressions and ripples (both symmetrical and asymmetrical types) are locally prolific. Ripples include linear, sinuous and bifurcating types, characterised by high amplitude to wavelength ratios, and
steep crests. The top of the succession is typically a dip slope of white silicified medium-grained thick-bededded cross-bededded quartzose sandstone.

The base of the member is locally lithic and immature, comprising coarse-grained, poorly- to moderately-sorted, lithic and feldspathic sandstone. Angular volcanic-derived quartz grains and felsic igneous rock fragments are common, indicating an epiclastic origin. Bedding is medium- to thick-bededded, massive to diffuse, with large-scale trough cross-beds.

A gradational conformable relationship exists with the underlying rhyolitic Maidjunga Member.

In thin-section, the most common rock fragments are porphyry, intraclastic mudstone and fine-grained sandstone. The porphyry comprises K-feldspar and quartz with a spherulitic to micrographic groundmass. Detrital K-feldspar is common and retains original features such as microporphyritic intergrowths, patchy albite exsolution and relict embayments. Detrital quartz grains exhibit features indicative of felsic igneous provenance. A small population of detrital grains has a mixed metamorphic and sedimentary origin. These features reflect derivation from Maidjunga porphyritic rhyolite, with a smaller contribution from the Mirarrmina Complex and Ritarango Formation.

Mudstone is red, brown or grey, micaceous, ferruginous and lithic. Outer surfaces are white, hard and silicified. Internally it ranges from massive to diffusely bedded to flat-laminated (flamy to medium-bededded). Mudstone and sandstone are generally discrete or independent rock-types, but locally they grade into one another. Some mudstone beds are significantly sandy with scattered fine- to medium-sized grains of quartz. The mudstone intervals are also the source of intraclasts within the interbedded sandstone. In some areas, thick monotonous mudstone sections, with little or no sandstone, dominate the sequence.

Plumb and Roberts (1992) suggested that this mudstone had a significant tuffaceous component. More recent petrographic studies (Rawlings, 1995) indicate they are volcanioclastic, but not necessarily pyroclastic. In thin-section they are composed of clay- to medium sand-size materials. The coarse fraction is dominantly quartz, whilst sericite, quartz and feldspar are the fine fraction. Fine-grained quartz is diagnostically angular and splintery in shape, but typically round in the coarse fraction. The mud-grade fraction is finely laminated, but frequently disrupted. No definitive vitriclastic textures are present.

The well-rounded and well-sorted nature of the coarse quartz fraction, even in the most mineralogically immature mudstone and sandstone, is intriguing. It may reflect the dominantly spherical nature and unimodal size distribution of quartz in the source rocks (presumably Maidjunga porphyritic rhyolite). These are characterised by phenocrysts of embayed near-spherical bipyramidal beta-quartz and microporphyritic K-feldspar. For this reason, the apparently mature quartz does not reflect a high degree of transport, but rather the characteristic of the source rocks.

The small population of quartz grains with a splintery fragmental appearance in mudstone was possibly misinterpreted by Plumb and Roberts (1992) to indicate a pyroclastic derivation. Gimeno (1994) was able to demonstrate that angular splintery quartz could also be generated by stripping materials from subaqueous lava domes which had undergone thermal shock. Evidence from thin-section studies of the rhyolite source (Maidjunga Member), including the characteristic concavo-convex fracture pattern within quartz phenocrysts, indicates thermal fracturing has taken place.

Mudstone and sandstone are also interbedded on the cm- to dm-scale, giving rise to wavy bedding, pinch and swell structures, slump structures, load casts, flame structures and synaeresis and desiccation cracks. Mudclasts are particularly common. Shallowing-upward cycles (sanding-up or thickening-up) are recognised where outcrop is continuous.

West of the Mattamurta Fault, the succession appears to become thicker and more complicated. Fault bounded blocks of coarser-grained and more immature sandstone than those described earlier occur with typical sandstone and mudstone. They are feldspathic, lithic, and locally pebbly, with clasts of felsic volcanic rock, mudstone, quartzite and vein quartz.

Immediately west of Sheridan Fault, this succession becomes further complicated. Various rock-types occur in the interval between Ritarango Formation and the igneous Dhupuwarirri Member. These include thick intervals of red-brown micaceous and ferruginous mudstone with sparse thin (<5 m) intervals of white fine- to medium-grained lithic sandstone. Mudstone is massive to thinly laminated with common ripples and occasional shrinkage cracks. Erratic and poorly defined units of white-grey-maroon coarse-grained lithic sandstone, pebbly to cobbly sandstone and open-framework conglomerate are common. They contain numerous clasts of mudstone, lesser felsic igneous rock and sandstone, and minor vein quartz and quartzite. They display low maturity and poor sorting, comprising angular grains and rock fragments. However, locally pebbly and cobbly sandstone is composed of well-rounded quartzite and felsic igneous clasts to 30 cm, in an angular sand matrix.

A contact between mudstone and coarse sandstone/conglomerate lithofacies is well exposed at GR NF476508. The contact takes the form of an erosional channel incising deeply into mudstone. One side is controlled by a low-angle normal fault. The sequence is at least 15 m thick and fines upward. Cobble and boulder conglomerate with abundant sub-rounded clasts of sandstone and rhyolite, grades up into white friable medium- to coarse-grained lithic sandstone with trough cross-bedding and current ripples. Large-scale trough cross-bedding and diffuse bedding predominate at the base.

Thin-section studies (Rawlings, 1995) indicate that the conglomeratic lithofacies had a similar provenance to that of the sandstone-mudstone lithofacies east of Sheridan Fault. They are derived mainly from Maidjunga porphyritic rhyolite, with a smaller contribution from Mirarrmina Complex and Ritarango Formation.

The boundary between Sheridan Member and the
underlying Maidjunga Member, as described earlier, is con-
formable, with porphyritic rhyolite overlain by a maturing-
upward succession of volcaniclastic sandstone. The contact
with the overlying Dhupuwamirri Member is conformable
and generally well exposed. Flow-banded, partly
ambygdaloidal and autoclastic, porphyritic rhyolite of the
Dhupuwamirri Member sits on red-brown mudstone and
white sandstone of the Sheridan Member. A peperite base
indicates emplacement of the extrusive body onto wet un-
consolidated sediment.

These relationships may not continue west of Mattamurta
Fault, where the sequence becomes thicker and more
complicated and there are fault bounded blocks of coarser-
grained immature sandstone. Immediately west of Sheridan
Fault, the Maidjunga Member appears to be absent and the
Sheridan Member sits unconformably on Ritararongo
Formation. Clast lithology suggests that Maidjunga Member
and part of Sheridan have been stripped and redeposited
locally.

Sandstone is locally foliated and quartz-veined, in most
cases due to faulting. This can become quite intense, result-
ing in extreme quartz grain attenuation (up to 700%), quartz
fracturing, abundant sub-grain development and recrystallisation, and destruction and reconstitution of lithic
fragments. In high stress zones, coarse-grained lithic sand-
stone displays low structural competence and is generally the
most sheared and foliated. The more mature sandstone tends
to develop a widely-spaced fracture cleavage in these zones.
Mudstone in places has taken on the local structure as a
closely-spaced cleavage.

Bedforms in the sandstone indicate that Sheridan Member
was deposited in a shallow-water, low- to moderate-energy
setting, perhaps a fan-delta. The depositional setting of
mudstone is, by association with sandstone, similarly shallow-
water and occasionally emergent. This is consistent with
features such as slumps, load casts, flame structures, synaeresis and desiccation cracks, and mudclasts.
The shallowing-upwards cycles in this facies reflect fluctuating
delta conditions. Possible evaporites were noted in the upper
part, east of the Mattamurta Fault, suggesting the onset of
sabkha conditions.

West of the Mattamurta Fault, the sequence contains
cosser higher-energy conglomeratic deposits. The
Mattamurta and Sheridan Faults are thought to have been
active during deposition of the upper part of this member.
During faulting, areas of rhyolite and un lithified sandstone
and mudstone were uplifted and rapidly stripped, forming
alluvial fans adjacent to the fault zones.

The age of this member is constrained by 1710 Ma U-Pb
SHRIMP zircon determinations (Rawlings and others, 1997)
of the enclosing Maidjunga and Dhupuwamirri Members.

Dhupuwamirri Member (EifØ)

The Dhupuwamirri Member is a complicated succession of
felsic and mafic igneous rocks, and lesser sandstone and
mudstone. It lies conformably between the Sheridan
sandstone-mudstone sequence and the quartzose sandstone
of the Parsons Range Group. Outcrop is restricted to two areas
in the northern and southern parts of Mitchell Ranges,
separated by the older Donydji Group. These areas comprise
two distinct igneous-sedimentary assemblages that show
broad lithostratigraphic similarities. The southern succession
is represented entirely within BLUE MUD BAY and is
considered a discrete entity in this report.

In BLUE MUD BAY, outcrop in high-relief areas is deeply
incised by tributaries of the Koolatong River and many
complete sections exist. Unfortunately, these are difficult to
access. The best sections follow the upper part of the river
between GR NF550540 and NF540490 which is the
nominated type section (Rawlings and others, 1997). It
comprises abundant intrusive and hybrid rocks. A reference
area, around GR NF580470, comprises a more diverse
sedimentary-dominated succession. Easily accessible outcrop
adjacent to the Central Arnhem Road near GR NF600880
(ARNHEM BAY-GOVE) is representative of the local vol-
canic rocks, but is incomplete.

The member has a uniform thickness of 450 m from east
to west across Mitchell Ranges. In some areas however, it is
thickened by an intrusive component.

Outcrop of Dhupuwamirri Member is typically recessive
and characterised by moderate to dark red-brown aerial
phototones. Some outcrops are sparsely vegetated domes and
boulders, which appear on aerial photographs as patches of
pale brown surrounded by vegetated dark green areas.

The individual successions in ARNHEM BAY-GOVE
and BLUE MUD BAY are mostly similar, however, a larger
proportion of the member in BLUE MUD BAY is mafic
igneous rocks and associated hybrids.

There is significant variation in igneous stratigraphy along
strike from east to west, particularly between areas divided
by major faults. For this reason, the stratigraphy and lithology
of igneous rock-types in each major fault-confined area are
described and compared. Sedimentary rocks are discussed
separately.

In the eastern part of the ranges (east of Fagan Fault),
there appears to be one single concordant felsic igneous unit,
of probable extrusive origin. Here it is the lowermost unit
of the member and is overlain by a thick sedimentary succession,
with minor intercalations of mainly extrusive basalt near the
top. The felsic unit is a monotonous porphyritic (K-feldspar-
quartz-albite) rhyolite. Phenocrysts of pink K-feldspar (30%)
plus lesser quartz (10%), minor green plagioclase (<5%, now
altered albite) and ferromagnesian minerals are set in a black
(fresh or silicified) to green, pink or red (altered or oxidised)
cryptocrystalline groundmass.

In thin-section, K-feldspar phenocrysts are microperthitic
and may exhibit patchy albite exsolution. They average 0.1
cm diameter, with a maximum of 1 cm. They typically form
stubby laths and are intricately embayed and strongly
resorbed, in places with spectacular skeletal textures. Resorption of K-feldspar is so intense in some specimens that they develop a fragmental appearance. Quartz phenocrysts average 0.05 cm diameter, with a maximum of 0.4 cm, and are also strongly resorbed and embayed. Many grains are cris-crossed by interconnecting curvilinear cracks, healed by silica and oxide. These are thought to result from thermal shock, as described by Gimeno (1994). Millimeter-sized glomerophenocrysts made of coarse K-feldspar, chlorite, sphene, biotite, opaques and zircon are present. These are thought to be relict mafic clots.

The groundmass is typically composed of crypto- to microcrystalline quartz, feldspar, opaques and minor chlorite. In the carapace rock of this igneous body, there is evidence of spherulites and stretched amygdalae, filled by secondary quartz, carbonate, sericite and chlorite. Near the top of the rhyolite body, outcrop is characterised by columnar jointing, contorted flow-bandning, autobreccia and rarely, collapsed pumiceous autobreccas.

A basal peperite is locally developed where rhyolite has been brecciated and incorporated into underlying wet sandstone of the Sheridan Member during emplacement. This breccia comprises angular to rounded cobble-sized clasts of rhyolite set in a lithic sandy matrix. Sandstone also fills joints in the rhyolite.

Rhyolite has undergone patchy alteration. Around GR NF612602, chlorite-sericite-carbonate alteration has resulted in unusual textures at outcrop and hand-specimen scale. Irregular green blebs and stringers of altered rock appear to invade and coalesce with less altered pink rock.

Near the top of the member, a number of amygdaloidal basalt and microdolerite bodies are intermingled (on a 5-10 m scale) with sandstone and mudstone. The body margins are fine-grained (chilled), occasionally autobrecciated and amygdaloidal (chlorite and haematite fill). Large (up to 6 cm) megacrysts of K-feldspar (and rare quartz) are present in one of the bodies. At GR NF583466, the upper surface of one basalt body is smooth and bulbous and overlain by mudclast-rich sandstone (Plate 7). This contact is interpreted to be a mild erosional surface, inferring the body to be extrusive. At most other localities, field relationships are inconclusive.

In the central part of Mitchell Ranges (between Sheridan and Fagan Faults), the sequence comprises a thick composite volcanic section, overlain by an equally thick sedimentary package. The volcanic section is composed of numerous sheets of felsic, mafic and hybrid rocks, each about 20 m thick. The top and bottom of each body is flow-banded (Plate 8) and autobrecciated. Some bodies have basal ramp structures and contorted underlying rocks. The uppermost sheet, possibly 50 m thick, is amygdaloidal and exhibits abundant flow features. It is thought to correlate with the top of the extrusive felsic unit on the eastern side of Fagan Fault.

In the lower part of the volcanic sequence, which is probably mainly intrusive, rhyolite is associated with dolerite and hybrid rocks. Rhyolite is porphyritic, with K-feldspar, quartz and plagioclase phenocrysts in a brown to black cryptocrystalline groundmass, and is petrographically indistinguishable from the extrusive rhyolite described earlier.

Dolerite and hybrid rocks are coarser than the rhyolite and are concentrated in the core of individual sheets. They exhibit a close spatial and temporal relationship, suggesting mixing of felsic and mafic magma. Dolerite is fresh, fine- to coarse-grained, and locally porphyritic. In thin-section, it is made up of coarse laths of plagioclase (50%), intergranular to ophitic pyroxene (40%), and minor interstitial opaques (5%) and quartz (5%). Accessory and minor mineral phases include K-feldspar and apatite.

Large xenocrysts of K-feldspar (up to 6 cm) and smaller quartz (<1 cm) are present locally, constituting 5%. K-feldspar xenocrysts are typically skeletal and poikilitic, with abundant inclusions of ferromagnesian minerals. They are surrounded by an outer margin free of inclusions, thought to be a reaction corona. Quartz xenocrysts are strongly embayed and resorbed. Also noted are occasional corroded masses of fine-grained equigranular metadolerite up to 1 cm in diameter. These and other disequilibrium textures, such as granophyre and micrographic intergrowths, suggest that the dolerite is a mafic magmatic hybrid.

Genuine hybrid rocks range from dark melanocratic dolerite (most mafic) to pink leucocratic K-feldspar-quartz porphyry with green/black spots. In thin-section, the groundmass is primarily granophyre or micrographic intergrowths of K-feldspar, quartz and minor albite, together with ferromagnesian minerals. A characteristic feature is spectacular columniform intergrowths of quartz and feldspar, radiating from small euhedral microperthitic K-feldspar grains. In some examples, acicular bladed K-feldspar and equant wedge-shaped interstitial quartz are radially intergrown.

Ferromagnesian minerals are distributed in two ways; finely dispersed in the groundmass; and as mafic clots up to 3 cm (average 3 mm). In many cases mafic clots dominate, leaving a transparent granophyric quartz-feldspar groundmass. In other cases, ferromagnesian minerals are even more dispersed in the groundmass, imposing a transopaque appearance. These two mafic components merge in the most melanocratic rocks. Compositionally, the clots are made up of pyroxene, amphibole, chlorite, plagioclase (mostly albite), orthoclase, opaque oxide, and in places epidote, sphene and zircon. Many clots are interpreted as metabasaltic inclusions, while others appear to be pseudomorphs after pyroxene phenocrysts.

Large residual xenocrysts of K-feldspar and quartz are locally common and exhibit disequilibrium textures as described earlier.

In the western part of Mitchell Ranges (west of Sheridan Fault), porphyritic K-feldspar-quartz rhyolite and minor dolerite and hybrid rock form a large composite sheeted body within the middle to upper part of the sedimentary succes-
sion. This is lithologically similar to, and probably correlates with, the sheeted igneous sequence east of Sheridan Fault but intrudes at a higher level in the stratigraphy. It is interpreted as a shallow-level sill in several places, but may be extrusive along strike. At GR N466475, the upper contact between the igneous body and overlying mudstone is demonstrably intrusive. A closed-framework peperitic breccia (Plate 9) is common, comprising large (up to 1 m), equant and angular rhyolite clasts in a mudstone/sandstone matrix. Bordering this, slender tongues of mudstone form fracture-fillings into the top of the sill. These features indicate that liquefied mudstone has been forcibly injected into fractures and joints in the rhyolite during emplacement.

The varied stratigraphic position of the sedimentary sequence relative to the igneous units appears to be the result of intrusion into various levels of the sedimentary pile. The sills have gradually transgressed the stratigraphy as they moved upward and outward from the site of intrusion, apparently using faults as conduits. On the extremities, they eventually become extrusive.

The central part of Mitchell Ranges, between Sheridan and Fagan Faults, appears to be the principal site of intrusion. Here, the composite sill is thickest and the sedimentary succession lies above the sill, indicating intrusion into the lower levels of the member. Inversely, on the eastern side of the ranges (east of Fagan Fault), the main sill is absent, and contiguous extrusive basaltic units occur near the top of the member. Sedimentary rocks lie uninterrupted between the basal felsic lava unit and the basalts. On the western side of the ranges (west of Sheridan Fault), the sedimentary succession appears to be condensed, and occurs both above and below the main sill, which borders on being emergent.

The sedimentary succession comprises mainly sandstone and lesser mudstone. Sandstone ranges from fine- to coarse-grained (rarely pebbly), lithic to quartzose, grey/purple to white, silicified to vuggy, and thin- to thick-bedded. Trough cross-bedding and ripples are common sedimentary structures.

The most distinct and traceable sandstone bed is near the base of the Dhupuwamirri Member, approximately 10 m above the basal felsic volcanic unit. It is coarse-grained (granular in places), vuggy, grey/purple to maroon, lithic, with prominent trough cross-bedding. Most noticeable is the high lithic component, which includes felsic igneous rock fragments and grey to purple mudstone intraclasts. Thin-section studies by Rawlings (1995) indicate the sandstone has a volcanioclastic provenance, indistinguishable from rhyolite of the Fagan Volcanics. Similar sandstone also occurs sporadically higher in the sequence, but is discontinuous along strike.

Mudstone is grey-green to red-brown in colour, slightly micaceous and ferruginous, and sandy. It is massive to crudely bedded, with small-scale trough cross-beds and ripples. Grey laminated micaceous-pyritic-dolomitic mudstone and coarse-grained dolomitic sandstone have been recognised from several levels. Water escape structures and intraclastic beds have in places led to the complete destruction of bedding, giving rise to a massive fabric. This process probably took place during dewatering with the aid of igneous-related seismic activity.

Some of the thicker (up to 40 m) monotonous mudstone intervals are lithologically indistinguishable from those in the underlying Sheridan Member. These thick intervals prograde laterally into interbedded sandstone-mudstone sequences.

Mudstone and sandstone are interbedded on a 10 m- to cm-scale. The cm to dm interbedded sections exhibit wavy bedding, soft-sediment deformation features (slumps), cross-lamination, ripple laminations and shrinkage cracks. Ripple forms include symmetrical or less commonly asymmetrical, interference, small- to medium-scale, linear and sinuous. Interbedded sandstone is lithic, medium-bedded and trough cross-bedded.

Toward the top of the sequence, mudclasts and mudclast impressions become common, and flaser bedding and hummocky cross-stratification are developed. Sandstone is mottled or uniformly ferruginous. Some levels are pervasively pitted with iron oxides, perhaps after pyrite or evaporites. On the eastern side of Mitchell Ranges, mainly extrusive amygdaoidal basalt and microdolerite is interbedded with sandstone and mudstone in this top part of the sequence. The contact with the overlying Mattamurra Sandstone is conformable with gradation from lithic- and matrix-rich sandstone and mudstone into quartzose sandstone.

On the western side of Mitchell Ranges, the sequence above and below the composite sill is dominated by mudstone, not unlike that described from adjacent areas. A sharp but conformable contact occurs between this mudstone and the overlying quartzose sandstone of the Parsons Range Group.

Discontinuous lenses of variably disrupted sandstone and mudstone also occur as enclaves within some sills. A peperitic breccia at the base of the lower volcanic unit of Dhupuwamirri Member indicates conformable contact with Sheridan Member mudstone and sandstone.

A conformable contact also separates the Dhupuwamirri Member from the overlying medium-grained quartzose sandstone of the Mattamurra Sandstone. This contact is interpreted as a sequence (chronostratigraphic) boundary and is sharply discernible on aerial photographs and in outcrop. However, the rock-type directly underlying this sequence boundary varies considerably along strike, to include red-brown mudstone, lithic sandstone and igneous rocks. This variation may be related to rapid lateral transitions in sedimentary facies, probably in response to emplacement of intrusive igneous bodies in the subsurface. The extrusive igneous units occupy a stratigraphic level at or near the sequence boundary.

All rocks are deformed adjacent to fault zones. Porphrytic rhyolite and coarse-grained lithic sandstone have a shear-related foliation. Foliations within rhyolite resemble welded
Plate 7 Irregular erosional contact between basalt and intraclastic sandstone, Dhupuwamirri Member of the Fagan Volcanics, GR NF583466, south of Koolatong River. Scale is 10 cm long.

Plate 8 Contorted flow banding in rhyolite of Dhupuwamirri Member of the Fagan Volcanics, GR NF543510, south of Koolatong River.

Plate 9 Peperitic breccia at top of shallow-level rhyolite sill in Dhupuwamirri Member of the Fagan Volcanics, GR NF466475, headwaters of Koolatong River. Scale is 10 cm long.
pyroclastic (eutaxitic) textures, even in thin-section, and appear to be the basis of Plumb and Roberts (1992) incorrect assertion that Fagan Volcanics is mostly pyroclastic. The development of foliation in the lithic sandstone is enhanced by pre-deformational alteration of unstable rock fragments and matrix.

The sedimentary lithofacies are not unlike that of the Sheridan Member, which deposited in a shallow water, low- to moderate-energy setting, perhaps a fan-delta. There does appear to be a greater diversity of sedimentary lithofacies, which may reflect the influence of shallow magmatism. The lower concordant felsic igneous body is likely to be extrusive, and textural features favour an effusive mode of emplacement. Conversely, some igneous bodies appear to transgress the stratigraphy along strike, indicating emplacement as shallow sills. An intrusive aspect can also be demonstrated from features such as peritectic upper margins, which indicate intrusion into wet sediment at shallow depths. There is considerable evidence that many of these igneous bodies, while being largely intrusive, have in places emerged to the sediment-water interface (ie cryptodomes). This is consistent with the abundance of locally-derived felsic igneous detritus in the enclosing sedimentary units, much of which is petrographically indistinguishable from the intraformational rhyolite.

Dhupawamirri porphyritic rhyolite produced a SHRIMP single zircon U-Pb age of 1706±10 Ma (R. Page, pers. comm., 1992). The sample was collected from a felsic igneous sheet near GR NF547518 (Koolatong).

**Regional correlation**

Rawlings (1994) first attempted regional correlation of the Donydj Group based on geochemical, petrological, lithostratigraphic and geochronological constraints, and the physical form of igneous units. Donydj Group, as an entity, equates stratigraphically to parts of the Tawallah and Katherine River Groups in the southern and western parts of the McArthur Basin.

On the basis of geochemistry, the upper part of the Donydj Group (Fagan Volcanics) correlates with igneous units of the Spencer Creek Group in northern ARNHEM BAY—GOVE. It also tentatively correlates with the Gadabara Volcanics in northeastern BLUE MUD BAY. Fagan Volcanics actually represent the type unit for the 'Fagan phase', which includes suites of felsic volcanics in the southern McArthur Basin (Hobblechain Rhyolite, Tanumbirini Rhyolite, Pucksaddle Microgranite) and western McArthur Basin (West Branch Volcanics). This unit may also be the volcanic equivalent of some of the undifferentiated rhyolite dykes (P*) elsewhere in the region, such as the K-feldspar-quartz porphyry intrusions within the nearby Mirarrmina Complex.

Furthermore, the close spatial and temporal relationship between Fagan Volcanics and underlying Ritararango Formation also favours correlation with the 'Fagan phase' and hence with the upper part of Tawallah and Katherine River Groups. Its association of coarse lithic-rich clastics with felsic volcanic rocks is also consistent with the lithological characteristics of this phase.

The mature sandstone-mudstone sequence in the lowest Dhunngarda Formation, is poorly constrained in age (1870-1710 Ma). Tentative lithostratigraphic correlation may be made with the upper Groote Eylandt Group (Alyangula Subgroup), and the Shadforth Sandstone/McCaw Formation couplet* (middle Katherine River Group), Wanunumtyala Sandstone/Wollogorang Formation couplet (middle Tawallah Group) and Gove Sandstone/Yuduyudu Formation couplet (Spencer Creek Group). Excluding structural characteristics, they all have similar lithofacies and petrology. This is consistent with regional correlation with the 'Tawallah phase' by Rawlings (1994). Felsic igneous rocks in the upper part of this formation are more akin to the 'Fagan phase' of Rawlings (1994), suggesting greater affinity with the upper part of Donydj Group.

**Unassigned to group**

**Gadabara Volcanics (P*)**

*By D.J. Rawlings*

The Gadabara Volcanics (new name, see APPENDIX) include an assemblage of volcanic, volcanoclastic and shallow intrusive rocks which are exposed over a small area on Round Hill Island in northeastern BLUE MUD BAY. They intrude and overlie the Bradshaw Complex and Woodah Sandstone and are in turn overlain unconformably by Coast Range Sandstone.

Outcrop assigned to Gadabara Volcanics was previously mapped as 'Bickerton Volcanics' (Plumb and Roberts, 1965). This term is abandoned as a result of the current mapping on Groote Eylandt and Bickerton Island (Pietsch and others, 1997), because outcrops were found to be non-correlatives, and in many cases different in age. These outcrops have subsequently been attributed to a series of new formations, including Gadabara Volcanics. A type locality has been assigned to exposures at the southern tip of Round Hill Island (GR PF181269).

The unit is composed of a 50 m-thick composite sequence of felsic igneous rock (rhyolite?) of likely volcanic, shallow intrusive and possibly volcanoclastic origin. Outcrop is resistant and comprises blocks, boulders and rubble of salmon pink, orange or brown rock, which exhibits dark red-brown aerial phototones.

About half of the exposure on Round Hill Island is coherent pink rock, the other half is volcanic breccia. The coherent rock is generally microcrystalline and aphyric to slightly porphyritic, and takes the form of dykes, sills and lava flows. It contains up to 30% small (average 1 mm wide and 4 mm long) euhedral lath-shaped phenocrysts of altered K-feldspar. In hand specimen, it resembles fine-grained pink

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*A couplet is an amalgamation of two vertically adjacent, genetically related formations which facilitates regional correlation.*
sandstone. Accessory fragments of sandstone and granite occur. Locally common amygdales contain quartz, chalcedony, amethyst and opaque oxides. Alteration and/or weathering result in the replacement of feldspar by white and orange clay, sericite and muscovite. Abundant dykes intrude the Bradshaw Complex on the western side of the island, and volcanic breccia elsewhere on the island. They are usually less than 1 m wide and are linear and sinuous, whereby they are irregular, indicating multiple generations. They range from vaguely to profusely banded (Plate 10) and are more aphyric than the lavas. The flows exhibit contorted flow banding, which dips steeply away from the centre of the island - the inferred volcanic edifice. They also contain occasional rafts of contorted sandstone, presumably derived from underlying Woodah Sandstone.

In thin-section, the groundmass of the coherent rock comprises small aligned feldspar laths with felted trachytic texture. These are now K-feldspar, but their original composition remains uncertain. The phenocrysts feldspar exhibits relic simple twins and appears to have been sanidine.

Volcanic breccia ranges from fine-grained volcanic sandstone to block and boulder volcanic breccia, and generally underlies or has been intruded by the coherent rock. Clasts range between mm- and m-size, but average less than mm-size. They are angular- or pillow-shaped and comprised mainly of pink-orange 'rhyolite' as described above. Mudgrade volcanioclastic material makes up the matrix. Breccias are generally unstratified, suggesting they formed in situ. In some cases, a crude stratification and size-grading is indicative of minor transport as a cohesive mass flow or semi-cohesive debris flow.

In thin-section, volcanic sandstone is composed of orange felsic igneous rock that is indistinguishable from the coherent phase. Locally, a variety of other fragment types become prominent, including lithic matrix-rich sandstone and mudstone (Grindall Formation), granite and composite quartz and feldspar fragments (Bukudal Granite and Bradshaw Complex), and detrital quartz sand with truncated overgrowths (Woodah Sandstone). This variety indicates derivation from a broad spectrum of units and hence an extensive subsurface source area. It is obvious that the source rocks were fragmented and finely comminuted prior to incorporation into the sandstone breccia, suggesting they may be pyroclasts. This is consistent with the fine-grained nature of the matrix.

This composite sequence appears to have evolved by repeated emplacement of lava flows and associated talus breccia from a single eruption site, interpreted to be the centre of the current island. These breccias were created by the combination of coarse autoclastic and hyaloclastic fragments from the flows, and finer-grained lithic material derived during concurrent pyroclastic activity, into debris- and mass-flows. Pyroclastic activity probably took the form of sporadic phreatic and phreatomagmatic eruptions. The resulting lava and talus breccia deposit became successively intruded during ensuing magmatic pulses. This process probably built up a small discrete volcanic pile, comparable to the current size of the island.

The age of the Gadabarn Volcanics is not well constrained. It intrudes and lies stratigraphically above Woodah Sandstone, indicating an age younger than the 1814 Ma Bickerton Rhyolite. The unconformably overlying Coast Range Sandstone is tentatively correlated with Parsons Range Group, which has a minimum age of 1640 Ma (the oldest age obtained from the McArthur Group, laterally equivalent to the overlying Balma Group; Haines, 1994.). In many ways Gadabarn Volcanics are similar to the 1710 Ma Yanunghi Volcanics in ARNHEM BAY–GOVE (Rawlings and others, 1997), and occupy a similar stratigraphic position. On this basis, they would also correlate with Fagan Volcanics to the west.

Parsons Range Group

*By I.P. Sweet*

The Parsons Range Group is a 5 to 6 km-thick succession of mainly siliciclastic sedimentary rocks that form the Parsons Range and the southern Mitchell Ranges in western and northern BLUE MUD BAY. Total outcrop area is around 1600 km², and geophysical evidence suggests that the group is present in the subsurface west of Parsons Range (Plumb, in Rawlings and others, 1997). The group lies conformably between Donyjdi Group (below) and Balma Group (above). Its maximum age is constrained by the age of the uppermost formation of the Donyjdi Group (Fagan Volcanics) at 1710 Ma (Pietsch and others, 1994). Its minimum age is less well constrained, but must be greater than the 1621 Ma Yarrawirrie Formation, in the overlying Balma Group, and the 1640 Ma Barney Creek Formation in the southern McArthur Basin (Pietsch and others, 1994).

Parsons Range Group was mapped informally by Crohn (1956) as the 'Parsons Range Formation', and remapped and subdivided into four formations during BMR regional mapping in 1962 (Plumb and Roberts, 1965, 1992; Dunnet, 1965). This nomenclature has been retained and in addition, 14 members, three of them formally named, have been recognised within the Badalngarmirri Formation. The stratigraphy of the group is summarised in Table 5. Reference sections, rather than type sections, for four formations were defined by Plumb and Roberts (1992), in recognition of the reconnaissance nature of the mapping (Dunnet, 1965; Plumb and Roberts, 1965). The various formations and members have now been formally defined (see APPENDIX). Sections measured during this study (locations in Figure 6) are presented schematically in Figure 7.

Quartzarenite is the dominant lithology in all formations except the Marura Siltstone, and is virtually the sole lithology in the basal and top formations. In the Badalngarmirri Formation, quartzarenite alternates with mudstone, siltstone, chert, and iron-rich (glaucolithic and pyritic) arenite and mudstone. Marura Siltstone was distinguished from Badalngarmirri Formation by Plumb and Roberts (1992) based on a change from quartzarenite to lutitic (siltstone and mudstone). This is not a particularly satisfactory criterion, given the presence of siltstone and mudstone in recessive units throughout the Badalngarmirri Formation. Nevertheless, for
practical reasons, the existing nomenclature is retained.

Regionally, the Parsons Range Group appears not to have any clear correlatives in the McArthur Basin. The Masterton Sandstone of the southern McArthur Basin may be equivalent to the Fleming Sandstone. However, the remainder of the group below the Fleming Sandstone appears to occupy the time represented by the hiatus between the Masterton Sandstone and the underlying Tawallah Group. Further afield, the Surprise Creek Formation in the Mount Isa Inlier (Derrick and others, 1980) occupies a similar stratigraphic position in relation to older volcanics and younger sedimentary sequences.

**Mattamurta Sandstone** (Ppt)

The Mattamurta Sandstone is a thick succession of mainly coarse-grained to pebbly quartzarenite which crops out as a broad arcuate ridge or plateau up to 17 km wide in northern BLUE MUD BAY. Outcrops narrow gradually to less than a kilometre wide to the southwest, forming the Parsons Range. It forms the highest elevation in the region, reaching 342 m above sea level in the drainage divide between Goyder and Koolatong Rivers. Rocky pavements are common, particularly in areas of greater relief, but generally the ridges are clothed in open eucalypt forest with grassy understorey.

The type section runs from GR NF418472 (base) to NF423378 (top). Exposure in the lower half of the section is good, but poor and partly sand-covered in the upper half. To compensate for this, a well-exposed reference section for the upper half is nominated, running from GR NF289345 to NF314313, in the upper reaches of the Goyder River.

Mattamurta Sandstone is estimated to be 3000 m thick at the type section. No complete section is preserved west of the type section as the formation is cut by a series of north-to-northeast-trending faults. Complete sections occur east of the type section, in southern Mitchell Ranges, where a conservative thickness of 2700 m is estimated for the section at the eastern side of the ranges, north of Mattamurta River.

The contact between Mattamurta Sandstone and underlying Fagan Volcanics was interpreted as an unconformity by Plumb and Roberts (1992), but no clear evidence of this was sighted during the current survey. On the contrary, the formations are concordant. Bodies of crystal-rich felsic porphyry, not unlike porphyritic rhyolite of the Fagan Volcanics, occur in the lowermost 200 metres of Mattamurta Sandstone. The upper and lower contacts of some bodies are irregular, and reveal evidence of magma/wet sediment interaction. It thus appears that volcanism continued briefly after initial sand deposition, and that the contact is basically conformable.

The contact with the overlying Badalgarmirri Formation is concordant and is presumed to be conformable. However, at the one locality where it is clearly exposed (GR NF347321), stromatolitic and oncotic chert of the Mount Fawcett Member of the Badalgarmirri Formation encrusts the irregular upper surface of the Mattamurta Sandstone. In places, fractures up to 0.1 m wide and 0.5 m deep in this sandstone surface are filled with debris of sandstone and chert, indicating at least minor lithification and erosion before deposition of the basal Badalgarmirri Formation.

A mappable tongue of Mattamurta Sandstone separates two tongues of fine-grained, recessively weathering rocks mapped as Mount Fawcett Member of Badalgarmirri Formation, west of Sheridan Fault in the headwaters of Walker River. The recessive tongues thin and lens out southwards, the lower one at GR NF198144, the upper one further south at GR NF222100, and the sandstone tongue merges with underlying Mattamurta Sandstone. A prominent bedding plane, possibly indicating a thin overlying interval of fine-grained rocks, can be traced south beyond the mappable upper tongue of Mount Fawcett Member. The upper boundary of the Mattamurta Sandstone is placed at this level in the southern Parsons Range.

Mattamurta Sandstone is dominated by white to pale pink, thick-bedded, medium- to very coarse-grained quartzarenite with granule laminae and scattered pebbles. Cross-bedding, the dominant sedimentary structure, is highlighted by

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**Plate 10** Banded felsic dyke of Gadahara Volcanics intruding Bradshaw Complex granite, GR PF180280, Round Hill Island.
variations in grain size, particularly coarser laminae at the toes of foresets, or as lags beneath cross-bed sets. Such rocks are well exposed in the lower part of both the type section and the Goyder River reference section. In the latter, they dominate the first 1000 m upward from the anticlinal axis at GR NF288342. The granules and scattered pebbles are generally subangular to subrounded, and are composed mainly of quartz. Other clasts include felsic volcanics, fine-grained siliceous rocks (?metamorphics), and indurated sandstone.

The uppermost 400 m in the Goyder River section consists of two facies which alternate on a scale of 50-100 m — the previously described gritty to pebbly facies (Plate 11), and a finer grained ripple-marked facies. The finer facies is generally dark red to reddish brown, thin- to medium-bedded, fine- to medium-grained, with sharply defined planar bedding surfaces displaying symmetrical ripples, interference ripples, and straight-crested asymmetrical ripples; all ripples are wave-generated forms (Plate 12). A very large cross-bed coset associated with rocks of this facies in the western limb of the anticline at GR NF270350, in the bed of the Goyder River, extends laterally for at least 20 m and comprises several large planar cross-beds separated by reactivation surfaces. It appears to be a channel-fill within the finer facies.

The rocks in the lower half of the easternmost section are white to light pink, medium- to coarse-grained, with some granules and pebbles, and are faintly to clearly cross-bedded. The upper part of the sandstone, 4-6 km to the south, but still north of Mattamurra River, is finer-grained than the equivalent part of the type section, containing only one interval of very coarse and granule-rich sandstone. Most of the rocks are fine- to medium-grained and are cross-bedded on a medium to large scale (Plate 13); few rippled intervals were seen. Mudcracks are present in outcrops immediately south of Mattamurra River. Above, in the youngest part of the forma-

**Figure 6** Location of measured sections of the Parsons Range Group in BLUE MUD BAY.
<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jalma Formation 70-130 m</td>
<td>Sandstone, brown to purple, medium-grained, thin- to medium-bedded, ferruginous, fine-grained, thin-bedded sandstone near base; local basal conglomerate; upper recessive laminated claystone unit.</td>
<td>Shallow-marine.</td>
<td>Unconformable on Coast Range Sandstone and Grindall Formation, Overlain with probable unconformity by Balbirini Dolomite.</td>
</tr>
<tr>
<td>Coast Range Sandstone (P2k) 20-40 m</td>
<td>Quartz sandstone, white, medium- to coarse-grained, thick-bedded, commonly pebbly; lenticular basal pebble or cobble conglomerate.</td>
<td>High-energy transgressive coastal deposit, with some fluvial facies.</td>
<td>Unconformably overlies Grindall Formation, Bradshaw Complex, undifferentiated volcanics and felsic dykes. Apparently unconformably overlies Gudabara Volcanics and Woodah Sandstone. Unconformably overlain by Jalma Formation.</td>
</tr>
<tr>
<td>PARSONS RANGE GROUP 5000-6000 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fleming Sandstone (Ppf) 50-200 m</td>
<td>Quartz sandstone, white to pink, fine- to medium-grained, thin- to thick-bedded; local intraclast conglomerate and cauliflower chert.</td>
<td>Shallow marine: shoreline and tidal flat.</td>
<td>Conformable on Marura Siltstone; conformable and gradational contact with overlying Koelatong Siltstone.</td>
</tr>
<tr>
<td>Marura Siltstone (Ppn) 100-250 m</td>
<td>Mudstone and siltstone, laminated to massive, grey, green and purple; dololulite and sandstone interbeds; stromatolitic chert near base.</td>
<td>Supratidal mudflats; sabkas.</td>
<td>Lower and upper contacts presumed conformable.</td>
</tr>
<tr>
<td>Badalgarrrmirri Formation (Ppb) 1900-2800 m</td>
<td>Quartz sandstone, medium- to thick-bedded, fine- to coarse-grained; laminated mudstone, siltstone and fine sandstone; pyritic and ferruginous mudstone &amp; sandstone; minor dolostone and chert.</td>
<td>Storm-dominated shelf, from deep basinal to shoreline.</td>
<td>Lower and upper contacts presumed conformable.</td>
</tr>
<tr>
<td>Fairy Glen Sandstone Member (Ppb) 0-100 m</td>
<td>Sandstone, thick-bedded, fine- to medium-grained, ferruginous (glaucolithic).</td>
<td>Offshore transition zone within a storm dominated shelf.</td>
<td>Lower and upper contacts presumed conformable.</td>
</tr>
<tr>
<td>Goli Member (Ppbq) 0-360 m</td>
<td>Siltstone, laminated and wavy bedded; sandstone, thin- to medium-bedded, fine-grained, clayey.</td>
<td>Storm-dominated shelf to upper shoreface.</td>
<td>Lower and upper contacts presumed conformable.</td>
</tr>
<tr>
<td>Mount Fawcett Member (Ppbu) 0-240 m</td>
<td>Siltstone, olive green and grey, laminated to thin-bedded; sandstone, thick-bedded, glaucolithic, coarse-grained; stromatolitic dolostone at base.</td>
<td>Shelf to marginal marine.</td>
<td>Lower contact locally disconformable; upper contact presumed conformable.</td>
</tr>
<tr>
<td>Mattamurra Sandstone (Ppt) 2700-3000 m</td>
<td>Quartz sandstone, fine- to coarse-grained; scattered granule and pebble layers; shallow sills of porphyritic rhyolite near base.</td>
<td>Shallow marine and possibly braided fluvial.</td>
<td>Conformable on Dhupewarriirri Member of Fagan Volcanics; overlain conformably (or locally erosionally) by Mount Fawcett Member.</td>
</tr>
</tbody>
</table>
tion, is fine-grained, dark red- to purple-stained sandstone.

In the southern Parsons Range, the Mattamurta Sandstone is mostly massive, structureless, white to light pink sandstone. Cross-bedding has not been etched by weathering, and is rarely visible. Both fine-grained and coarse pebbly beds are present, but no rippled intervals were observed in the fine sandstone.

Most of the sandstone can be classified as quartzarenite, consisting of over 95% quartz; grains are cemented by quartz, and matrix is sparse or absent. A typical sample in thin-section consists of 98% quartz and 2% altered feldspar or lithic fragments. The grains are cemented mainly by syntaxial quartz overgrowths, with traces of authigenic illite filling voids not filled by quartz cement. Poorly-sorted pebbly sandstone in thin-section is composed of well-rounded pebbles of vein quartz, igneous quartz, and scattered altered porphyritic felsic volcanic rock fragments. A sample from GR NF593436, at the base of the Mattamurta Sandstone, is unusually feldspathic, containing medium to coarse, well rounded grains of microcline and cloudy altered feldspar of indeterminate composition. The sample also contains minor authigenic iron-rich chlorite, perhaps a metamorphic effect of the nearby high-level intrusive.

**Figure 7** Stratigraphic columns for the Parsons Range Group. Thicknesses are based on calculations from aerial photographs using measured dips, except for the upper part of the Parsons east section. Complete sections of Mattamurta Sandstone are preserved in outcrop only between Bath Range Fault and Parsons north section.
Palaeocurrents are predominantly to the northeast (Figure 8), albeit based on limited data for such a large volume of sandstone. Several readings towards the southeast are from the large channel structure in the Goyder River section.

Mattamurta Sandstone is a remarkably uniform quartzarenite unit, comprising up to 3000 m of coarse-grained to pebbly arenite, with interbeds of fine-grained, well-sorted, wave-ripped arenite in the upper part. The poor sorting, the ubiquity of cross-bedding and the strong mode indicating transport to the northeast, and the lack of ripple lamination and interbedded mudstone in the coarse facies, are all common attributes of fluvial arenite. However, the mineralogical maturity and moderate to good grain-rounding of the arenite are more consistent with shallow marine deposition. The genesis of the quartzarenite has long been debated, focusing on mechanisms for producing thick sequences of mineralogically mature sandstone (Chandler, 1988). Compounding the problem in the Proterozoic is the lack of palaeontologic indicators to distinguish marine from non-marine facies. The lower Mattamurta Sandstone is therefore tentatively interpreted as being of fluvial origin.

The upper beds of Mattamurta Sandstone, with their finer-grained, thinner bedded, wave-ripped character present little problem. Although lake-deposition can be totally discounted, a near-shore marine environment is envisaged. The close association of pebbly sandstone with the rippled facies suggests that it too could be shallow marine. A possible analogy are the bars or sandwaves formed by strong longshore currents in the Nowra Sandstone (Le Roux and Jones, 1994). The channel structure in the Goyder River section, with current indicators diametrically opposed to the remainder, may be a flood-tide channel.

**Badalngarriirri Formation** (2pb)

The Badalngarriirri Formation (redefined unit, see APPENDIX), up to 3 km thick, is composed of mildly deformed quartzarenite, mudstone, ferruginous arenite, and minor chert and dolostone. It is eroded into distinctive ridge and valley topography east and south of the less incised plateau of Mattamurta Sandstone in the Parsons Range. The ridges correspond to thick-bedded quartzarenite, the valleys to less resistant, generally thinner-bedded siliciclastic rocks, mainly mudstone, and minor carbonate and chert.

The name Badalngarriirri Formation was introduced by Plumb and Roberts (1965), and is retained here, although several mappable units have been recognised within it. Over much of the area the formation has been divided into 13 photogeological units, reflecting the ridge and valley topography (Figures 7 and 9). These units meet the criteria for definition as lithostratigraphic units, and consequently they have been mapped as members. However, only 3 have been formally named and defined, as many of the others are too thin to delineate accurately on a 1:250 000 scale map, particularly in areas of steep dip. In easternmost Parsons Range, for instance, the recessive units cannot be delineated in a steeply dipping and extensively fractured zone. Fault-bounded sandstone units at the western margin of the Parsons Range are designated undivided Badalngarriirri Formation because they are not sufficiently distinctive to permit subdivision into members. This situation is most clearly revealed in the southern Parsons Range, where the recessive members thin and lens out in line with a thinning of the whole Badalngarriirri Formation.

The contact with the underlying Mattamurta Sandstone is locally erosive (see section on ‘Mattamurta Sandstone’), but regionally appears to be conformable. The upper contact, with the Marura Siltstone, is conformable. The grounds for distinguishing the Marura Siltstone as a separate formation were not stated by Plumb and Roberts (1965, 1992), except that the boundary “is marked by a lithological change from blocky quartzarenite to lutite”. The same, however, can be said of the changes between most mappable members of the Badalngarriirri Formation. The differences are a markedly lower iron content and a greater abundance of massive and dolomitic mudstone in the Marura Siltstone relative to the Badalngarriirri Formation.

Badalngarriirri Formation varies in thickness from 2800 m in the type section in the northeastern part of Parsons Range (Figure 9), to 1900 m in southern Parsons Range (Figure 7). Much of the thinning results from lensing out of the recessive mudstone/siltstone members.

Descriptions of the units within the Badalngarriirri Formation given below treat all the major sandstone units together, followed by individual descriptions of named and unnamed recessive and mixed units.

*Unnamed sandstone members (Units 2, 4, 6, 8, 10 & 13)*

Badalngarriirri sandstone is characteristically white, thick-bedded quartzarenite with few visible internal sedimentary structures. In the formation type section, five units composed entirely of quartzarenite – Units 2, 4, 6, 8, and 10 – have been recognised below the Fairy Glen Sandstone Member. Above that member, quartzarenite constitutes a significant part of Unit 12 and most of Unit 13.

The sandstone units can be regarded as informal members as they are mappable throughout northern Parsons Range, where they are separated by recessive, fine-grained units. South of Mount Parsons the lower recessive members, including Mount Fawcett and Gali Members, thin and lens out. The sandstone units thus amalgamate, but in some cases can still be identified through the continuation of bedding trends at the stratigraphic level of the boundaries (e.g. between Units 2 and 4, and between Units 6 and 8). Because the base of Unit 2 can be traced south in this fashion, despite the absence of the Mount Fawcett Member, it is possible to define a meaningful boundary between Mattamurta Sandstone and Badalngarriirri Formation in the southern Parsons Range (otherwise all the sandstone units within Badalngarriirri Formation would have to be regarded as tongues of Mattamurta Sandstone).
Plate 11 Cluster of quartz pebbles in the upper Mattamurta Sandstone in the Goyder River section at GR NF303323.

Plate 12 Fine-grained, dark red, thin- to medium-bedded, wave rippled facies in upper Mattamurta Sandstone in the Goyder River section at GR NF310317.

Plate 13 Medium-scale planar cross-beds in Mattamurta Sandstone in the eastern Mitchell Ranges at GR NF589383.
The apparent paucity of sedimentary structures in the quartzarenite may result partly from masking of structures by weathering and silicification. It may also result from a lack of compositional variation in the sandstone, which renders sedimentary structures that do exist difficult to observe.

**Unit 2** is composed of fine- to medium-grained, well sorted quartzarenite in the lower part of the type section, but consists of medium-, coarse-, and very coarse-grained quartzarenite, with scattered granules and pebbles, in most other outcrops. At GR NF347314, in the headwaters of the Goyder River, sub-rounded pebbles 30-40 mm across are mostly composed of quartz, but include quartzarenite, and very fine-grained 'tuff' or felsic volcanic rock. The sandstone generally appears massive, although in a few outcrops medium- and large-scale planar cross-beds are visible. Mudflakes were observed only at the top of the member in eastern Parsons Range.

Lithologically, **Unit 4** is similar to **Unit 2**. In the northeast, it includes thick-bedded, fine-grained quartzarenite, and in the southwest it contains very coarse and gritty layers with scattered pebbles 5-10 mm in diameter. Cross-bedding is present, but is only faintly etched due to the lack of compositional variation within the beds.

**Unit 6** is similar to **Units 2 and 4**, but is thinner, being only 32 m thick at the type section. There, the sandstone is fine- to medium-grained, thick-bedded, quartz-rich with rare black tourmaline grains. At GR NF509307, 4 km west of the type section, the upper surface of the sandstone is wavy on a scale of a few decimetres; this may be of tectonic origin rather than sedimentary. Above the surface is a 10-20 cm thick transitional interval of thin-bedded, very fine-grained sandstone, capped by thinly interbedded siltstone and sandstone of the Gali Member. White and light pink, medium- to thick-bedded, medium- to very coarse-grained quartzarenite is present at the stratigraphic level of **Unit 6** in the southwest. Medium scale planar cross-bedding and mudflake intervals were observed.

**Unit 8** is the thickest quartzarenite member in the Badalngamirri Formation, reaching 500 m in thickness in the headwaters area between Goyder and Walker Rivers. In the type section for the whole formation (Figure 9), **Unit 8** is less than 300 m thick, and includes several poorly outcropping intervals of very fine micaceous and lithic sandstone similar to that in the Gali Member. The dominant lithology in **Unit 8** is thick- to very thick-bedded, fine- to medium-grained quartzarenite. It is generally massive, but in rare outcrops medium to large scale planar cross-beds are preserved. Crossbed set boundaries are notably planar, and outcrops are brilliantly white and almost tor-like (Plate 14). In the type section the upper quartzarenite beds of **Unit 8** appear to be cyclic sequences, with boldly outcropping sandstone beds 2-3 m thick, alternating with poorly outcropping intervals. At GR NF366275 the upper surface of the member is undulating, and has patches of symmetrical ripples, some interference ripples, and mudflakes. In the southwest, the sandstone is less well sorted, ranging from fine- to coarse-grained. Mudflakes and small-scale planar cross-beds were observed, but horizontal planar lamination, generated by layers of well rounded coarse sand grains set in a well sorted 'matrix' of fine sand grains, dominates.

**Unit 10** is similar to sandstone units lower in the Badalngamirri Formation. In the 130 metre thick section at GR NF369270 the sandstone is uniformly white, thick- to very thick-bedded and generally massive, although faint cross-beds are evident in the upper part. Grain size ranges from fine near the base, to fine with widespread coarse grains in the central part. Sandstone is pure quartzarenite, with rare dark coloured grains of tourmaline. Scattered mudflakes and symmetrical ripples occur on bedding planes.

**Unit 13** is a composite sandstone-mudstone unit, but unlike underlying units, 11 and 12, sandstone dominates. Best outcrops are along the Walker River around Fairy Glen, where pyritic sandstone alternates with dark grey siltstone and black mudstone. Synaeresis cracks are common in the sandstone (Plate 15) in virtually all outcrops. The unit varies from 70 m thick in the Parsons south section to 140 m in Parsons central (Figure 7). Outcrops at, and east of, the type section show the unit is clearly composed of a basal and top resistant quartz sandstone horizons, separated by a thicker interval of siltstone and mudstone. In contrast, southwestern outcrops consist of just one resistant quartzarenite unit. At GR NF523255, the 20 m-thick upper sandstone is a slightly upwards-fining sequence of trough cross-bedded quartzarenite. A few coarse beds occur near the base, and the remainder of the sequence is comprised of medium- to fine-grained sandstone. Polygonal mudcracks, indicating desiccation rather than synaeresis, occur near the base, and wave ripples and mudstone intraclasts occur throughout the section.

*Mount Fawcett, Unit 1 (Ppbf)*

The basal part of the Badalngamirri Formation in eastern Parsons Range is a mappable member of interbedded mudstone, sandstone, dolostone and chert, here named Mount Fawcett Member. The unit thins to the west, and clearly forms two tongues of mudstone, separated by white quartzarenite that is continuous with the uppermost Mattamurta Sandstone further southwest. The tongue of sandstone is mapped as Mattamurta Sandstone as far east as the north-trending fault zone in the headwaters of Walker River, although it probably extends east of there. The recessive tongues, which are mapped collectively as Mount Fawcett Member, lens out east of Mount Fawcett, the upper tongue extending 3-4 km further south than the lower tongue.

In the type section (Figure 9), only resistant beds of chert (silicified dolostone) and sandstone crop out; the unexposed part of the member is presumed to be mudstone and siltstone similar to small outcrops 8 km west. There, olive green mudstone is interlaminated with coarse quartz siltstone/fine sandstone on a 1-5 mm scale, with thicker interbeds of medium to coarse, matrix-rich quartzarenite.

The silicified dolostone bed extends both west and south of the type section. In fault-bounded outcrops 10 km south,
Figure 9 Composite type section for Badalingarrmirri Formation, Marura Siltstone and Fleming Sandstone. Thicknesses for Mount Fawcett Member and Units 1 to 6 of Badalingarrmirri Formation are based on measurements from aerial photographs. All units above Unit 6 were measured by tape and compass.
pink laminated chert has probable relict cryptalgal laminations, and 8 km south at GR NF581251, there are small columnar stromatolites (Plate 16). Twenty-three kilometres west of the type section, at GR NF347321, chert encrusts the irregular upper surface of the Mattamurta Sandstone. In places, cracks 0.1m wide and 0.5 m deep in the sandstone contain debris of sandstone and chert. The chert varies from wavyly cryptalgal-laminated to columnar stromatolitic. Sample 92773402 contains distinctive well-rounded, medium quartz grains and scattered laminated chert oncoid grains up to small pebble size.

Unit 3 (unnamed mudstone/sandstone member)

Unit 3 is predominantly mudstone between the massive quartzarenite sequences of Units 2 and 4. It was observed only in the northeast, at GR NF583326, where it includes a lower mudstone-siltstone-sandstone sequence commonly forming a subsidiary scarp flanking the Unit 2 ridge, overlain by poorly exposed mudstone. Medium to coarse-grained Unit 2 sandstone is overlain abruptly by finely laminated leached mudstone, which grades up into laminated, hummocky cross-stratified coarse-grained illitic siltstone and very fine-grained sandstone, which is capped by 8-10 m of medium- to coarse-grained sandstone. It is white, thick bedded, well sorted, and contains scattered pale green glauconite grains; it is rich in mudflakes near the top.

Nine kilometres to the west the upper surface of this sandstone is an extensive undulating dip slope resulting from partly washed out megaripples; clusters of mudflakes 10-30 mm across are common. In the same section the remainder of Unit 3, in the recessive interval above the sandstone, is better exposed. It is very similar to the lower interval, consisting of very laminated shale and siltstone with at least one bed, 1-2 m thick, of hummocky cross-stratified very fine-grained sandstone. This is capped by the quartzarenite of Unit 4.

Laminated to thin-bedded coarse-grained siltstone to very fine-grained sandstone 7 km south of the type section, at GR NF579253, is tentatively assigned to this member. The rocks are finely laminated, horizontally-bedded to hummocky cross-stratified, and contain around 30% iron-rich chlorite. Texturally the rocks are very similar to the illitic

Plate 14 Typical outcrop of quartzarenite in Badalngarmiri Formation - thick-bedded, massive, white sandstone of Unit 8, in eastern Parsons Range at GR NF510293. Hammer near top of sandstone boulder for scale.

Plate 15 Mudcrack infilling in Unit 13 of Badalngarmiri Formation at GR NF392195. Various patterns occur in Units 11, 12 and 13, ranging from rectilinear to polygonal, and are interpreted as synaeresis and desiccation cracks respectively.
rocks to the north, but have been recrystallised, perhaps because of low-grade metamorphism in the strongly faulted zone in which they outcrop.

Unit 3 comprises one complete coarsening/shallowing-upwards cycle 50 m thick in the east, and a 150 m-thick fine-grained part of a second cycle, the upper part of which appears to be Unit 4 (or part of it). The whole unit in the central Parsons section is 140 m thick.

**Unit 5 (unnamed siltstone member)**

Unit 5 can be traced as a well defined valley in the northern Parsons Range, but thins and lenses out 7 km southeast of Mount Fawcett. The only outcrop observed, in a scarp slope beneath Unit 6 at GR NF537313, consists of finely laminated white-grey coarse-grained quartz siltstone. Based on measured dips in the sandstone, the unit is 90-100m thick in the north, thinning or grading into sandstone in the southwest.

**Gali Member, Unit 7 (Ppbg)**

Gali Member is the thickest of the recessive members in the Badalanggarmirri Formation, and like the others thins progressively southwestwards, apparently lensing out 5 km further south than Units 3 and 5.

The dominant lithologies, laminated mudstone and fine to coarse siltstone merging into very fine-grained sandstone, are similar to other fine-grained units in the Badalanggarmirri Formation. At GR NF509307, the basal part of the member consists of coarse-grained quartz siltstone and very fine-grained sandstone in beds up to 0.1 m thick, with prominent mudstone partings. The coarser beds are generally horizontally laminated, but some laminations undulate on a scale of 0.5 m wavelength and are truncated by succeeding laminae; they show low amplitude hummocky cross-stratification. Synaeresis cracks and parting lineations are present in some beds. Intermittent outcrop of similar siltstone is present throughout the member.

Gali Member differs from the other recessive units in that it contains two intervals, each about 20 m thick (Figure 9), of very fine- to fine-grained, white, laminated clayey sandstone in beds 0.5 to 3 m thick. The sandstone consists of 85% quartz grains, the remainder being detrital clay grains. Some grains are sericite or illite, others kaolinite or mixtures of both. They may be altered feldspar grains, although no relict feldspar textures or altered lithic grains have been observed. The rocks are best classified as sublitharenite. Muscovite flakes and heavy mineral accessories are more common than in the mineralogically more mature quartzarenite which forms the resistant members.

**Unit 9 (unnamed mudstone-siltstone member)**

Unit 9 was observed in one section only, between GR NF364274 and NF368271, in the headwaters of Walker River. The 150 m-thick section includes poorly outcropping brown to purple laminated siltstone with rare interbeds up to 0.1 m thick of purple, medium- to coarse-grained, well sorted sandstone in the lower half. The upper part is a coarsening-up cycle 50 m thick, commencing with 5 m of pale green to drab olive-grey finely laminated shale, grading upwards into 15 m of coarser mudstone and siltstone. The siltstone beds are up to 8 cm thick, commonly form lenses 2-3 m long, and display a 0.3 m wavelength undulating bedding which may be low amplitude, low-energy hummocky cross-stratification. The proportion and thickness of the siltstone beds increases upwards, and a 20 m interval consists of siltstone only. Medium interbeds of dark purple, very iron oxide-rich sandstone occur in the last 8 m of the section below Unit 10; the iron oxides may reflect the former presence of glauconite.

**Fairy Glen Sandstone Member (Ppbu)**

The Fairy Glen Sandstone Member is a distinctive dark-toned, hummocky cross-stratified ferruginous sandstone that crops out as a ridge flanking the southern and eastern sides of the broader Unit 10 sandstone ridge. It marks a significant change from the rather regular alternation of light coloured resistant quartzarenite and dark coloured recessive mudstone-siltstone units that characterise lower Badalanggarmirri Formation. Grainsize ranges from very fine to coarse. In the central and southern Parsons sections, the basal part is very fine- to fine-

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**Plate 16** Small columnar stromatolites in chert (silicified dolostone) near the base of the Mount Fawcett Member of the Badalanggarmirri Formation, in eastern Parsons Range (GR NF580253). Base of frame is ~2m.
grained, slightly ferruginous, lithic or clay-grain-rich sandstone. The strongly ferruginous rocks which constitute most of the member are medium grained and well sorted in the type section. To the west and southwest, the member becomes finer-grained, and less ferruginous.

The Fairy Glen Sandstone Member is characterised by hummocky cross-stratification (HCS) and swaley cross-stratification (SCS), which is highlighted by thin colour banding. In outcrops 2-3 km west of the type section, HCS is common at the base (Plate 17), and SCS near the top of the member. The HCS is generally of ‘medium scale’, with a wavelength of 1-2 m. The sandstone beds appear to be amalgamated HCS sets, and no other interbedded lithology was noted. The SCS beds are laminated in identical fashion to the HCS beds, but only shallow trough-cross-beds through their symmetry – sections at any orientation reveal bedforms of roughly the same shape, indicating that they were not generated by unidirectional currents.

The distinctive lamination is apparently caused by variations in the concentration of haematite. The dark red oxide is clearly an alteration product of original grains of similar size to the quartz grains. Some of the altered grains are voids rimmed by haematite, rendering the sandstone porous and friable. Scattered through the rock are haematite-rimmed grains of aggregates of a fine granular mineral, probably kaolinite, speckled with haematite. The most likely precursor of the haematite and kaolinite is glauconite, although none has been preserved. Where the oxide has migrated into interstices between quartz grains it has corroded grains and formed a cement.

**Unit 11 (unnamed mudstone/siltstone member)**

Like Units 3, 5 and 9, and parts of the Gali Member, Unit 11 crops out very poorly. The only outcrops are in the upper half of the unit, giving the impression that it may be slightly more resistant, perhaps coarser grained or thicker bedded, than the lower part. The rocks are laminated to thin-beded, coarse-grained quartz-rich siltstone with thin mudstone partings. The siltstone beds are 1-5 cm thick with continuous wavy laminations; truncations of these internal laminae indicate that the beds are hummocky cross-stratified on a decimetre scale. At GR NF515273, 4 km west of the Badalgharmirri Formation type section and near the top of Unit 11, thin to medium bedded, very fine grained sandstone displays bedding surfaces which are covered with sandstone infills of mudcracks. The infills form a rectilinear rather than polygonal pattern, and may be synaeresis rather than desiccation cracks.

The contact between Units 11 and 12 is best seen in the type section at GR NF537283. There, the uppermost 55 m of Unit 11 is dominated by sandstone – very fine-grained white quartzarenite with at least two beds, up to 0.5 m thick, of medium- to coarse-grained ferruginous sandstone. The contact with Unit 12 is placed above the ferruginous beds, at the base of a unit of resistant massive white quartzarenite.

**Unit 12 (unnamed sandstone/siltstone member)**

Unit 12 is a composite member, made up of several units traceable locally on aerial photographs. It is treated here as an individual member, as the individual units cannot be carried through the entire Parsons Range outcrop belt. Its thickness is 400-500 m (Figure 7). It overlies Unit 11, presumably conformably, the boundary being placed at the base of a prominent ridge-forming sandstone above highly ferruginous sandstone. The basal sandstone, a massive white quartzarenite of similar type to resistant members lower in the Badalgharmirri Formation, is around 35 m thick in the type section. It is overlain by resistant layers of quartzarenite similar to the basal unit, and recessive layers of interbedded fine sandstone, siltstone and mudstone. In the steeply east-dipping outcrops of Units 12 and 13 about 2 km east of the type section of the Badalgharmirri Formation, upper Unit 12 rocks are well exposed and reveal a cyclicality on a scale of a few metres. Thinely-beded to laminated, dark grey, pyritic siltstone with mudstone partings alternate with thick-beded, medium-grained, well sorted quartzose sandstone with scattered limonite-stained grains, possibly after glauconite. Cyclicality is also apparent in the southern Parsons Range, where sandstone intervals a few metres thick alternate with mudstone beds tens of metres thick.

The quartz-rich Unit 12 sandstone is light grey, strongly silicified and flinty in character with visible pyrite which is presumed to be secondary. The siltstone and mudstone are darker grey to black, and are carbonaceous and/or pyritic. When weathered, the sandstone is porous and iron-stained due to alteration of pyrite, and has a speckled appearance. Another distinctive feature of the finer grained rocks is the presence of mudcracks on sandstone bedding surfaces. The sandstone infillings of the cracks rarely form polygonal patterns, although some incomplete polygons were observed. As in Unit 11, most tend towards a rectangular or highly complex pattern due to the overlapping of several episodes of crack infilling, and they may be synaeresis cracks rather than desiccation features.

Siltstone and mudstone in Unit 12 are thinly interbedded in a similar manner to those in Unit 11, and individual siltstone beds have been observed to lens out over a few metres laterally. At GR NF521268, a well-exposed 12 m sequence that overlies siltstone/mudstone contains two dolomitic beds. Within the lower bed are two clusters of intraclast breccia that may be tepee structures. The upper dolomitic bed is marl in composition. The fine-grained, spectacularly laminated sandstone that caps the sequence appears to be hummocky cross-stratified. Higher in the Unit, a 7 m thick coarsening-up sequence of sandstone is porous and strongly cross-beded in the upper part. Weathering of pyrite or glauconite could account for the high porosity.

To the west, outcrops along Walker River include an excellent exposure of laminated, wavy-beded, coarse-grained quartzose siltstone with partings of black micaceous mudstone. A few small sandstone dykes reveal the presence of probable synaeresis cracks, and some of the ripple laminations is unidirectional, indicating it was current rather than
wave generated. The uppermost quartzarenite bed in Unit 12 in this area, at GR NF377247, reveals a bedding surface with giant symmetrical ripple marks – their wavelength is 0.8 m, their height 8 cm.

In the fault-bounded zone south of Fairy Glen, drab olive green mudstone assigned to upper Unit 12 contains interbeds 10 cm thick of dark grey fine-grained pyritic dolomitic sandstone. Local thickening of the sandstone beds, in the form of elongate rounded ridges and circular steep-sided depressions, is interpreted as infilling of erosional scours in the mudstone.

**Discussion of Badalingarmirri Formation**

The outstanding features of Badalingarmirri Formation are its alternating coarse and fine siliciclastics and the dominance of quartzarenite. Also notable are the ferruginous character (including both glauconite and pyrite) of the upper part of the sequence, and the presence of hummocky cross-stratification in many finer-grained units.

The white quartzarenite which characterises the coarse, resistant members is mineralogically supermature, consisting of quartz grains, quartz cement, and little else apart from rare heavy mineral grains (tourmaline and rare zircon). The grains are moderately to well rounded and for the most part well sorted. The problematic origin and depositional environment of quartzarenite have been addressed by Chandler (1988). The general character of quartzarenite in the Badalingarmirri Formation, and its association with finer-grained, hummocky cross-stratified strata, indicates that it was deposited in a shallow marine environment.

Hummocky cross-stratification is widely used as an indicator of storm-dominated deposition above storm wave-base, although the exact conditions under which it forms, and the influence of unidirectional currents, are not fully understood (Cheel and Leckie, 1993). Its occurrence throughout Badalingarmirri siltstone and sandstone, associated with coarsening-up and alternating fine-coarse siliciclastic sediments, coupled with the preferred shallow marine environment for the sandstone, suggests that the bulk of Badalingarmirri Formation is a storm-dominated, marine shelf deposit.

**Marura Siltstone (Ppm)**

Marura Siltstone is a mudstone unit with minor sandstone and dolostone which occupies a narrow valley between resistant sandstone of Badalingarmirri Formation below, and Fleming Sandstone above. It is exposed east of Walker River in the Parsons Range outcrop belt, and in the steeply-dipping zone at the southern margin of southern Mitchell Ranges. West of Walker River, exposure is completely lacking due to a more persistent cover of sand and coarser colluvium from the adjacent units, particularly from the Fleming Sandstone.

Marura Siltstone varies from less than 100 m thick in western Parsons Range, to 250 m in the east (Figure 7). It is dominated by mudstone, ranging from siltstone to claystone, and minor sandstone, dolostone and chert. The chert is a single unit near the base, but sandstone is present throughout. The thickest sandstone bed, 4 m thick and trough cross-bedded, forms a prominent marker 60 m beneath the top of Marura Siltstone at GR NF532252, near Marura Creek.

Mudstone is well exposed beneath a thin colluvial veneer at GR NF539260, one km northeast of Marura Creek. Purplish grey to olive green dolomitic siltstone, lacking any clear lamination, contains a polygonal network of sandstone-filled desiccation cracks up to several decimetres long and a decimetre or more deep. A 0.2 m thick lens of dolostone and several thin (<5 cm) beds of fine- to medium-grained, current ripple-laminated sandstone are interbedded with the siltstone. Similar rocks are exposed northeast of Fairy Glen and 17 km south at GR NF395027. At the latter locality, hopper halite casts, as well as desiccation cracks, are present in the siltstone. The lack of internal laminations in the mudstone is common in Marura Siltstone, the only visible structure being a small-scale blocky fracture pattern as the exposed rocks disintegrate.
The chert, including a silicified stromatolitic dolostone bed 0.5 m thick (Plate 18), and undulating cryptagal-laminated chert, occurs within a few metres of the base of the formation in eastern Parsons Range.

**Fleming Sandstone (Ppf)**

Fleming Sandstone, the uppermost formation of the Parsons Range Group, is more resistant to erosion than the overlying Koolatong Siltstone, and forms a ridge that extends much of the length of Parsons Range. The formation is 200 m thick west and south of Walker River, thinning eastwards to 150 m at Marura Creek and to 53 m at GR NF588209. In ARNHEM BAY–GOVE, it is up to 370 m thick (Rawlings and others, 1997).

The formation is lithologically similar to the sandstone units of Badalangrimmir Formation, namely quartzarenite. It differs from older sandstone units, however, in that it is more obviously cross-bedded due to etching of structures in weathered outcrop. Most outcrops are thin- to medium-bedded, and cross-beds are small to medium scale troughs (up to about 0.3 m thick), quite distinct from structures in Badalangrimmir Formation sandstone, which are medium to large scale. In the upper Marura Creek section, wave-rippled bedding planes and mudflakes are common and in the type section at GR NF588209, mudflakes are so prolific that they form intraclast conglomerate. A series of thin sandstone beds, which form a transition interval between Fleming Sandstone and overlying Koolatong Siltstone along the eastern Mitchell Ranges, contain ‘cauliflower chert’ nodules (Plate 19; cf. Chowns and Elkins, 1974).

Sandstone from this formation (92773393, collected from GR NF642659, 3 km beyond the northern boundary of the mapsheet area) reveals in thin-sections, mainly monocrystalline quartz grains and scattered polycrystalline quartz of both sedimentary and metamorphic origin. Minor non-quartz lithic grains are present, including composite clay grains, which could be of intraformational origin.

**Discussion of Parsons Range Group**

Figure 7 is a fence diagram for the entire Parsons Range Group. No trends can be determined for the Mattamurra Sandstone because the formation is incomplete in all areas except northern Parsons Range and southern Mitchell Ranges. Even there, the estimates of 3000 m are approximate only, given the structural disturbance. The remainder of the group, however, is complete throughout Parsons Range, and can be seen to have a northeasterwards component to the thickening; other components cannot be measured. The dominant structural trends in the region suggest that west to east thickening is most likely, but south to north thickening cannot be excluded. Thinning of Unit 8, and complementary thickening of the Gali Member between the central and east Parsons sections, is probably due to interdigitating of the two units.

The cyclic nature of Badalangrimmir Formation at the member level is very clear. Less clear because of incomplete outcrop, but nevertheless apparent on aerial photographs and outcrop, is cyclicity at a scale of metres to tens of metres. This is particularly true of Unit 2, 8, and 10 sandstones, and in the alternation of sandstone and mudstone in Unit 12. In sequence stratigraphic terminology, the cyclic deposits are parasequences and parasequence sets (van Wagoner and others, 1988). The boundary between Mattamurra Sandstone and Badalangrimmir Formation is probably a sequence boundary. Retrogradational parasequences, reflected in recessive units from Mount Fawcett Member up to Unit 9, suggest that much of the Badalangrimmir Formation is a very thick transgressive systems tract. Above Unit 11 is an apparent basinward shift in facies, suggesting that the Unit 11 to Fleming Sandstone interval belongs to the Highstand Systems Tract.

**Unassigned to group**

**Coast Range Sandstone (Pk)**

*By P.W. Haines*

Coast Range Sandstone (new name, see APPENDIX) is a thin unit of sandstone and minor conglomerate restricted in outcrop to the northeastern quadrant of BLUE MUD BAY. The best exposures are along Coast Range and near Mount Grindall, but other outcrops occur west of Jalma Bay, near Gan Gan community, on Round Hill Island and along the mainland coast, and Gooninnah Island further east. Plumb and Roberts (1965) originally mapped these outcrops as part of "Groote Eylandt Beds", most exposures of which have now been assigned to various formations of the Groote Eylandt Group (Pietsch and others, 1997). However, Coast Range Sandstone is inferred to be significantly younger than the Groote Eylandt Group and remains ungrouped.

Coast Range Sandstone unconformably overlies Grindall Formation, Bradshaw Complex, Proterozoic rhyolite dykes and undifferentiated volcanics along the central part of Coast Range. On Round Hill Island, it is inferred to overlite Gadabara Volcanics, while at Grindall Point it is inferred to overlite Woodah Sandstone (Alyangula Subgroup, Groote Eylandt Group). In both cases contact relationships are not exposed but are inferred to be unconformable. Coast Range Sandstone is overlain by Jalma Formation, but the contact is not well exposed. Essentially, it appears to be concordant, however, an angular unconformity can be demonstrated near the southern end of Coast Range where this surface locally removes the Coast Range Sandstone. Here, Jalma Formation lies directly on Grindall Formation and Bradshaw Complex. The Coast Range Sandstone is intruded by thin northwest-trending mafic dykes along central Coast Range. These are rarely exposed and deeply weathered, and are best demonstrated on aeromagnetic images. The type section lies between GR NF905180 and NF902180 across the northern part of Coast Range, 1 km east of a point where the only access track from the west first reaches the range. The thickness of the formation is 20 m or less along the Coast Range, thickening to 30-40 m in the Mount Grindall area.

In the Coast Range area, Coast Range Sandstone is subdivided into three units: a lenticular basal conglomerate;
a lenticular brownish pebbly, coarse-grained sandstone/granule conglomerate; and a ubiquitous upper unit of white, mainly medium- to coarse-grained sandstone. The basal conglomerate, where present, varies from clast-supported cobble conglomerate, to matrix-supported (coarse-grained sandstone matrix) cobble conglomerate, to pebbly sandstone. Larger clasts are typically rounded, and are dominated by quartz as well as pebbles of underlying rock-types, particularly Grindall Formation. White to pink well-silicified sandstone clasts present near the southern end of the range are of uncertain source, possibly Woodah Sandstone. The brownish pebbly sandstone unit is only exposed near the northern end of Coast Range, including the type section, where it consists of friable, poorly-sorted, thickly-bedded, coarse- to very coarse-grained, quartz-rich sandstone and granule conglomerate, bearing occasional small pebbles. Most outcrops consist of the third unit, comprising medium- to coarse-grained, variably sorted, generally thick-bedded, white, quartz-rich sandstone. Pebby horizons are present at most localities and rare cobbles of sandstone and chert have been noted. Beds may be massive, flat-bedded, or display trough and low angle cross-beds. Current and wave ripples, and desiccation cracks are present. At several localities lenticular vugs and quartz-filled pseudomorphs up to 2 cm long, probably after gypsum, have been noted.

The age of the Coast Range Sandstone can be demonstrated to be younger than rhyolite dykes, as scattered angular blocks of the dyke rock occur at GR NF870054, between Grindall Formation and Coast Range Sandstone. The dyke rock bears close petrographic and geochemical affinity to the 1700-1710 Ma ‘Fagan phase’, in particular the Maidjunga Member (Fagan Volcanics), but an older age cannot be ruled out. The most likely regional correlate of Coast Range Sandstone is the very much thicker Parsons Range Group to the west. On the northeastern Caledon Shelf in ARNHEM BAY–GOVE, the Rornruvy Sandstone, top formation of the Spencer Creek Group, is inferred to occupy a similar stratigraphic position (Rawlings and others, 1997). Coast Range Sandstone probably deposited as a high-energy transgressive coastal facies, but may contain some fluvial facies.

**Plate 18** Surface of a silicified dolostone bed near the base of Manara Silstone, at GR NF500243, showing selective silification of small columnar stromatolites. Base of frame is ~2m.

**Plate 19** Cauliflower chert in thin sandstone interbeds in basal Koolatong Silstone (transitional beds from underlying Fleming Sandstone) in northern Mitchell Ranges (GR NF709862). 50 cents for scale.
Jalma Formation (Pc)

By P.W. Haines

Jalma Formation (new name, see APPENDIX) is a sequence of sandstone, mudstone and minor carbonate restricted to the western flank of Coast Range and several small outcrops to the north. Plumb and Roberts (1965) included most of these outcrops in the now abandoned ‘Groote Eylandt Beds’.

Jalma Formation lies unconformably on Coast Range Sandstone near the southern end of Coast Range and locally on Grindall Formation. It is in turn overlain, with probable unconformity, by Balbirini Dolomite. The formation varies in thickness from 70-80 m at the northern and southern ends of Coast Range, to 130 m in the middle. A type section is selected between GR NF865051 (base) and NF858055, as this is the only area where outcrop of the upper recessive part has been observed. Thickness at the type section is 110 m.

Jalma Formation is subdivided into a lower moderately resistant sandstone-dominated unit making up two thirds of the formation, and an upper very recessive unit. In addition, a thin basal unit of mixed lithology is present near the southern end of Coast Range where Jalma Formation lies with marked angular unconformity on older units.

The main part of Jalma Formation crops out as low undulating ridges of ferruginous sandstone. These hills are dark brown on aerial photographs and are easily distinguished from the bare, white, sandstone dips-slopes of the underlying Coast Range Sandstone. It is composed of medium-grained, thin- to medium-bedded, brown, purple and white sandstone with varying ferruginisation. Fine-grained, thin-bedded sandstone is exposed near the base, while interbeds of coarse-grained sandstone and granule conglomerate occur near the top. Sedimentary structures include flat-bedding, minor cross-bedding and wave ripples. Hummocky cross-stratification has been observed near the base. Ferruginisation takes the form of abundant goethite patches up to several millimetres in size, which are concentrated in layers defining bedding. These are probably after original pyrite. In many horizons, weathering has produced large concentric angular liegang structures that control outcrop patterns more so than bedding. Masses of haematite and goethite are common in some areas.

A basal conglomeratic unit is developed near the southern end of Coast Range, where Jalma Formation lies with observable low-angle unconformity on older units. The unit consists of pebble and cobble conglomerate, with sandstone matrix, interbedded with silicified and leached carbonate and ooidal ironstone. Well-rounded clasts in the conglomeratic horizons reach 20 cm in diameter and comprise sandstone, together with minor quartz, and metamorphic and volcanic rocks. Altered carbonate displays botryoidal structures and laminations resembling stromatolites, but these are inorganic. Ooidal ironstone displays ooids 1-2 mm in diameter, with detrital (mainly quartz) nuclei, and a cortex of goethite or less commonly ?chamosite. Granules, pebbles, cobbles and intraclasts are scattered through the poorly sorted ironstone.

The upper unit of Jalma Formation is rarely exposed, being normally expressed as a valley between the ferruginous sandstone below and the basal ridge of overlying Balbirini Dolomite. In the type section, minor outcrop of the lower part is present in a creek bank. This outcrop consists of flat-laminated, thin- to medium-bedded weathered mudstone which ranges from white to red and yellow with varying degrees of leaching and ferruginisation. These rocks were probably originally dolomitic. Just north of the type section, the basal ridge of Balbirini Dolomite appears to cut through the recessive unit to lie on the ferruginous sandstone.

Based on stratigraphic position, Jalma Formation may correlate with part of Parsons Range Group or Balma Group further west. Lithologically it bears some resemblance to the ferruginous units of Badalgarmirri Formation of Parsons Range Group, but has little in common with Balma Group. On lithological grounds and its stratigraphic position, it possibly correlates with Mount Bonner Sandstone (Rawlings and others, 1997) in ARNHM BAY–GOVE. Jalma Formation is interpreted as a shallow marine transgressive unit.

PALAEO- TO MESOPROTEROZOIC – STATHERIAN TO CALYMMIAN

Balma Group

By P.W. Haines

The formations now collectively termed Balma Group were informally referred to as ‘Koolatong Formation’ by Crohn (1956). Plumb and Roberts (1965) named the formations now recognised in this report (restricting the name Koolatong Stithestone to the basal unit only) and assigned them to the McArthur Group. However, despite correlation with the McArthur Group of the southern McArthur Basin, there are no common formations between these areas. Correlation with the closer Habgood Group in ARNHM BAY is much more plausible than with McArthur Group in the south. To alleviate these inconsistencies, Haines (1994) erected the term Balma Group to include formations mapped as McArthur Group on BLUE MUD BAY and southern ARNHM BAY–GOVE, with the exception of the ‘Kookaburra Creek Formation’ and ‘Blue Mud Bay Beds’ which are now assigned to Balbirini Dolomite (Nathan Group). A definition of Balma Group is in the APPENDIX.

Balma Group conformably overlies the Fleming Sandstone of the arenaceous Parsons Range Group. It is in turn overlain by Balbirini Dolomite of the Nathan Group, however the contact is not exposed. To the south, Nathan Group lies over McArthur Group, or older units, with a low-angle unconformity, and thus it is reasonable to assume an unconformity at this level. Along the Coast Range, Balbirini Dolomite lies with probable unconformity on Jalma Formation, a probable Balma or upper Parsons Range Group equivalent, and there is evidence of an angular unconformity with the Balma Group near this area.

Balma Group comprises eight formations, which were defined in Plumb and Roberts (1992). Balma Group
stratigraphy, summarised in Table 6, is composed of mudstone, carbonate and sandstone of shallow water and locally evaporitic origin, with minor tuft. The facies are similar to those identified in the McArthur Group, which has been studied by Jackson and others (1987). Compared with McArthur Group, Balma Group contains a greater proportion of siliciclastic lutite and arenite, and less carbonate. This trend is even better developed further north in the Habgood Group.

Although there are several resistant horizons within the Balma Group, the majority of the sequence, particularly Koolatong, Vaughton and Zamia Creek Siltstones, and Baiguridi Formation are generally recessive. In addition, what outcrops are available suffer from leaching and silicification, which destroys the original lithology and obscures primary depositional textures. Although most carbonate rocks are probably dolomitic (limestone has actually been observed in the Koolatong Siltstone), the non-specific term ‘carbonate’ is used to denote these rocks.

Haines (1994) has identified two hiatuses within the Balma Group, and proposed correlations with both McArthur and Habgood Groups based on a sequence stratigraphic approach. The lower hiatus lies between Strawbridge Breccia and Vaughton Siltstone, and is associated with extensive brecciation and silification, but no substantial erosion. The higher lies at the base of the Yarrawirrie Formation where erosion has locally cut down to the level of Vaughton Siltstone. Both are considered to be associated with debris shed from tectonically uplifted Parsons Range Group and lower units of Balma Group. A possible third break is suggested at or near the base of Bath Range Formation as indicated by abundant lithic detritus suggesting erosion of the underlying succession. Correlation of these breaks, and of individual formations (below), are now revised in line with the new age framework for the Mount Isa and McArthur Basin regions (Southgate and others, 1997a; and Page, 1997).

There are no complete sections through the Balma Group and thickness estimates are of a composite nature. It has a maximum thickness of 4500 m.

**Koolatong Siltstone (Pak, Pak)***

Koolatong Siltstone is a thick sequence of mudstone, sandstone and minor carbonate that conformably overlies the Fleming Sandstone of the Parsons Range Group, and is overlain by Strawbridge Breccia. It is largely restricted to BLUE MUD BAY where it crops out between Bath Range and Koolatong Faults, and in an arcuate zone south of Parsons Range. Minor outcrop is recognised in southern ARNHEM BAY–GOVE.

Due to poor outcrop and structural complexity, all sections are incomplete. The unit is defined in Plumb and Roberts (1992) with a nominated reference area surrounding the Walker River and tributaries, after it emerges from Parsons Range near Mount Fleming (around lat 13°25′20″S and long 135°25′30″E).

A reasonable thickness of 1800 m can be estimated in the far west near the southern tip of Parsons Range, based on dips and measurements from aerial photographs.

The sparse outcrops consist mainly of green and red mudstone interbedded with fine-grained, thin-bedded sandstone, dolostone and limestone. A resistant ridge-forming sandstone is present near the middle of the formation. This may represent a marker bed to subdivide the formation. It has been distinguished as Pak, where it forms a mappable strike ridge north of Bath Range, and further west.

The rarely seen basal contact with Fleming Sandstone has been observed to be gradational over a narrow interval. Cauliflower chert, probably after anhydrite, occurs in thin-bedded sandstone in this transitional interval.

Fresh outcrops of lower Koolatong Siltstone consist of alternating khaki green, purple or reddish, laminated, variably dolomitic mudstone, with more resistant beds of siltly dolostone. Desiccation cracks, halite pseudomorphs, and cauliflower chert attest to periodic evaporitic conditions. In the Koolatong River area, thin-bedded, fine-grained, flat-laminated, white to brown sandstone beds, displaying sharp bases with tool marks, current lineations and gutter casts, are interbedded with red-brown and purple, micaceous, laminated mudstone not far below the sandstone marker.

The sandstone marker unit is at most several tens of metres thick. It consists of white to grey (locally weathering to brown, yellow and red with minor ferruginisation), fine- to medium-grained, thin- to medium-bedded (rarely thick-bedded), variably lithic sandstone. Some beds contain lenses of granules and small pebbles, many of which are carbonate intraclasts that weather to give a characteristic vuggy texture. Thin interbeds of microbial-laminated and stromatolitic chert (silicified carbonate) are present. Small columnar, pseudocolummar and conical stromatolites have been noted as well as small tepee structures and evaporite pseudomorphs. The sandstone is flat- to cross-bedded, with wave and current ripples, cross-lamination, small-scale hummocky cross-stratification, synaeresis cracks and soft-sediment deformation. A thickening- and coarsening-upward trend is evident in places.

In the upper Walker River area, distinctive beds of grey stromatolitic and microbial dolostone and chert are present at a stratigraphic position inferred to be just above the marker (best outcrops GR NF454158; Plate 20). The dolostone weathers to buff yellow and contains white and black chert. Large domal bioherms up to a couple of metres in diameter are composed of small columnar stromatolites from 5 mm to several centimetres in width.

The sequence above the sandstone marker is dominated by khaki green to grey mudstone, which in places displays cyclically interbedded packets of intraclastic, arenitic and stromatolitic dolostone and limestone. Some of the best outcrops are found around GR NF687530 and NF673580, south and north of Koolatong River respectively. These comprise packets of buff weathering grey dolostone 0.5-1 m thick, cyclically interbedded with grey-green, locally pyritic dolomitic mudstone.
<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bath Range Formation (Eae)</strong> max. -600 m in west</td>
<td>Sandstone, fine- to coarse-grained, lithic (chert clasts), dolomitic to leached; chert (sili蜚ous carbonate), relict peloidal and stromatolitic textures; tuffaceous mudstone, white, rarely greenish or pink, thin- to thick-beded.</td>
<td>Shallow ?marine, varying from subtidal storm-dominated to very shallow high-energy.</td>
<td>Base ?conformable; overlain by Nathan Group but contact is not exposed.</td>
</tr>
<tr>
<td><strong>Baiguridji Formation (Eai)</strong> max. -400 m</td>
<td>Sandstone, commonly dolomitic, fine-grained, thin-beded, flaggy, thicker in west; mudstone, grey to black, dolomitic in part; tuffaceous mudstone, white, thin beds; rock types are interbedded, relative proportions vary across map sheet area.</td>
<td>Subtidal, partly storm-influenced; shallowing at top.</td>
<td>Sharp conformable lower contact with Yarrarirrie Formation; upper contact ?conformable.</td>
</tr>
<tr>
<td><strong>Yarrarirrie Formation (Eay)</strong> max. -600 m (inc. Eyyn)</td>
<td>Dololitite and dolarenite, commonly microbial-laminated, stromatolitic, nodular, inextricable; silty dololitite; dolomitic sandstone; mudstone, commonly dolomitic, very recessive; carbonate rocks often leached or silicified (chert) in outcrop; white, yellow to red weathering colours.</td>
<td>Very shallow ?marine or lacustrine; periodic exposure and evaporitic conditions.</td>
<td>Base conformable or disconformable in the west, unconformable in the north (overlies Eaz, Eac, Eav); top sharp but conformable.</td>
</tr>
<tr>
<td><strong>Ngilipiti Conglomerate Member (Eyyn)</strong> 0-200 m</td>
<td>Conglomerate, polymict with dominantly sandstone clasts, pebble- to cobble-size, friable lithic sandstone matrix.</td>
<td>High-energy transgressive marginal ?marine/fluvial.</td>
<td>Base is unconformable (overlies Eaz, Eac and Eav); gradational contact with upper Eay.</td>
</tr>
<tr>
<td><strong>Zania Creek Siltstone (Eaz)</strong> max. -300 m</td>
<td>Mudstone, grey, laminated, commonly dolomitic; dolostone, brown to grey, microbial laminations, fenestral fabrics, often leached or silicified; minor sandstone; cauliflower chert nodules.</td>
<td>Subtidal to very shallow with evaporitic conditions.</td>
<td>Base is ?conformable; unconformably to disconformably (and possibly conformably) overlain by Eay and Eay.</td>
</tr>
<tr>
<td><strong>Conway Formation (Eac)</strong> ~50-100 m</td>
<td>Upper: chert bands (sili蜚ous carbonate), grey to white, massive to weakly stromatolitic, interbedded lithology very recessive. Lower: cherty to dolomitic siltstone, laminated, thin- to medium-beded, black to grey when fresh; sandstone, fine-grained, dolomitic; interbedded khaki green mudstone.</td>
<td>Shallowing-up from subtidal to intertidal.</td>
<td>Gradational lower contact with Eav; top contact with Eac is ?conformable; locally unconformably overlain by Payn.</td>
</tr>
<tr>
<td><strong>Vaughton Siltstone (Eav)</strong> ~600-1000 m</td>
<td>Mudstone, khaki green to black, partly carbonaceous, generally massive; minor sandstone and dolostone interbeds; common siderite nodules; basal conglomerate with friable sandstone matrix; very recessive.</td>
<td>Mostly deep subtidal below wave-base; marginal ?marine transgressive/fluvial unit at base.</td>
<td>Basal contact with Eas is disconformable; upper contact with Eac gradational; locally unconformably overlain by Payn.</td>
</tr>
<tr>
<td><strong>Strawbridge Breccia (Eas)</strong> &lt;100 m</td>
<td>Chert breccia, relict microbial laminations, stromatolites, intraclastic conglomerate, ooids; locally ferruginous and manganeseous.</td>
<td>Shallow intertidal.</td>
<td>Base not seen, but probably conformable; upper contact with Eav disconformable.</td>
</tr>
<tr>
<td><strong>Koolatong Siltstone (Eak)</strong> ~1800 m in west</td>
<td>Sandstone, fine- to medium-grained, granule lenses, thin- to medium-beded, flat- to cross-beded, rippled, variably lithic, characteristically vuggy (after carbonate); local interbedded stromatolitic chert; commonly ridge-forming.</td>
<td>Variable environments from subtidal to very shallow ?marine with periodic exposure and evaporitic conditions.</td>
<td>Conformably overlies Parsons Range Group; contact with Pas not seen, but probably conformable.</td>
</tr>
</tbody>
</table>
The dolostone cycles are commonly stromatolitic or at least microbial-laminated, and include cross-bedded ooid grainstone, intraformational conglomerate, and dololite. Stromatolites occur as large isolated and linked domes 0.5-2 m (rarely to 4 m) wide (Plate 21), or as smaller pseudocolumnar forms. Isolated mushroom-shaped domes are found in the mudstone between dolostone cycles. Early diagenetic black chert is associated with some stromatolite horizons.

Around GR NF450145 in the upper Walker River area, outcrop is dominated by massive khaki green mudstone generally with a splintery, non-bedded habit. Desiccation polygons are visible in places and there are occasional thin resistant interbeds of fine-grained, laminated, dolomitized sandstone. The sequence is interbedded with cycles of grey ooidal and intraclastic dolostone, some with microbial laminations and domal stromatolites, and beds with nodules of dark grey dololite. Near the top of the formation is red or purple splinterly mudstone with minor interbedded dolomitized mudstone and dolostone. Much of the upper half of Koolatong Siltstone is overlain unconformably by plateau-forming Cretaceous rocks and laterite. At these localities, leaching and silification have destroyed the original composition leaving resistant white chalky rocks with relict sedimentary fabrics.

Most of the Koolatong Siltstone was deposited in a quiet, shallow, reducing environment, with periods of exposure and desiccation. Evidence of evaporitic conditions is found mainly in the lower half. Just prior to deposition of the sandstone marker, conditions were a little deeper and more energetic. Haines (1994) interpreted the Fleming Sandstone/Koolatong Siltstone contact as a paraconformity boundary related to the Masterton Sandstone/Mallapunyah Formation and Kurara Sandstone/Slippery Creek Siltstone contacts of McArthur and Habgood Groups respectively. If this is correct then the Koolatong Siltstone correlates with the Slippery Creek Siltstone (Habgood Group) and most of the Umbolooga Subgroup (McArthur Group). As such, it therefore encompasses most, if not all, of the interregional Accommodation Packages 1-4 of Jackson and Southgate (1997a) and Southgate and others (1997a).

It is possible that the sandstone marker (Zak, on the mapface) correlates with the widespread Tatool Sandstone of the Umbolooga Subgroup. A similar sandstone unit is recognised within the Slippery Creek Siltstone in ARNHIM BAY–GOVE (Rawlings and others, 1997). If so, the base of the sandstone correlates with one of the major Basin Event Boundaries of Southgate and others (1997a), such as boundary C at the base of Accommodation Package 3.

Strawbridge Breccia (Pa8s)

The Strawbridge Breccia is a resistant ridge-forming unit of chert breccia (silicified carbonate rocks) which overlies Koolatong Siltstone and is overlain by Vaughton Siltstone. Though thin relative to these enclosing units, it forms an essential marker horizon for subdividing the otherwise poorly-exposed lower Balma Group. It is also the primary means of defining structural trends in the area between Parsons Range and Koolatong Fault, north of Bath Range. The basal contact with the Koolatong Siltstone is not exposed but is probably conformable. However, the upper contact with the Vaughton Siltstone is marked by a basal conglomerate, containing reworked lower Balma Group and older clasts suggesting the contact is unconformable. Thickness cannot be measured accurately as brecciation and bedding contortion produce uncertainties in dip angle. Its estimated maximum thickness is 100 m, but it is generally only a few tens of metres. Outcrop of Strawbridge Breccia occurs between the Koolatong and Parsons Range Faults.

Plumb and Roberts (1992) defined a reference area at lat 13°14′30″S, long 135°36′E*, where an east-dipping ridge of breccia is intersected by the Matta Murta River (GR NF650362). A more accessible reference section is at GR NF670330, where a southeast-dipping strike ridge is traversed by a track. This is the most accessible outcrop of Strawbridge Breccia in an area not complicated by faulting.

Strawbridge Breccia is dominated by chert formed by silification of sedimentary carbonate as it preserves relic microbial laminations, stromatolites, ooids and intraclast conglomerate. Stromatolites are common, though rarely well preserved, and include domal, columnar and, more rarely, conical varieties. Conical stromatolites vary in height up to several tens of centimetres, and some are polygonal in plan view. Chert is commonly laminated and brecciated to varying degrees. Chert clasts are frequently colour banded, white to grey and black (reddish and yellowish where the breccia is ferruginous), on a mm- to cm-scale, apparently highlighting original bedding. The breccia has a siliceous (chert and chalcedony) matrix and displays 'jigsaw' texture suggesting solution collapse origin. Near faults, the breccia develops a ferruginous-manganiferous matrix producing massive outcrops of Fe and Mn oxides.

Silicification is not just a surface phenomenon, but continues to depth as indicated by percussion drilling in the early 1970s (BHP, 1974). In many sections, the degree of brecciation increases up-section from well bedded strata in the lowest exposed beds, to massive, chaotic and unbedded chert breccia at the top. In places, including the type section and reference sections, the uppermost beds contain scattered rounded pebbles and cobbles of sandstone. These beds may represent a fossil regolith, mixed with some transported components, that forms a transition into the overlying conglomerate at the base of the Vaughton Siltstone.

Relict structures and fabrics imply that the breccia was originally a package of shallow water, intertidal carbonates. The presence of ooids, other arenitic carbonate particles and intraclasts indicate deposition in agitated water, while the abundance of stromatolites and other microbial fabrics indicate shallow depths within the photic zone. That silicification and brecciation continues to depth suggests it is not related to the modern weathering environment or the Cretaceous unconformity like other chert breccias in the region.

*Note that Plumb and Roberts (1992) actually give the longitude 133°, but this is a typing error.
Plate 20 Close-up of selectively-silicified columnar stromatolites in a bioherm in Koolatong Siltstone just above the ‘marker sandstone unit’ (GR NF454158).

Plate 21 Large domal stromatolites in a dolostone bed within upper Koolatong Siltstone (GR NF687530).

Textural evidence also suggests that ferruginisation near faults formed after silicification and brecciation, hence silicification is pre-deformation. Silicification most likely formed during exposure between original carbonate deposition and the transgression of the Vaughton Siltstone.

Although no direct correlative is recognised in the Habgood Group in ARNHEM BAY-GOVE, Haines (1994) considered that its stratigraphic position might lie within the unexposed interval between Slippery Creek Siltstone and Yarawoi Formation.

On a wider scale, Haines (1994) suggested that the unconformity above Strawbridge Breccia is a tectonic-related sequence boundary that may extend to the southern McArthur Basin, possibly represented by an hiatus between the Mitchell Yard Dolomite Member (Emmeruuga Dolomite) and Teena Dolomite. This latter karstic event is interpreted as a major interregional break (Basin Event Boundary E) between Accommodation Packages 4 and 5 (Jackson and Southgate, 1997a; Southgate and others, 1997a).

*Vaughton Siltstone (Pav)*

The Vaughton Siltstone is a thick, though poorly known recessive unit, which lies between the thin, more resistant marker horizons of Strawbridge Breccia below and Conway Formation above. Sections are incomplete, however, Plumb and Roberts (1992) nominated a reference area surrounding lat 13°20'S, long 135°35'E. This area provides good outcrop of the top of the formation at GR NF638240 as well as small scattered outcrops lower in the sequence. The thickness of the Vaughton Siltstone cannot be accurately determined, but is estimated at 600-1000 m.

In most areas, the dip slope at the top of Strawbridge Breccia is covered by sand (Czs) often bearing rounded cobbles and pebbles of sandstone. The sand usually extends with low relief some distance from the ridge. Outcrops of lithified pebble to cobbble conglomerate with a sandy matrix occur rarely. One of the best exposures is in a creek bed at GR NF588175 west of the northern tip of Bath Range (Plate 22), which represents a basal conglomerate to Vaughton Siltstone. The sand and loose cobbles represent the disaggregated
basal unit. Similarities in the clast assemblage at widely separated sites supports this view, as known Cretaceous conglomerate and Cainozoic gravel vary in clast assemblage (and in other features such as roundness). Supportive evidence also comes from BHP percussion drilling, in particular hole B27 on Traverse 32 (BHP, 1974). In this drillhole, 5 m of gravel was logged between 90 m of chert breccia interpreted as Strawbridge Breccia and 40 m of siltstone and clay interpreted as Vaughton Siltstone. The clast assemblage is similar to that observed in Ngilipiitji Conglomerate Member of the Yarrawirrie Formation. Sandstone clasts were probably derived from Parsons Range Group suggesting that this succession was uplifted west of Bath Range Fault during sedimentation.

Few outcrops in the main interval of the formation were observed. Sparse outcrops in creek beds and wash-outs are of weathered fissile khaki green mudstone. Interbeds of sandstone are present locally, such as in the reference area where several beds of massive coarse-grained, brown, lithic and slightly dolomitic sandstone are interbedded with finely-laminated khaki green mudstone. A rare fresh exposure from the middle of the formation occurs around GR NES13897 where grey to black clay shale is interbedded with thin-beded grey-green dolomitic siltstone. Lenticular pods of coarse-grained conglomerary siderite are common. Fresh outcrops of predominantly dark grey and black siltstone and clay shale at or near the top of the formation were observed at several localities, for example at GR NF638240, where the conformable Vaughton Siltstone-Conway Formation contact is well exposed.

In the 1970s, BHP undertook exploration in the Vaughton Siltstone north of Bath Range, including several percussion drill holes (maximum depth 135 m) and shallow soil auger holes (BHP, 1972b; 1973; 1974). These reports confirm that most of the formation is composed of mudstone with minor dolostone and sandstone interbeds. Black carbonaceous shale is not confined to the upper part, as seen from surface exposure, but is also present in the subsurface in lower parts of the formation. These horizons are reported to contain up to 10% pyrite.

The basal conglomerate may be a fluvial, or high-energy transgressive deposit. The rest of Vaughton Siltstone lacks diagnostic indicators but the abundance of reduced carbonaceous mudstone and fine laminations imply a quiet subtidal anoxic environment below storm wave-base. The contact with the overlying Conway Formation indicates shallowing-upward.

Haines (1994) correlated the Vaughton Siltstone with the lower Yarrawoi Formation of the Habgood Group (ARNHEM BAY–GOVE). He also suggested that the basal contact with Strawbridge Breccia is a sequence boundary of tectonic origin related to an inferred hiatus in the McArthur Group between Emmerugga and Teena Dolomites. Vaughton Siltstone may thus be the time equivalent of the upper Umbolooqa Subgroup above Emmerugga Dolomite. Plumb and Derrick (1975) had previously suggested that black shale in the upper Vaughton Siltstone correlated with the economically important Barney Creek Formation of the McArthur Group. The inferred hiatus and possible karstic event at the top of the Emmerugga Dolomite is interpreted (Jackson and Southgate, 1997a; Southgate and others, 1997a, b) as a major break throughout the Mount Isa and McArthur Basin region between Accommodation Packages 4 and 5 (Basin Event Boundary E). If Strawbridge Breccia does correlate with boundary E, then the Vaughton Siltstone probably lies within Accommodation Package 5, which encompasses the McArthur Group between Teena Dolomite and Yaloa Formation, and includes several higher-order sequences. Thus, the Conway Formation may lie chronostatigraphically higher than earlier believed, and the upper black shale of the Vaughton Siltstone may well be equivalent to the black shale Caranbirini Member of the Lynott Formation (Batten Subgroup). The lower black shale of the Vaughton Siltstone would then equate to Barney Creek Formation.

Conway Formation (Eac)

Conway Formation is a thin, resistant, ridge-forming unit which separates the recessive Vaughton Siltstone (below) from the Zamia Creek Siltstone. Plumb and Roberts (1992) nominated a reference area around lat 13°22'S, long 135°35'E. The lower boundary is placed where interbeds of flaggy, laminated cherty siltstone, dolomitic siltstone and dolomitic fine-grained sandstone suddenly appear above the monotonous black shale of upper Vaughton Siltstone. The contact is well exposed near the top of a creek bank at GR NF638240 in the reference area. The top is marked by the last significant prominent chert band. Conway Formation ranges between 50 and 100 m thick.

Conway Formation can generally be subdivided into a lower, more recessive, and upper prominent ridge-forming unit. In surface outcrop, the lower unit consists of pale grey to pink and white (in places iron stained), thin-beded, flaggy, planar-laminated mudstone, chert and some fine-grained sandstone. These rocks have been strongly leached of any original carbonate and carbonaceous components. In creek bed outcrop in the reference area, the sequence is grey to black and consists of siliceous and dolomitic siltstone beds, interbedded with mudstone. The rocks are somewhat carbonaceous and siderite may be present. Some beds are probably tuffaceous.

The upper unit has several prominent chert beds up to several metres thick. Six distinct chert bands can be discerned on aerial photographs, the last such horizon marking the top of the formation. The mottled grey and white chert is vuggy and brecciated, and is clearly related to silification of cyclic shallow water carbonates. Though generally massive, it may display relict microbial laminations, domal stromatolites and intraclastic textures.

Conway Formation is interpreted as a shallowing-upward sequence from subtidal mudstone at the base to shallow intertidal carbonate cycles at the top. Haines (1994) correlated the formation with a ridge-forming unit in the middle
of Yarawoi Formation of Habgood Group. This unit shows a similar shallowing trend culminating with stromatolitic chert and sandstone. With respect to McArthur Group, Haines (1994) and Plumb and others (1990) suggested a correlation with the Reward Dolomite in the upper Umbolooga Subgroup. However, new geochronology and correlations of Yarrawirrie Formation (see below) imply that Conway Formation better correlates with the Hot Springs Member of the Lynott Formation, with which it shares many lithological similarities.

**Zamia Creek Siltstone (Paz)**

Zamia Creek Siltstone is a recessive interval between the ridge-forming Conway (below) and Yarrawirrie Formations. The lower contact is placed above the last stromatolitic chert band of Conway Formation (Plumb and Roberts, 1992). The upper contact with Yarrawirrie Formation is unconformable, at least in areas north of Walker River where a basal conglomerate (Ngilipi Conglomerate Member) cuts down through Zamia Creek Siltstone, in places totally removing it.

Zamia Creek Siltstone has not been mapped north of lat 13°20'S, probably due to removal by incision. South of Walker River, the contact is always obscured, but appears concordant. In the far west, Zamia Creek Siltstone has a thickness of 300 m, however, further east the thickness is around 120-150 m. This thinning trend is the reverse of that in some other units and suggests the unconformity beneath Yarrawirrie Formation extends into this area, removing the upper part of the formation. There are no continuously exposed sections through the formation. Plumb and Roberts (1992) nominated a reference area southwest of Mount Rankin near lat 13°39'S, long 135°31'E*.

Zamia Creek Siltstone is recessive and generally poorly exposed. Most outcrops are leached or silicified. Fresh outcrops occur in creek bed exposures, but as these are limited section intervals, it remains uncertain how representative they are. Around the reference area are creek exposures of grey dolomitic siltstone and silty dolostone with cherty interbeds typically displaying fenestral fabrics. Cauliflower chert, probably after anhydrite, is found in float from the upper part. Along a creek bed at GR NF623227, sparse outcrops comprise medium-bedded, yellow, microbial dolostone with chert nodules, interbedded with silty dololute and massive, grey to khaki green dolomitic siltstone. Some beds at this location contain granule-size lithic clasts.

Away from incised creeks, surface exposure consists of rubble of chert and leached or silicified siltstone, most of which probably had a carbonate component. The rocks display microbial lamination and relic stromatolites are observed. One of the most characteristic features is the presence of fenestral fabric. Sandstone is uncommon, however, in the area north of Bath Range, fine- to medium-grained ferruginous sandstone, and coarse-grained sandstone to granule conglomerate composed of angular chert clasts, is commonly interbedded. In this same area, cauliflower chert nodules up to 30 cm in size are abundant in float from the lower part of the formation. Smooth, spherical and irregular chert nodules are also present in this area.

There is evidence of both shallow evaporitic, and deeper sedimentation in the Zamia Creek Siltstone. Very poor outcrop precludes determination of the temporal and spatial relationships of these facies.

Haines (1994) correlated Zamia Creek Siltstone with upper Yarawoi Formation of the Habgood Group and with uppermost Umbolooga Subgroup of the McArthur Group (Reward Dolomite). However, new geochronology (see below) now implies that Zamia Creek Siltstone lies higher in Accommodation Package 5 (Jackson and Southgate, 1997a; Southgate and others, 1997a, b). It may thus equate to the level of the upper Lynott and Yalco Formations (Batten Subgroup).

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*Note that Plumb and Roberts (1992) actually give longitude 135°36'E, but this is a typing error.
Yarrawirrie Formation (Puy)

The ridge-forming carbonate, sandstone and mudstone of the Yarrawirrie Formation separate the recessive Zamia Creek siltstone from Baiguridi Formation. Its steep-sided strike ridges are useful marker horizons for defining regional structure. The base is unconformable or disconformable on underlying formations, at least locally. The basal Ngilipi Ji Conglomerate Member is recognised where this unconformity is pronounced. Several formations are locally removed by the unconformity. The upper contact with Baiguridi Formation is concordant and lies above a conspicuous dip slope-forming chert horizon.

Plumb and Roberts (1992) nominated a reference section at lat 13°35'S, long 135°32'E where the formation is cut by the Walker River 4 km south-southeast of Ngilipi Ji outstation. In the far southwest near Rose River, the formation is 200 m thick and thins eastward to around 500 m in the reference area near Walker River. The maximum thickness observed is 600 m west of the northern tip of Bath Range, but this includes 200 m of basal Ngilipi Ji Conglomerate Member, also at its thickest here. To the immediate northeast, the formation thins rapidly to 200-250 m. Further north most sections are affected by strike-parallel faults and thickness estimates are not considered reliable. Thinning of the unit is also apparent west of Coast Range, but all outcrops are brecciated and inferred to lie adjacent to a concealed major north trending fault.

Most Yarrawirrie outcrops have extensive surface leaching and silicification of all originally carbonate bearing rocks. Except in some gorce incisions most are rubby with little or no rock in situ. Thus the original nature of the altered rocks, and their vertical and horizontal relationships are uncertain.

Where Ngilipi Ji Conglomerate Member is absent, the base of the Yarrawirrie Formation is marked by medium- to coarse-grained, thin- to medium-bedded, lithic sandstone, of variable thickness. The sandstone is relatively quartz-rich, but also contains chert and leached carbonate grains. Sedimentary structures include flat- and cross-bedding, ripples, desiccation and synaeresis cracks. There are carbonate interbeds, and possibly carbonate matrix in the sandstone, but this has been leached. Carbonate interbeds display microbial features. It is possible that the basal sandstone is the lateral distal equivalent of Ngilipi Ji Conglomerate Member. The unit is generally less resistant than the overlying carbonate and is largely covered by scree.

The main part of Yarrawirrie Formation is leached silicified carbonate (originally dololutite and dolorenten), mudstone and sandstone leached of original carbonate components. Some massive white mudstone beds are possibly tuffaceous. The altered carbonate ranges from massive chert, sometimes brecciated, to more commonly porous, chalky beds, varying in colour from white to pale grey with yellowish, purplish and reddish iron oxide stained horizons. One characteristic feature of the carbonate is the presence of distinct white-grey banding on a centimetre scale, which apparently reflects bands of relatively pure dololutite interbedded with silty dolostone. Relict textures after original arenaceous and rudaceous (intraclast breccia and conglomerate) carbonate particles are common. Other original carbonate rocks have an internal mush-like brecciation. This is not a primary sedimentary or tectonic feature and is perhaps related to carbonate leaching or dissolution of interbedded evaporites. Microfabrics and stromatolites are common and include domal, conical and columnar varieties. Chert nodules are also common in a variety of forms including ovoid, irregular (Plate 23) and cauliflower shapes, the latter probably replacing sulphate evaporites. Current structures are common, particularly in facies with detrital components, and include flat- to cross-lamination, wave and current ripples and ripple cross-lamination. Desiccation cracks are occasionally observed.

The top of the Yarrawirrie Formation is identified in outcrop by a dip slope covered with chert rubble, although locally it is replaced by lithic sandstone. The top chert horizon may be a couple of metres thick and usually contains relict microbial lamination and stromatolites. The chert displays distinctive irregular surface textures possibly after evaporites. It is immediately overlain by Baiguridi Formation mudstone. The contact is sharp and conformable, probably indicating rapid deepening and thus may represent a major flooding surface.

The reference section along the bank of Walker River is one of the few localities where fresh exposure is present. This section is described by Plumb and Roberts (1992) who observed interlaminated dolostone, siltstone and fine-grained sandstone.

Yarrawirrie Formation was deposited in shallow conditions, perhaps an intertidal to sabkha environment. There is evidence of evaporitic and occasionally emergent conditions. Tuffaceous rock in the Yarrawirrie Formation produced a SHRIMP U-Pb single zircon age of 1621±21 Ma (Pietsch and others, 1994).

Haines (1994) suggested that the sequence boundary beneath Yarrawirrie Formation correlates with the base of the Darwarunga Sandstone (Haibgood Group). The northern-most outcrops of Yarrawirrie Formation near Mitchell Ranges show increased sand content, interpreted as a lateral transition into Darwarunga Sandstone facies. The sand content decreases further east away from Mitchell Ranges. In the southern McArthur Basin, Plumb and others (1990) and Haines (1994) suggested equivalence of this unit with Lynott and Yalco Formations. Lynott Formation is likewise disconformable on underlying units near major faults where incision of underlying formations is evident. However, recent dating of Stretton Sandstone (1625±2 Ma; Page, 1997), which overlies Yalco Formation, indicates a similar age to Yarrawirrie Formation, although the SHRIMP date for the latter formation has large error range. The Stretton Sandstone occupies interregional Accommodation Package 6 of Southgate and others (1997a, b); boundary F at its base represents a hiatus of about 10 Ma. While boundary F below Stretton Sandstone is thought to be a major flooding surface, the equivalent surface in the Mount Isa region is demonstrably erosional.
(Domagala and others, 1997). Based on geochronological and sequence evidence, Yarrawirrie Formation may equate to Stretton Sandstone of McArthur Group and Accommodation Package 6.

**Ngilipitji Conglomerate Member (Bayn)**

Ngilipitji Conglomerate Member (new name, see APPENDIX) is a lenticular basal conglomeratic unit of the Yarrawirrie Formation which ranges up to 200 m thick. It crops out sporadically from west of Ngilipitji airstrip to the top of the map sheet. Previous workers (Plumb and Roberts, 1965; 1992) only recorded basal conglomerate adjacent to the Koolatong Fault.

The type section is from GR NF624226 (base) to NF622221, 3 km north-northwest of the northern tip of Bath Range. The section extends along the southern bank of an unnamed creek and ends beneath a cliff of upper Yarrawirrie Formation in the axis of a gentle syncline. The actual basal contact with the underlying Zamia Creek Siltstone is not seen.

The lowest exposures are coarse-grained to granular sandstone which grade upward into pebble and cobble conglomerate with a cemented lithic sandy and, locally, muddy matrix. Pebble- and cobble-sized clasts vary from well-rounded to angular, and are composed dominantly of fine- to medium-grained white sandstone, with lesser dolomitic siltstone, dolostone, mudstone and chert (Plate 24). Rare thin leached carbonate horizons are interbedded with the conglomerate. At the top there is a 4 m thick transitional zone of interbedded pebble conglomerate and dolomitic sandstone, overlain by typical carbonate-dominated upper Yarrawirrie Formation. To the east of the type section the member rapidly thins around the nose of a syncline and becomes more distal in facies. On the eastern flank of this syncline, the conglomerate pinches out, the base of the Yarrawirrie Formation being marked only by thin granule bearing beds overlain by flaggy sandstone. However, the basal unconformity is pronounced, having largely removed the Zamia Creek Siltstone.

South of the type section, Ngilipitji Conglomerate Member can be mapped semi-continuously for 15 km to the west of Ngilipitji airstrip. However, 5 km further south where the Ngilipitji access road crosses Yarrawirrie Formation, the conglomerate is absent, being replaced by a basal lithic

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**Plate 23** Irregular chert nodules in a silicified carbonate bed within Yarrawirrie Formation (GR NE584891).

**Plate 24** Close-up of Ngilipitji Conglomerate Member at the type section (GR NF623222). Largest clasts are fine-grained sandstone. Carbonate clasts have been leached out to leave voids.
sandstone. The member reaches its greatest thickness (200 m) and most proximal facies a few kilometres south of the type section. Sandstone clasts reach boulder size (maximum 40 cm). North of the type section, Ngilipiti Conglomerate Member is somewhat lenticular, but the basal unconformity is pronounced. Further north, both Zamia Creek Siltstone and Conway Formation have been removed and Ngilipiti Conglomerate Member rests directly on Vaughton Siltstone. Plumb and Roberts (1992) record 75 m of conglomerate at the base of Yarrarwirrie Formation in the Koolatong River area, where chert clasts are particularly abundant.

Outcrop is poor consisting of low hills and mounds of loose pebbles, as the sandy matrix has disintegrated at the surface. The outcrop expression is similar to that of the basal conglomerate of Vaughton Siltstone.

The thickest and most proximal development of Ngilipiti Conglomerate Member occurs at the closest approach to present outcrops of Parsons Range Group along the Bath Range Fault Zone. Depth of incision of underlying strata is also greatest in this area and along the Koolatong Fault Zone. This suggests that the sandstone clasts were derived from Parsons Range Group and that syndepositional faulting along the site of the current fault zones was responsible for the local unconformity and sequence boundary. Chert clasts near the Koolatong River were probably derived from Zamia Creek Siltstone and Conway Formation. Although incision may have been mainly fluvial in origin, the conglomerate was probably deposited along a high-energy shoreline close to up-faulted cliffs of older units.

*Baiguridji Formation* (Pai)

The Baiguridji Formation is a regionally variable succession of fine-grained sandstone, mudstone and dolostone. In most areas, it forms valleys between resistant Yarrarwirrie and Bath Range Formations.

Plumb and Roberts (1992) nominated a reference area at lat 13°07'S, long 135°43'E (around GR NF770500), about one km southwest of Koolatong River crossing. The lower contact with the Yarrarwirrie Formation is sharp and lies above a widespread dipslope-forming chert bed. The actual point of contact is rarely seen. The top of the formation has been defined as the base of the first prominent white tuffaceous mudstone of Bath Range Formation by Plumb and Roberts (1992). This definition breaks down in the far west and east where other significant tuffaceous bands are absent. In these areas the boundary is picked at the incoming of medium- to coarse-grained, chert-rich, lithic sandstone and pelloidial chert, the appearance of which are elsewhere associated with tuffaceous mudstone. The nature of this contact is discussed in the ‘Bath Range Formation’ section.

Thickness is consistently 350-400 m in the western and northern Bath Range areas. However, it thins to 200-300 m in the southern Bath Range region. Plumb and Roberts (1992) give a thickness of 195 m for the reference area, although it is possible that strike-parallel faulting has reduced the apparent thickness.

The Baiguridji Formation is regionally variable. In northern Bath Range, it is dominated by mudstone, with lesser fine-grained, thin-beded sandstone and dolostone. In this area, with the exception of cliff exposures of the top of the formation around the edge of Bath Range (Plate 25), it is rarely exposed. However, creek bank outcrops around GR NF65075 consist of planar-laminated, dark grey, carbonaceous, fine-grained, splinterly siltstone, coarser beds, some of which are micaceous.

Locally, the sequence is interbedded with thin (3-4 cm), sharp-based beds of resistant grey, planar-laminated, micaceous, dolomite siltstone, which may comprise 20% of the total section. Away from creek banks and cliffs, outcrops consist of ferruginous rubble of thin-beded, flaggy, fine-grained sandstone and siltstone which are probably the resistant interbeds of a predominantly mudstone sequence. Near the top of the formation, outcrops consist of grey to black, thin and medium-beded, fine-grained micaceous sandstone and siltstone interbedded with mudstone (Plate 26). This sequence is variably dolomitic and locally includes interbeds of dolomite. The ferruginous surface exposure is probably related to breakdown of pyritic beds. Sedimentary structures include planar and wavy laminations, pinch-and-swell bedding, small-scale hummocky cross-stratification, and soft-sediment deformation.

The proportion of sandstone in the upper half of the formation increases westwards, and outcrops become more prominent. In fact, around GR NE24075 near the Parsons Range Fault, the upper part is more resistant than the overlying Bath Range Formation and forms the central backbone of an arcuate strike ridge of upper Balma Group. As elsewhere, the lower half of the formation is recessive and probably dominated by mudstone. The upper sandstone facies consists of fine-grained, thin- to medium-beded (rarely thick-beded), pale grey to grey-purple and reddish sandstone. Thickening-upward packages may be discerned in areas of better outcrop, and beds progressively thicken upwards towards Bath Range Formation. The sandstone is slightly micaceous and some may be dolomitic in the subsurface, but all carbonate has been leached at the surface. Ferruginisation takes the form of speckly millimetre-sized iron oxide concretions, probably representing oxidised pyrite. Planar to wavy lamination, hummocky cross-stratification, wave ripples and soft-sediment deformation features are common. Beds are sharp-based, displaying tool marks and synaeresis cracks. Thinly interbedded white resistant mudstone is possibly tuffaceous, but no distinct thick tuffaceous beds are present to define the base of the Bath Range Formation. Sandstone content also increases in the far east, close to Coast Range.

Around and north of Koolatong River, the Baiguridji Formation develops a central strike ridge effectively subdividing the formation into three subunits. The lower subunit is poorly outcropping, but appears to be comprised of mudstone, dolomite mudstone and minor fine-grained sandstone. The central ridge-forming subunit contains fine- to medium-grained, thin-beded sandstone and interbedded mudstone. Thin lithic sandstone and sandy dolarenite beds are a minor component. Wavy bedding, ripples, tool marks
and soft-sediment deformations are present. The upper sub-unit consists of thin-bedded, fine- to very fine-grained sandstone interbedded with silicified siltstone. Isolated, thin-to medium-bedded tuffaceous horizons are present. Soft-sediment deformation is present near the top of the sequence. A 3-4 metre thick unit of rubbly chert (silicified carbonate) with interbedded sandstone and siltstone, displays relict domalstromatolites.

South of Koolatong River, a continuous strike ridge lying below Bath Range Formation extends south for 25 km within the south trending Koolatong Fault Zone. It consists of silicified leached carbonate rock (formerly dolarenite and dolomitic mudstone) interbedded with fine-grained, thin-bedded, flaggy sandstone. Though superficially resembling facies within the Yarrawirrie Formation, this unit is placed in the Baiguridji Formation as unfaulted contacts with Bath Range Formation could be demonstrated in places.

In most areas, Baiguridji Formation appears to be entirely of subtidal origin with abundant evidence (hummocky cross-stratification) of storm-wave reworking in the fine-grained sandstone in the upper part of the formation. In most sections, there is a shallowing-upward trend, culminating in coarsely-grained sandstone of Bath Range Formation. This rapid shallowing event and the incoming of coarse sand does not always occur at the formation boundary as defined by the thick tuffaceous beds.

The boundary with underlying Yarrawirrie Formation is interpreted as a major flooding surface and provides evidence of rapid deepening into a quiet mud-dominated environment. The northern Bath Range area apparently remained deeper, or more distal from sediment sources through much of the formation, while areas close to the trough margin were slightly shallower, and received abundant fine sand.

The underlying and overlying formations (Yarrawirrie and Bath Range Formations) can be correlated with Darwarunga and Gvakura Formations respectively of the Habgood Group (in ARNHEM BAY-GOVE) with reasonable confidence (Haines, 1994). This implies correlation of Baiguridji Formation with Ulunourwi Formation of the Habgood Group (Rawlings and others, 1997). Ulunourwi Formation is likewise dominated by fine-grained clastics, mainly mudstone, but was deposited in a shallow to emergent, evaporitic, oxidising environment. As such, the units bare little lithologic similarity, except that near the top of the Ulunourwi Formation, deeper storm-dominated conditions prevailed, depositing a facies similar to upper Baiguridji Formation. Haines (1994) also suggested correlation with the Stretton Sandstone of the upper Batten Subgroup (McArthur Group), southern McArthur Basin. Its inclusion within the interregional Accommodation Package 6 of Southgate and others (1997a, b) is in accord with geochronology for the conformably underlying Yarrawirrie Formation. Accommodation Package 6 includes several higher-order sequences, bounded by maximum flooding surfaces (Domagala and others, 1997; Southgate and others, 1997a, b), consistent with the major flooding surface that separates Baiguridji and Yarrawirrie Formations.

**Bath Range Formation (Pae)**

Bath Range Formation overlies Baiguridji Formation and is the youngest and most widely outcropping formation of the Balma Group. It is almost entirely restricted to BLUE MUD BAY, where it crops out in a broad belt running east from Parsons Range Fault, south of the southern tip of Parsons Range, to Bath Range and Yarrawirrie Plains, then north to the edge of the mapsheet. A small area of outcrop is identified along the western flank of southern Parsons Range, west of Parsons Range Fault. Outcrop is mostly extensive on the dissected plateau of Bath Range, and a low plateau extending north to Koolatong River area. Outcrop is good where the plateau of Bath Range is deeply incised by rivers, but generally poor to the north. A number of sinkholes have developed in this area (Plate 27).

The complete formation is only exposed in the far southwest of its distribution, where it is overlain by Balbirini Dolomite of the Nathan Group. The actual point of contact is not exposed and hence the nature of the boundary is speculative. There is no evidence of an angular relationship.

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**Plate 25** Cliffs developed in upper Baiguridji Formation on the western side of Bath Range, just north of Walker River (GR N595975). Bath Range Formation crops out above. Base of frame is ~ 100 m.
exposures are weathered, leached or silicified to varying degrees. The base is defined by Plumb and Roberts (1992) as the first thick, resistant “white to pale grey, feldspathic siltstone or fine-grained sandstone”. These distinct beds have high K-feldspar content, and are probably tuffaceous. Such beds are also present within the upper Baigrudji Formation, but at that level they are thinner and do not crop out prominently.

In most areas the base, thus defined, also coincides with a topographic inflection, Bath Range Formation being notably more resistant than the finer grained Baigrudji Formation. Around Bath Range and northwest of Andanangki outstation, upper Baigrudji Formation forms cliffs capped by the basal Bath Range Formation. The lower boundary definition of Plumb and Roberts (1992) breaks down near the southern tip of the Parsons Range, and in far eastern outcrops close to Coast Range. In these areas, thick tuffaceous marker beds are absent. Isolated thin beds are present but cannot be distinguished from those in the Baigrudji Formation. In these areas, the base is defined as the incoming of medium- to coarse-grained chert-rich sandstone, and peloidal chert, rock-types which appear in proximity to the basal tuffaceous marker in most sections elsewhere. In far eastern outcrops, the base coincides with a topographic inflection, however, in the far west the upper Baigrudji Formation is more resistant than usual due to the abundance of medium-bedded fine-grained sandstone. Consequently, the contact cannot be easily positioned on topographic grounds.

Shortly above the basal marker, the first coarse-grained granular lithic sandstone appears, interbedded with medium-grained lithic sandstone. Though quartz is dominant, these also contain abundant carbonate and chert grains, and grade to rocks described as ‘peloidal chert’ and interpreted to be altered dolarenite. Some sandstone contains abundant goethitic and haematitic clasts. Carbonate cement is variably leached at surface. In the upper part of the formation, sandstone is finer grained, where it is thin- to medium-bedded, but in places thick- to very thick-bedded units are observed. Sedimentary structures include flat-bedding, cross-bedding, current lineations, wave and current ripples and ripple cross-lamination, synaeresis and desiccation cracks. Around GR NE280705, cross-bedding with 2-3 m foresets was observed in thick-bedded units (Plate 28). Carbonate rocks, either leached or silicified to chert, occur sparsely through the sequence, preserving relict carbonate textures including microbial laminations and stromatolites. A variety of nodular and pseudomodular textures have also been noted (Plate 29), which are brecciated to varying degrees.

Tuffaceous beds are typically white to pale grey, greenish and pink, and are notably more abundant near the base. Grain size varies from silt to fine sand, with coarser beds containing higher proportions of detrital components. The beds have sharp bases and are internally massive, or contain indistinct laminations and current bedding, which is usually confined to coarser rocks. Ripples are found rarely on upper surfaces. Small lenticular vugs after gypsum pseudomorphs are present. Tuffaceous beds vary in thickness from a few centimetres to 2 m. The thickest are on the east side of Bath Range and

or any significant erosive down-cutting, however, elsewhere Nathan Group is always unconformable on older rocks including the McArthur Group. In the area west of Coast Range, there is evidence of an angular relationship with older Balma Group units.

Plumb and Roberts (1992) give a reference area as the Bath Range north of Walker River around lat 13°35'S, long 135°35'E. Although this area provides some of the best outcrop of the lower half of the formation, it is far from complete (about 300 m of section is exposed in a syncline between GR NF639027 and NF629027). To rectify this situation a subsidiary reference section is nominated between GR NE245753 (base) and NE240725. This 600 m thick section is essentially complete, although outcrop is not as good as in the Walker River area, and is particularly poor in the upper part. This is the thickest known section of Bath Range Formation, noting that the estimate “up to 1000 m” given by Plumb and Roberts (1992) for this area included rocks now recognised as Balbirini Dolomite. Incomplete sections in the Bath Range area have thicknesses of 400 m along Harris Creek and 300 m in the type area north of Walker River.

Bath Range Formation contains a variety of rock-types, but is dominantly arenaceous. Carbonate rocks are present and most arenite probably had carbonate cement. Almost all
northwest of Andanangki outstation. On the east side of Bath Range, east of Ngilpiti, two thick white beds (lower 2 m; upper 1.5 m) are prominently exposed some distance above the base. They are interbedded in a sequence of fine-grained, thin-bedded, dolomitic sandstone and siltstone displaying abundant hummocky cross stratification. Tuffaceous rocks at the base yield a SHRIMP U-Pb zircon age of 1599±11 Ma (Pietsch and others, 1994).

The basal beds are of subtidal, storm-dominated origin, similar to the upper Bajuridji Formation, but punctuated by discrete tuffaceous beds, the thickness of which suggests moderately proximal volcanism. The coarser sandstone above deposited in shallow, higher energy, intertidal conditions. The incoming of abundant chert detritus along with coarse sandstone suggests uplift and erosion of underlying sequences in adjacent areas, perhaps along the trough margin. The incoming of lithic material tends to be sudden, but the actual point of contact is usually scree covered. Where exposed, the incoming of lithics coincides with the basal tuffaceous beds. In some cases, the thick tuffaceous beds may be absent altogether.

This relationship can be explained in two ways. Firstly, the tuffaceous beds are lenticular, such that the first thick bed defining the base may lie at different levels in the stratigraphy. Alternatively, the incoming of coarse lithic detritus marks an unconformity and sequence boundary that incises at a low angle to various levels, locally below the thick tuffaceous beds near the trough margins. If the latter is the case, then the boundary could in future be better defined on the incoming of coarse lithic detritus. On the current map the boundary criteria of Plumb and Roberts (1992) has been retained.

Bath Range Formation is very similar in facies to the Gwakura Formation of the Habgood Group (Rawlings and others, 1997). Haines (1994) identified a probable sequence boundary at the base of Bath Range and Gwakura Formations, and correlated this with the break at the base of the Looking Glass Formation (southern McArthur Basin). This infer correlation of Bath Range Formation with the uppermost McArthur Group. However, recent radiometric dating indicates that it may be younger.

The lowermost units of interregional Accommodation Package 7 of Southgate and others (1997a, b), which incorporates the uppermost McArthur Group and at least the lower part of the Nathan Group, have recently been dated by SHRIMP U-Pb techniques (Fuge, 1997; Jackson and Southgate, 1997b; Jackson and others, in prep.). These are 1614±4 Ma (Amos Formation; uppermost McArthur Group), 1613±4 Ma and 1609±3 Ma [both from lowermost Balbirini Dolomite (Nathan Group) at the type section, Abner Range area]. These dates are within statistical error of the SHRIMP age for the basal Bath Range Formation (1599±11 Ma), allowing correlation of these units. However, the Bath Range date exhibits similar statistical overlap with a SHRIMP date of 1589±3 Ma for upper Balbirini Dolomite at the type section.

MESOPROTEROZOIC — CALYMMIAN

Nathan Group

By P.W. Haines and D.J. Rawlings

Jackson and others (1987) recognised a major regional unconformity near the top of the revised McArthur Group of Plumb and Brown (1973). They erected the Nathan Group to separate those formations above this stratigraphic break, but older than the unconformably overlying Roper Group. The nominated type section is the Abner Range of the southern McArthur Basin (BAUHINIA DOWNS). As thus conceived, the carbonate-dominated Nathan Group comprises three formations in the southern McArthur Basin, the Smythe Sandstone, Balbirini Dolomite and Dungaminnie Formation, in ascending order (Jackson and others, 1987; Pietsch and others, 1991). Only Balbirini Dolomite is recognised in BLUE MUD BAY, although a local basal sandstone (not differentiated on the map) which crops out along the western flank of the northern Coast Range, may be equivalent to Smythe Sandstone. The Dungaminnie Formation appears to be restricted to the general area of the type section in BAUHINIA DOWNS (Jackson and others, 1987; Pietsch and others,
essentially dividing the ‘evaporitic’ and ‘stromatolitic’ units in the Balbirini Dolomite type section (Jackson and others, 1987 – Figure 153; 350 m level). If this is the case, then the lower Balbirini Dolomite may have a greater affinity with the upper McArthur Group, as the previously identified McArthur-Nathan Group bounding surface in this area (the upper boundary stratotype of the Amos Formation) is not consistent with a significant hiatus or period of erosion. This assertion is supported by the geochronology (above) and the findings of Jackson and others (in prep).

The obvious connotation is that the sandstone and dolarenite interval is a lateral equivalent of the Smythe Sandstone as mapped elsewhere, and perhaps only the upper ‘stromatolitic’ and ‘recrystallised’ units at the type section are valid lithostratigraphic correlatives of Balbirini Dolomite outside the type area. The underlying ‘evaporitic’ unit, including the Balbirina prima stromatolite marker, may thus represent a separate entity that is restricted to Abner Range area. In support of this proposal, the Balbirina prima marker has not been positively identified outside the type area, yet the Kussiella kussiensis marker, which lies above the inferred

Plate 28 Large-scale cross-bedding (~2 m foresets) in a sandstone unit within Bath Range Formation (GR NE280705).

Plate 29 Pseudonodular texture in silicified dolostone of Bath Range Formation GR NE775010, north of Walker River. Scale is 10 cm long.
Plate 30 Plan view of large conical stromatolites in lower Balbirini Dolomite (GR NF852090).

Plate 31 Silicified branching columnar stromatolites in lower Balbirini Dolomite (GR NF852090).

break, is widespread. However, evidence presented by Pietsch and others (1991) and Haines and others (1993) supports the notion of widespread distribution of the ‘evaporitic’ unit, and correlation of Smythe Sandstone with redbeds at the base of the Nathan Group type section. This evidence includes the recognition of evaporitic carbonates and sandstone, and tentatively the stromatolite Balbirina prima, in the lower Balbirini Dolomite in distal sections and drillholes, such as DDH 82-4 in MOUNT YOUNG. Further section measuring, gamma-ray logging and geochronology will be required to resolve this question.

Balbirini Dolomite (Enz)

Balbirini Dolomite (and its equivalents) displays a remarkable consistency of facies over a large part of the McArthur Basin. Balbirini Dolomite was formalised by Jackson and others (1987), and amended by Pietsch and others (1991) who redefined the former basal member as a separate formation, the Smythe Sandstone. As currently perceived, the type section near Almer Range in BAUHNIA DOWNS, approximately 300 km south of BLUE MUD BAY, is about 900 m thick. However, stratigraphic interpretation of this section is presently in a state of flux (see discussion in ‘Nathan Group’). The thickness in BLUE MUD BAY cannot be determined due to poor outcrop.

Rocks formally assigned to the ‘Kookaburra Creek Formation’ and ‘Blue Mud Bay Beds’ in BLUE MUD BAY by Plumb and Roberts (1965) are now mostly assigned to Balbirini Dolomite. Also included are some rocks previously mapped as upper Bath Range Formation near the southwestern corner of the mapsheet. Near the southern margin of BLUE MUD BAY, Balbirini Dolomite overlies Bath Range Formation. The contact shows no angular discordance but its exact nature is obscured by Cainozoic cover. Elsewhere in the basin, the base of Nathan Group is demonstrably unconformable, for example, west of Coast Range in eastern BLUE MUD BAY, where it overlies Jalma Formation. West of Coast Range, gently dipping Balbirini Dolomite also occurs in juxtaposition to outcrops of Yarrawirrie Formation dipping at 20°-40° west. Whether this discordant relationship is structural or an angular unconformity cannot be confidently ascertained due to poor outcrop and silicification.
Table 7 Stratigraphy of the Nathan and Mount Rigg Groups in BLUE MUD BAY

<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL, THICKNESS</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
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<tr>
<td><strong>MOUNT RIGG GROUP</strong></td>
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<tr>
<td>Dook Creek Formation (Eoo)</td>
<td>Chert, blue-grey to brown, altered carbonate containing relic stromatolites, ooids and intraclast breccia; lesser interbedded sandstone, chert-clast rich, cross-bedded.</td>
<td>Shallow-water marginal marine, supratidal to intertidal.</td>
<td>Relationships not exposed in BLUE MUD BAY. Immediately west it lies unconformably between Katherine River Group (below) and Roper Group (above).</td>
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<td>&lt;30 m</td>
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<tr>
<td><strong>NATHAN GROUP</strong></td>
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<tr>
<td>Balbirini Dolomite (2nz)</td>
<td>Chert, altered carbonate containing stromatolites, locally common ooids, evaporites and intraclast breccia; lesser interbedded sandstone, chert-clast rich, cross-bedded. Local basal sandstone and conglomerate, polymict, open-framework.</td>
<td>Shallow-water marginal marine or continental sabkha, with fluvial influences in the basal part of the sequence.</td>
<td>Unconformably overlies the Balma Formation and Balma Group, although the relationship with the Bath Range Formation is unclear. Unconformably overlain by the Roper Group.</td>
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<tr>
<td>Probably up to 100 m</td>
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</table>

In BLUE MUD BAY, all outcrops of Balbirini Dolomite are silicified, being white to grey chert, commonly displaying relic textures after shallow water carbonates, with scattered interbedded sandstone (Table 7). Particularly characteristic is the abundance of ooidal chert, which easily distinguishes it from other formations, although not all horizons are ooid-bearing. Ooids first appear some distance above the base in the Coast Range area. In contrast, ooids are uncommon in the Balma Group and are found rarely in Strawbridge Breccia chert, and in unsilicified dolostone in Koolatong Siltstone. Outcrops of Balbirini Dolomite are generally low, very rubbly and brecciated, and bedding is indistinct. Ferrugisation of breccia is common. Microbial lamination, stromatolites and relic textures typical of shallow water carbonates are common. Primary lithologies consist of interbedded ooidal, intraclastic, stromatolitic and evaporitic dolostone interbedded with minor sandstone.

Along the western flank of northern Coast Range, the base is marked by a lenticular ridge-forming sandstone unit, possibly equivalent of the Smythe Sandstone, although it has not been differentiated on the mapface. This unit is medium- to coarse-grained, thin- to medium-bedded and flaggy to blocky in habit. Shrinkage cracks, both synaeresis and desiccation, are common. Angular pebble- and cobble-sized clasts of sandstone are present at the base. Although relatively quartz-rich, the sandstone contains a significant proportion of chert, carbonate and mudstone clasts, some of which leach to give a characteristic vuggy appearance. Leached and silicified carbonate interbeds increase in abundance up-section demonstrating a gradation into the more typical carbonate-dominated sequence above.

Evidence of evaporites is preserved. Halite pseudomorphs are found on sandstone interbeds, and large cauliflower-shaped nodular masses and discrete enterolithic layers of chert and quartz are common above the lenticular basal sandstone described above. These display relic lenticular crystals arranged in rosettes, suggesting that the original mineral was gypsum. Domal, columnar and conical stromatolites are associated.

Along the western flank of southern Coast Range, a distinctive ridge-forming chert unit overlying the Balma Formation with probable unconformity, has been included in Balbirini Dolomite on the mapface. This ridge contrasts with the typical low rubbly outcrops of Balbirini Dolomite elsewhere, and the basal sandstone of this formation, seen further north, seems to be absent in this area. The unit consists of bedded white chert, with variable ferrugisation. The chert displays current laminations, microbial lamination and abundant stromatolites, including cones 60 cm high and 30 cm wide (Plate 30). Branching columnar and domal stromatolites are also present. A bioherm at GR N852090 contains forms resembling *Balbirina prima*, described from the lower part of Balbirini Dolomite type section (Walter and others, 1988), although silicification precludes positive identification (Plate 30, 31).

The chert unit may be a lateral equivalent of the sandstone unit mapped further north. However it is also possible that this unit is older than Balbirini Dolomite, having been removed during an erosional hiatus in the northern Coast Range area. If so, the sandstone unit, defining the Balbirini base further north, may be obscured to the west of the chert ridge by Cainozoic cover. It is unlikely that the stratigraphic relationships in this area can be fully resolved without stratigraphic drilling. If the *B. prima* identification is correct, a correlation with the lower part of the Balbirini Dolomite type section (as conceived by Jackson and others, 1987; and
Pietsch and others, 1991) could be inferred. However, as discussed under 'Nathan Group', a significant hiatus within this section now seems likely. Thus, the possibility that the ridge-forming chert unit of southern Coast Range has a greater affinity with the upper Balma Group, must be considered.

All indicators suggest similarity with the sequence in the southern McArthur Basin, which has been interpreted by Jackson and others (1987) as a shallow marginal marine or continental sabkha environment with evaporitic conditions and distal volcanic influence. No tuffaceous rocks were recognised in BLUE MUD BAY, but this may be a function of surface weathering. The abundance of ooids indicates a regularly agitated environment.

If Bath Range Formation correlates with lower Nathan Group then the ooid-rich Balbirini Dolomite overlying Bath Range Formation in southwest BLUE MUD BAY represents only the upper part of the formation, as defined at the type section at Abner Range (Jackson and others, 1987). This is consistent with findings in URAPUNGA, where ooid-rich dolostone is characteristic of the upper Nathan Group (K. Plumb, pers comm, 1997).

**Mount Rigg Group**

By B.A. Pietsch

Walpole and others (1968) defined the Mount Rigg Group based on mapping in KATHERINE. A detailed description is given by Plumb and Roberts (1992). The Mount Rigg Group has been correlated with the Nathan Group by Jackson and others (1987), Plumb and Roberts (1992) and Sweet and others (in prep).

To the west of BLUE MUD BAY, Mount Rigg Group unconformably overlies Katherine River Group and it is unconformably overlain by Roper Group. Both unconformities are of regional extent but not markedly angular. The age of Mount Rigg Group is constrained only by stratigraphic position. As a correlative of the Nathan Group, this interval is between 1614±4 Ma (Amos Formation, uppermost McArthur Group; Page, 1997) and 1430 Ma (diagenetic age of the Roper Group; Krilik, 1982).

**Dook Creek Formation** (Eoo)

Dook Creek Formation (Table 7) is widespread in the northwest part of BLUE MUD BAY where it is exposed in a northeast-trending zone extending through Beswick (KATHERINE) and Bulman (MOUNT MARUMBA). The formation was defined by Ruker (1959) who nominated a reference area between Waterhouse and West Branch Rivers around lat 14°27'S and long 133°07'E in KATHERINE. A definition and detailed description are given by Plumb and Roberts (1992).

Essentially, the Dook Creek Formation contains a variety of rocks that, apart from some interbedded quartz sandstone and siltstone, have a carbonate component. Dolostone, siltstone and silty dolostone with intervals of stromatolitic and ooidal dolostone predominate. This unit is extensively silicified, resulting in the surficial development of rubbly chert outcrop.

The Bone Creek Formation below Dook Creek Formation, which outcrops to the west in MOUNT MARUMBA has not been recognised in BLUE MUD BAY.

**PALAEOPROTEROZOIC -- CALYMMIAN TO ?ECTASIAN**

**Roper Group**

By B.A. Pietsch

This is the youngest group of the McArthur Basin and is separated from older rocks by a regional unconformity. The Roper Group is markedly different from the carbonate-rich sequence of the underlying Nathan, McRigg and McArthur Groups. It consists of a thick sandstone and mudstone succession that forms five major sanding- and shallowing-upward depositional cycles. Powell and others (1987) suggested that each cycle begins with sediments deposited in a low energy (deeper) marine environment, which is progressively overlain by sediments which reflect an increase in energy (subtidal and intertidal environments).

McDougall and others (1965) provided a minimum age of 1280 Ma by K-Ar dating of a dolerite sill that intrudes the group. The oldest Rb-Sr age on glauconite from the Crawford Formation near the base of the group is 1390±20 Ma. Krilik (1982) interpreted a 1429±31 Ma Rb-Sr date from illite separated from McMinn Formation carbonates near the top of the Roper Group: this age provides a minimum estimate for diagenesis. The maximum age is constrained by a SHRIMP U-Pb zircon age of 1589±3 Ma for the upper part of the underlying Nathan Group (Jackson and others, in prep).

The maximum age is constrained a SHRIMP U-Pb zircon age of 1589±3 Ma for the upper part of the unconformably underlying Nathan Group (Jackson and others, in prep).

In BLUE MUD BAY (Table 8), the Roper Group occupies the area west of Parsons Range where it is deeply weathered and outcrop is sparse. Stratigraphy is based mainly on the relative position of intermittent quartzarenite exposures, because much of the section is not exposed. Full descriptions and accurate thickness estimates of each formation are impossible to make.

Poorly exposed carbonate rocks of Mount Rigg Group in the north, and Nathan Group in the south occur adjacent to the basal unit of the Roper Group. This relationship, in addition to the presence of chert (after carbonate) in basal conglomerate of the Roper Group, indicates that these two groups underlie Roper Group. To the north in ARNHEM BAY--GOVE, Roper Group is unconformably overlain by the Neoproterozoic Wessel Group of the Arfakara Basin (Rawlings and others, 1997). Erosional remnants of flat-lying Cretaceous sandstone unconformably overlie the group throughout the region.
<table>
<thead>
<tr>
<th>UNIT, MAP SYMBOL</th>
<th>LITHOLOGY</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>STRATIGRAPHIC RELATIONSHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bessie Creek Sandstone (Ere)</td>
<td>Quartzarenite, buff to red-brown, fine- to coarse-grained, thin- to thick-bedded, planar and trough cross-beds.</td>
<td>Very shallow, high-energy marine, shoreline setting.</td>
<td>Contacts not exposed, an abrupt change from fine- to coarse-grained sediments marks the lower erosional (~conformable) boundary with Ere.</td>
</tr>
<tr>
<td>Corcoran Formation (Ero)</td>
<td>Sandstone, buff to pink-brown, fine- to medium-grained, thin-bedded, hummocky cross-beds; mudstone, ferruginous, in places micaceous, scree only.</td>
<td>Low to moderate energy. Subtidal to lower shoreface to intertidal.</td>
<td>Sharp, mildly erosional (but concordant) contact with Ere. Lower contact not exposed. Lower unit (Munyi Member) absent.</td>
</tr>
<tr>
<td>Hodgson Sandstone (Erh)</td>
<td>Quartzarenite, grey to brown, mainly coarse-grained, medium- to thick-bedded, lenticular thin quartz granule beds, planar and trough cross-beds, current ripples, pseudo-karstically weathered.</td>
<td>High-energy, shallow marine shoreline.</td>
<td>Upper contact not exposed; lower conformable contact with Erj.</td>
</tr>
<tr>
<td>Jalbo Formation (Erj)</td>
<td>Mudstone and fine- to medium-grained sandstone; red-brown, ferruginous, finely micaceous, glauconitic in places, flaggy to thin-bedded, hummocky cross-beds; local thin basal quartz granule conglomerate.</td>
<td>Shallow-marine, lower shoreface environment. Possible basal fluvial facies.</td>
<td>Upper conformable contact with Erh Sharper erosional (but concordant) contact with underlying Erx.</td>
</tr>
<tr>
<td>Arnold Sandstone (Err)</td>
<td>Quartzarenite, white, coarse-grained, medium-bedded, lenticular thin quartz granule beds, planar and trough cross-beds, current ripples, pseudo-karstically weathered.</td>
<td>High-energy, shallow marine shoreline.</td>
<td>Sharp conformable contact with underlying Err. Contact with Err overlying Erj erosional but conformant.</td>
</tr>
<tr>
<td>Crawford Formation (Err)</td>
<td>Sandstone, grey to red-brown, fine-grained, thin- to thick-bedded, commonly micaceous and/or glauconitic, hummocky cross-beds, wave ripples, tool marks, soft-sediment deformation features; interbedded mudstone, khaki green to red, micaceous, thin-bedded.</td>
<td>Subtidal, storm-dominated marine shelf.</td>
<td>Lower contact is conformable and gradational. Sharp conformable contact with Err.</td>
</tr>
<tr>
<td>Mainoru Formation (Eru)</td>
<td>Mudstone, white to red-brown, micaceous in places; interbedded with sandstone, grey to red-purple, fine-grained, thin- to medium-bedded, locally glauconitic, small-scale hummocky cross-beds, soft-sediment deformation features, mudstone intraclasts.</td>
<td>Subtidal marine shelf; locally storm influenced or - dominated.</td>
<td>Base probably conformable over Eru(actual contact not seen); upper contact conformable and gradational.</td>
</tr>
<tr>
<td>Limmen Sandstone (Eri)</td>
<td>Quartzarenite, usually fine- to medium-grained, medium-bedded, extensively cross-bedded (planar and trough); quartz and minor chert granule- or pebble-rich conglomeratic beds near base.</td>
<td>Shallow-marine shelf. Possibly nearshore intertidal at base.</td>
<td>Contacts not exposed. Likely basal unconformity.</td>
</tr>
</tbody>
</table>
Limmen Sandstone (Eri)

Limmen Sandstone crops out as light coloured rubbly discontinuous low ridges and in creek beds. The presence of white chert (after carbonate) in basal conglomerate beds indicates an absence of concealed Mantungula Formation, a fine-grained unit present locally both south and north of BLUE MUD BAY.

The main rock-type is quartzarenite, which is usually fine- to medium-grained, rarely coarse-grained and conglomeratic, and commonly contains siltstone flakes. Generally the quartzarenite is silicified, medium bedded, graded (fining upward) and extensively cross-stratified, although beds may also be planar-stratified and rippled. Conglomerate beds consist of pebbles and granules of sub-rounded quartz and white chert in a finer chert/siltstone matrix. High angle cross-beds, many identified as troughs, are common in the medium-bedded conglomerate.

A fluvial facies has been interpreted in some areas by Powell and others (1987), however, a shallow marine depositional environments is inferred for Limmen Sandstone in BLUE MUD BAY.

Mainoru Formation (Eru)

Regionally, the Mainoru Formation is conformable in the sedimentary succession and is dominated by thinly-laminated to thin-bedded, commonly micaceous mudstone. Fine-grained, micaceous and glauconitic siltstone forms thin interbeds and, in places, forms intervals tens of metres thick.

All occurrences of Mainoru Formation in BLUE MUD BAY consist of sccre on low rises and hills. The sccre comprises reddish brown, thinly-laminated, thin-bedded, ferruginous micaceous siltstone and fine-grained lithic sandstone.

The flavoured depositional environment is one of low energy, such as that expected in a deeper water shelf with subtidal and, for the lower part of the formation, non-marine conditions.

Crawford Formation (Err)

The Crawford Formation is a sandstone-mudstone unit, which, because of increased sandstone content, is more resistant than the underlying Mainoru Formation. The lower contact is conformable and gradational. It outcrops recessively as rubbly exposures on low rises. Low hills of Crawford Formation may occur adjacent to the upstanding Arnold Sandstone.

Both sandstone and mudstone are grey to red-brown, ferruginous and commonly micaceous. Sandstone is generally fine-grained but ranges to coarse-grained. Fine sandstone is usually flaggy and commonly contains fine bedded-parallel detrital mica, while medium- to coarse-grained sandstone contains iron oxide after glauconite and may have considerable silt and iron oxide matrix. Sandstone and mudstone are thinly interbedded and individual beds normally fine upward. High- and low-angle cross-beds and hummocky cross-stratification (Plate 32) are common. A generally subtidal, storm-dominated marine environment is inferred.

Arnold Sandstone (Erx)

The Arnold Sandstone is quartzarenite with unquiet surface silicification and pseudo-karstic weathering. It forms indistinct, light coloured low rises and ridges in which thicknesses of only a few tens of metres of continuous section are exposed.

The sandstone is mainly coarse-grained medium-bedded and contains thin lenticular quartz-granule beds. Cross-beds and asymmetrical ripples, in places with wavelengths up to 50 cm are common.

The contact with the underlying Crawford Formation is sharply transitional from red, ferruginous, micaceous siltstone and fine-grained sandstone, to white coarse-grained sandstone. The base of the overlying Jalboi Formation is a thin bed of quartz-granule conglomerate, overlain by ferruginous fine- to medium-grained sandstone. A sharp erosional contact exists with the clean, coarse-grained Arnold Sandstone.

The depositional environment is interpreted to be very shallow, high-energy marine, probably a shoreline setting.

Jalboi Formation (Erij)

Jalboi Formation forms rubbly outcrops of ferruginous sandstone and siltstone conformably between upstanding quartzarenite units of Arnold and Hodgson Sandstones. Both the sandstone and siltstone are red-brown, ferruginous and contain fine, bedding-parallel detrital mica. The fine- to medium-grained sandstone, contains glauconite grains altered to iron oxides. Both rock-types are thinly colour laminated, flaggy and thin-bedded, and display hummocky cross-stratification. The base is a sharp mildly erosional surface, overlain by a thin quartz granule conglomerate bed.

The depositional environment is interpreted to be a lower shoreface environment in slightly deeper water than the Arnold and Hodgson Sandstones. The basal erosional surface and conglomerate attest to initial high-energy, transgressive shallow marine or fluviatile conditions.

Hodgson Sandstone (Erh)

Hodgson Sandstone, like Arnold Sandstone, comprises friable surface-silicified quartzarenite on low hills and ridges which locally is pseudo-karstically weathered. The quartzarenite is grey to light-brown, medium- to coarse-grained and medium- to thick-bedded. Cross-beds, in places recognised as troughs, may have quartz granule bases. Asymmetrical ripples are rare.

The base comprises thick beds of white to pink, medium- to coarse-grained, clean friable quartz sandstone and medium- to coarse-grained red, ferruginous, micaceous quartz sandstone, and minor flaggy fine-grained ferruginous sandstone. This represents transition from fine-grained, micaceous Jalboi Formation to coarse-grained, clean Hodgson Sandstone.
The upper part of the flat-lying Hodgson Sandstone coincides with the present-day weathering surface, and is very ferruginous. If the lower unit of the overlying Corcoran Formation (Munyi Member) is present, it has not been identified because of the effects of lateritisation.

The depositional environment is the same as Arnold Sandstone – very shallow, high-energy marine, shoreline setting.

Corcoran Formation (Pro)

The Corcoran Formation is recessively outcropping mudstone and sandstone located between Hodgson and Bessie Creek Sandstones. The description of this unit is based on a few poor exposures on rubbly rises, similar to the other recessive Roper Group mudstone units.

The Munyi Member of the Corcoran Formation has not been positively identified in BLUE MUD BAY, probably because of deep weathering and lateritisation. In MOUNT YOUNG, the Munyi Member, once considered part of Abner Sandstone, has been recognised as the basal member of Corcoran Formation (Haines and others, 1993). It lies on a sharp, irregular surface, produced by minor erosion of the top of the Hodgson Sandstone. The change from fine- to coarse-grained sediments, marking the boundary of Corcoran Formation and Bessie Creek Sandstone, is abrupt. In this area, medium- to coarse-grained, buff to red-brown, rippled and cross-bedded sandstone forms the basal beds of the Bessie Creek Sandstone.

Ferruginous, and in places micaceous, siltstone occurs as rubble around discontinuous outcrops of thin-bedded sandstone. The sandstone (mainly quartzarenite) is buff to pink-brown, fine- to medium-grained, well-sorted and commonly laminated. Common features are low-angle cross-beds, pinch-and-swell structures and hummocky cross-stratification.

Deposition occurred in low- to moderate-energy marine environments such as subtidal, lower shoreface to intertidal.

Bessie Creek Sandstone (Ere)

Bessie Creek Sandstone is the youngest Roper Group formation in BLUE MUD BAY. It forms prominent white pseudo-karstically weathered sandstone escarpments and ridges.

Buff-grey to red-brown quartzarenite is the dominant rock-type. The sandstone varies from fine- to mainly medium- and coarse-grained, is well-sorted and may be thin- to thick-bedded. Ferruginous, fine-grained micaceous sandstone is rarely exposed.

Further south, Bessie Creek Sandstone is overlain by the Velkerri Formation of the Maiwok Subgroup, but this unit has not been recognised in BLUE MUD BAY. Bessie Creek Sandstone probably deposited in a shallow high-energy shelf setting, similar to the Arnold and Hodgson Sandstones.

UNDIVIDED PROTEROZOIC INTRUSIVES

Proterozoic dolerite dykes (P_dm)

By K.A. Plumb and D.J. Rawlings

Dolerite and basalt dykes are widespread throughout BLUE MUD BAY, but outcrop is rare. They are known mainly from magnetic signatures and airphoto patterns. Most are of Mesoproterozoic age.

The most prolific swarm occurs in the Mitchell–Flinders Thrust Belt at the northern edge of BLUE MUD BAY. These abundant, largely non-outcropping dykes have not been represented on the map face. The dykes are thin (<5m wide), vertical, and oriented 0°-015°. They are most common in the older Dhunganda and Ritarango units, probably reflecting the preference of sandstone to fracture brittlely. The dykes postdate larger dolerite bodies which demonstrably relate to Fagan Volcanics and extend up into Mattamurra Sandstone at the northern end of Parsons Range. Rare fresh outcrop of altered pyritic dolerite has been found intruding Mattamurra Sandstone, and also Mirarrmina Complex in ARNHEM BAY–GOVE. No fresh outcrops have been found within Donydji Group.

These non outcropping dykes have a dark expression on aerial photographs, following faults and shear zones in sandstone. In most cases, the surface expression consists of deeply incised linear depressions with walls of ferruginised sandstone. Some dykes exhibit no magnetic expression, due either to ubiquitous alteration or to narrow width.

Freshest material from the Mirarrmina Complex comprises black, medium-grained, saussuritised and chloritised, subophitic pyritic dolerite. Plagioclase (labradorite?) is altered to epidote and chlorite. Clinopyroxene (augite) has reaction rims of pale-green pleochroic amphibole. Chlorite and epidote is scattered throughout the groundmass and concentrated in vugs. Dyke rock in Mitchell Ranges is never in situ, and comprises pebbly and gravelly scree of deeply weathered and leached red-brown and yellow ferruginous clay. Despite the degree of alteration, rare vugs or amygdales have been identified. In thin-section, a relict intergranular trachytic texture is visible, but all primary minerals are replaced by opaque oxide and sericite.

The distribution of dykes is controlled by local and regional structures. Many follow shear zones and fractures of the Mitchell–Flinders Thrust Belt, which developed between deposition of Nathan and Roper Groups. Walls rock structures within Mattamurra Sandstone suggest east-west extension. The dyke swarm was emplaced into pre-existing fractures during a later extension event. Dykes in the Mattamurra Sandstone have been offset and deformed by faults related to the Post-Roper Inversion.

Large dykes identified from aeromagnetic patterns are widespread throughout the Caledon Shelf and eastern Walker Trough, but outcrop is rare. Two-dimensional modelling
indicates subvertical dips and susceptibilities typical of average dolerite. Small outcrops have been confirmed in the areas of Coast Range, and the intersection of the Lela and Koolatong Faults, south of Koolatong River.

Magnetic dyke anomalies occur as individual arcuate traces and as en echelon arrays several tens of kilometres in length. Many are associated with significant magnetic gradients, or lie on trend with extensions of major basinal faults, suggesting reactivation of pre-existing structures. Dykes appear to intrude rocks extending in age from basement to Balma Group in BLUE MUD BAY and up to Roper Group in ARNHEM BAY–GOVE.

Dykes sets are classified according to their predominant trend - 315°, 340°, 000° and 045°. The 315° dykes form a conjugate pattern with the less-abundant 045° set. Some 000° dykes swing through arcuate traces from north in BLUE MUD BAY to northwest in ARNHEM BAY–GOVE. 315°-trending en echelon arrays, such as that cutting the Coast Range, indicate a dextral component of movement, or east-west extension. Near where the Koolatong Fault cuts Koolatong River in northern BLUE MUD BAY, a prominent en echelon array of dykes has been emplaced into sinistral tension gashes along the northern extension of the Lela Fault. While this might imply a temporal connection between dyke emplacement and the Post-Nathan Shortening, the dykes cut the Koolatong Fault itself and appear to cut the main shear zone. It is considered that they have been emplaced into pre-existing fractures, which extended perpendicular to strike. All dyke sets of the Caledon Shelf and adjacent Walker Fault Zone have been offset by small faults related to the Post-Roper Inversion.

Dyke anomalies show both positive and negative magnetisation, but there is no consistent pattern recognised. Individual dykes display polarity reversals along strike. Therefore, polarity cannot be used as criteria for relative age. Apparent crosscutting relationships are similarly inconsistent and equivocal. For example, in the Grindall Point-Isle Woodah area, a 000° dyke offsets a 340° dyke dextrally, but is itself offset sinistrally by a different 340° dyke. Another 340° dyke in turn offsets 315° dykes and the Groote Eylandt Group dextrally. The dextral offsets could be consistent with the east-west extension, but other, apparently inconsistent offsets, may be due to reactivation during the Post-Roper Inversion, or simply reflect the pre-existing pattern of fractures into which they have been emplaced. There is no evidence on the Caledon Shelf-Walker Trough for any dyke set older than the Roper Group, or younger than the Post-Roper Inversion.

The magnetic expression of the Bukudal Granite is characterised by small, closely-spaced northerly-trending negative magnetic lineaments that might represent an old dyke set.

Dyke anomalies are also common on the Arnhem Shelf and within the western Walker Fault Zone. Two main trends are apparent: 000° and 045°. The northerly set is conspicuous as a semi-continuous set of dykes intruding all units from the Parsons Range Group through to Roper Group for 100 km through western Parsons Range and adjoining areas to the north and south. These dykes are clearly continuous through older structures of the Post-Nathan Shortening event. The 045° dykes intrude Roper Group along the western edge of BLUE MUD BAY, and form a conjugate set with 315° dykes on adjoining map sheets to the west and northwest. Both sets have been offset dextrally by 045° faults during the Post-Roper Inversion.

Summing up, while dykes intrude rocks of a range of ages throughout BLUE MUD BAY, and might appear to form different sets, evidence for multiple emplacement within the northern McArthur Basin is equivocal. Apart from possible early dykes intruding the granite, all other dykes in BLUE MUD BAY postdate the Post-Nathan Shortening. The principal dyke trends (315°, 045°, and 000°) intrude the Roper Group, and either intrude or immediately underlie sills associated with the Roper Group (P.). All dykes precede the Post-Roper Inversion. Similar lineaments and dykes in MILINGIMBI reveals a regional east-west extensional event (K. Plumb, personal observations, 1994). The simplest interpretation is that dykes in this region were emplaced into
pre-existing faults, or reactivations of pre-existing faults, during a single extension event that separated deposition of the Roper Group and the Post-Roper Inversion. The obvious temporal correlation is with the post-Roper Group sills ($P_{u_d}$).

Proterozoic dolerite sills ($P_{u_d}$)

By B.A. Pietsch

Thick (10-100 m) sills of dolerite intrude the Roper Group in far western BLUE MUD BAY, but outcrop is poor. These may correlate with sills intruding the top of the Roper Group in western McArthur Basin, which have an Rb-Sr age of 1280 Ma (McDougall and others, 1965).

Fresh rock is composed of coarse-grained plagioclase-pyroxene-Fe/Ti-oxides, with a doleritic to grabbroic texture. Outcrop generally weathered to red-brown soil with scattered exfoliating corestones. Abundant fresh magnetite is common in the local drainage.

Proterozoic rhyolite dykes ($P_{u_e}$)

By P.W. Haines

Rhyolite dykes are most plentiful in the Mirarrmina Complex on the western side of Mitchell Ranges. However, these are too small to be differentiated at map-scale from the older basement rocks of the complex.

A large elongate intrusive body of rhyolite porphyry crops out just east of Coast Range at GR NF889096. Although contacts are not exposed, the dyke is discordant with Grindall Formation and undifferentiated Orosirian volcanics, and is unconformably overlain by Coast Range Sandstone. It comprises coarse porphyritic rhyolite with phenocrysts of K-feldspar, quartz and minor altered plagioclase, set in a brown microcrystalline groundmass (Plate 33). K-feldspar phenocrysts are large (up to 4 cm) ovoid and intricately embayed and skeletal. Quartz phenocrysts are relatively small and are also resorbed and embayed. These are set in a micrographic oxide-stained quartzfeldspathic groundmass. Textural evidence indicates magnatic disequilibrium and a possible hybrid origin for this rock. The dyke contains xenoliths of fine-grained sandstone and mudstone, presumably from the Grindall Formation.

The dyke rock is similar in texture, petrography and geochemistry to the coarsely porphyritic phases of the 1710Ma Fagan Volcanics (Maidjunga Member). There is possibly wider correlation of felsic volcanics elsewhere in northern McArthur Basin (Spencer Creek Group and Gadambara Volcanics?). However, this is tenuous, as there are demonstrated older igneous phases in the region (Bickerton and Erringkarri Rhyolites) and hence probably several generations of rhyolite dykes.

Carpentaria Basin

By A.A. Krassay

Mesozoic – Cretaceous

Cretaceous sedimentary rocks exposed intermittently in mesas and plateaux across much of the northern part of the Northern Territory have previously been mapped as undifferentiated Cretaceous (K1). They form a flat-lying, undeformed siliciclastic coastal-plain to shelf succesion resting on mainly Proterozoic rocks. In BLUE MUD BAY, good exposure of Cretaceous rocks is restricted to the western and central parts of the mapsheet. Here, landform precursors of Bath, Parsons, and Mitchell Ranges formed the margins of a large embayment in which sediment accumulated. Sparse low-lying Cretaceous outcrops also occur on the coastal fringe to the north and east of exposed granites near Myaola Bay.

Noakes (1949) gave the name ‘Mullaman Group’ to Mesozoic sediments in the Katherine-Darwin region. Later workers down-graded this term to ‘Mullaman beds’, a name which was then used to describe all Mesozoic sediments in northern NT (Skwarko, 1966). The term ‘Mullaman beds’ became meaningless in northeastern NT when Hughes (1978) subdivided the beds into lithological units and assigned them to other formations. On the basis of detailed studies by Krassay (1994a, b), Mullaman rocks along the western and southwestern margins of the Gulf of Carpentaria are assigned to the newly defined Walker River and Yirrkala Formations.

Palaeontological and biostratigraphic observations by Skwarko (1966) constituted the first detailed work on the ‘Mullaman beds’, which he divided into the ‘Inland’ and ‘Coastal’ belts, based on geographical position and fossil assemblages. Cretaceous rocks in ARNHEM BAY–GOVE and BLUE MUD BAY belong exclusively to the ‘Coastal’ belt, consisting of seven units which Skwarko (1966) recognised and stacked to form a composite section.

Krassay (1994b) also developed a sequence stratigraphic nomenclature, superseding the (simplest) lithostratigraphy of Skwarko (1966). In the new nomenclature, the Cretaceous succession in both ARNHEM BAY–GOVE and BLUE MUD BAY has been subdivided into 24 facies as part of a larger study (Krassay, 1994a). These facies are in turn grouped (vertically stacked) into eight facies successions. The only other work has been isolated studies of local areas as part of reconnaissance exploration and shallow drilling undertaken sporadically by companies over the past two decades.

Skwarko (1966) suggests a Neocomian age for rocks in ARNHEM BAY–GOVE. Regional stratigraphic and sedimentological studies (Frakes and Krassay, 1992; Krassay, 1994a & b) provide evidence for a revised Aptian to Cenomanian age based on microfauna and regional stratigraphic correlation.

In BLUE MUD BAY, the maximum observed thickness is 26 m (Figure 10), but most outcrops are thinner (10-15 m).
Lithostratigraphic correlation suggests that the the complete composite section is 45-50 m (excluding 50 m-thick fluvial equivalents on the eastern flank of Parsons Range near GR NF260060).

The bulk of exposed Cretaceous succession is composed of sandstone, conglomerate (typically thin lags), interbedded sandstone and siltstone, and rarer claystone and clayey siltstone. Many rocks are fossiliferous. Most marine rocks are moderately to well sorted, have rounded to well-rounded clasts, and display bioturbation. Rocks are typically stained by iron and manganese oxides usually in association with laterite. Coarse-grained sandstone tends to be friable and weathers to rubbley outcrops. Finer-grained units are commonly silicified, and form resistant units towards the top of mesa-like outcrops.
Walker River Formation (Kw)

Walker River Formation encompasses moderately-to well-sorted, typically cross-bedded, fossiliferous, fine- to coarse-grained quartzose sandstone, interbedded with laminated clayey siltstone and chert granule and pebble conglomerate. The unit forms both fining-upwards and coarsening-upwards cycles, typically 5 to 10 m thick. Where the base of the unit is exposed, it consists of thick graded beds of chert cobble and pebble conglomerate which grades up into sandstone containing molluscan macrofossils and marine trace fossils.

Sedimentary structures include hummocky cross-stratification, planar cross-bedding, wave and current ripples, convolute lamination, slump structures, gutters, scours and tool marks. Walker River Formation contains molluscan macrofossils, mainly bivalves, but also rare ammonites and belemnites. Rare stratigraphic intervals have segmented plant fossils mixed with molluscan fossils. Marine trace fossils of *Skolithos* and *Cruziana* ichnofacies are common.

Yirrkala Formation (Ky)

The Yirrkala Formation encompass poorly-sorted, fine- to very coarse-grained, thickly-bedded, massive to planar bedded and large-scale cross-bedded matrix-poor quartz sandstone with dispersed chert pebbles and rare plant fossils. Upper, finer-grained parts of the unit contain rare, poorly preserved external moulds of segmented plant fossils on upper bedding surfaces.

Discussion of Cretaceous deposits

The contact between the Cretaceous and basement is rarely exposed but is distinctly disconformable. In the area between Bath and Parsons Ranges, the basal conglomerate lies with angular unconformity on Proterozoic siltstone. Cretaceous marine sandstone overlies the basal conglomerate, and onlaps south-dipping Proterozoic basement at the northern end of the large Cretaceous embayment at the base of Parsons Range near Marura Creek. Coarse-grained wedges of Cretaceous non-marine clastics with little or no structural dip have obvious angular unconformable contacts with steeply-dipping Proterozoic rocks in the elevated parts of Parsons and Mitchell Ranges in central BLUE MUD BAY.

Within the Cretaceous sequence, most contacts between individual facies are gradational, but contacts between parent facies are mostly disconformable. The nature of the contacts varies from paraconformable, with sharp planar contacts of 'mud on sand' or vice versa, to truly disconformable where local scours a few centimetres deep separate different rock-types. These contacts can also be major erosional surfaces, involving incision with metres of relief.

In the lower part of the Cretaceous succession in BLUE MUD BAY, conglomerate fines upwards into fossiliferous (bivalves, ammonites, gastropods and trace fossils) marine sandstone, indicating transition from coarse-grained non-marine valley-fill deposits, through paralic deposits, to marine deposits. Most of the overlying sandstone and interbedded siltstone and (associated intraformational conglomeratic lags and coquinas) accumulated in shallow-marine depositional systems that characterised the western shelf of the Carpentaria Basin during Aptian to Cenomanian time. Coarse-grained units within this middle shelf succession display sedimentary structures consistent with deposition in high-energy marine environments. These shallow-marine environments were storm- and wave-dominated, and erosion and reworking of sediments in near-shore zones was common.

Finer-grained rocks typically display smaller-scale sedimentary structures indicative of distal deposition in offshore areas beneath fair-weather wave-base, but still in water depths where large storms were capable of affecting deposition. The lateral (southeasterly) change in trace fossil suites from *isoloc* ichnofacies to *Cruziana* ichnofacies provides further evidence of finer-grained offshore facies in this direction (Pemberton and Frey, 1984). Similar vertical changes in trace fossil suites record changes in depositional environments over time.

The upper part of the Cretaceous succession, particularly in ARNHEM BAY–GOVE, is composed of coarse-grained
fluvial channel sandstone and the equivalent the restricted-marine interbedded sandstone and siltsstone facies. The fluvial rocks exhibit fining-upwards (?point-bar) sequences, and are amalgamated into thicker units, suggestive of lateral accretion of high-energy fluvial channels on an alluvial plain. The restricted marine sections are similar to open marine sections lower in the succession, but are more fossiliferous (some with articulated valves) and bioturbated. They have clay content and exhibit lamination indicative of a lower-energy marine environment. In ARNHEM BAY–GOVE, Proterozoic basement uplands now exposed along the eastern coast of Arnhem Land were emergent in the Cretaceous. During major transgressive pulses, the sea flooded across the pre-existing topography which was probably similar to that of today, and basement barriers, islands and peninsulas, allowed fine grained sediments to accumulate in large marine lagoons.

At any one time in the evolution of the pre-existing shelf, rocks in ARNHEM BAY–GOVE were the coarsest and most proximal with respect to areas to the south. The rocks preserved here represent coastal/alluvial-plain and inner shelf depositional environments. To the south in BLUE MUD BAY, contemporaneous rocks were deposited in marginally deeper water in more distal zones, but still characteristic of inner shelf or distal deltaic environments. Still further south of BLUE MUD BAY along the margin of the Gulf of Carpentaria, Cretaceous rocks accumulated in progressively more distal marine environments. In this sense, outcrop exposed along the western margin of the Gulf of Carpentaria provides an oblique transect across an exhumed Cretaceous shelf system. ARNHEM BAY–GOVE and BLUE MUD BAY represent the proximal (coastal-plain to inner shelf) part of this broad, low-gradient epeiric shelf. Walker River and Yirrkala Formations are considered to be broadly equivalent in age and depositional environment to the Culbert River Formation and Rolling Downs Group, as described by Smart and others (1980), of the Carpentaria Basin.

Sequence Stratigraphy

The sequence stratigraphic history of the western and southwestern margin of the Carpentaria Basin involves multiple changes in relative sea level on the shelf over a time interval of approximately 20 Ma. Six major sequences were deposited on the shelf, from the beginning of the initial Aptian transgressive pulse, to final retreat of the sea in the latter Cenomanian. The sequences are bounded by six regional unconformities and correlative conformities (sequence boundaries). Four sequence boundaries and four sequences are recognised in BLUE MUD BAY.

Most sequence boundaries are type 1 examples (sensu van Wagoner and others, 1990), which record large basinward shifts in depositional ‘facies belts’ at times of major regression, and involve erosional relief in the order of 10 m. For example, on Wonga Creek in ARNHEM BAY–GOVE (Rawlings and others, 1997), coarse-grained cross-bedded shoreface sandstone fines steadily upwards over 8 m through hummocky cross-stratified sandstone (transgressive systems tract, TST) to a condensed section of silty claystone (highstand systems tract, HST). The top of the HST is incised, with prominent unconformity, and is overlain by coarse-grained trough cross-bedded fluvial channel sandstone. The unconformity is regional in extent, and the erosional incision may be as much as 10 m over a distance of 90 m. The unconformity represents the sequence boundary formed by subaerial erosion on the shelf during lowstand, when a major fall in sea-level caused regression and a progradational shift in ‘facies belts’.

Throughout BLUE MUD BAY, shifts in ‘facies belts’ are evidenced by similar vertical and lateral facies changes. Most of the sequences are composed of lowstand, transgressive, and highstand systems tracts in the conventional manner (shelf-margin systems tracts are missing). In turn, the systems tracts are composed of stacked fining-upwards (TST) and coarsening-upwards (HST) parasequences. A parasequence equates to a facies succession. Relatively short time breaks occurred between deposition of each facies succession within a stacked series of facies successions, and these hiatuses which occur as regional disconformities are evidenced by scouring on the order of decimetres to a metre.

The exact duration of the sequences is unknown, but their estimated range of 1 to 6 Ma corresponds to third-order cycles. Higher-frequency individual coarsening- or fining-upwards facies successions probably correspond to fourth-order cycles. In general, the record of relative sea level changes on the Carpentaria Basin shelf (interpreted from the depositional cycles) has poor correspondence with the global eustatic curve of Haq and others (1988). Conversely, it has better correspondence with other eustatic sea level curves, and a good correspondence with major events on other northern Australian curves. From a sedimentological and stratigraphic perspective, the storm-dominated depositional systems which characterise the ‘Mullaman beds’ shelf succession have much in common with similar shallow-marine systems described in the analogous broad Cretaceous epeiric seaway of the Western Interior Basin of North America.

Regional correlations with the central Carpentaria Basin

The Walker River and Yirrkala Formations and their undifferentiated equivalents are broadly equivalent in age and depositional environment to the Gilbert River Formation and Rolling Downs Group (Smart and others, 1980) of the central Carpentaria Basin. The lower conglomeratic part of the shelf succession is non-marine and probably corresponds to Gilbert River Formation. Overlying these units are late Aptian sandstone successions which are equivalent to lower Wallumbilla Formation, and other marine successions which are probably equivalent to lower to middle Wallumbilla Formation. The sandy middle part of the shelf succession is equivalent to upper Wallumbilla Formation and Allarau Mudstone. Toolubuc Formation, which separates Wallumbilla Formation and Allarau Mudstone in the central part of the Basin, has no equivalent in the onshore succession of the NT.

Non-marine, restricted-marine, and marine rocks in the upper part of the Cretaceous shelf succession are equivalent to the Normanton Formation of early Cenomanian age. The major erosion surface documented on Wonga Creek in ARNHEM BAY–GOVE is considered to represent the bound-
ary between marine Allaru Mudstone-equivalent rocks and younger non-marine and restricted-marine Normanton Formation-equivalent rocks. The Cretaceous sequence is capped by laterite and soil of supposed Tertiary age, although a ferruginised regolith at Cape Arnhem (eastern ARNHEM BAY–GOVE) has been tentatively dated as Late Cretaceous in age by palaeomagnetics (unpublished date, M. Idnurm, pers. comm., 1994).

CAINOZOIC
By P.W. Haines

Unnamed units (Cz, Czl, Czs, Qa, Qb, Qc, Qd, Qt)

Thin Cainozoic deposits cover about 50% of the land area of BLUE MUD BAY but are generally not more than a few metres thick. Where practical, these deposits are subdivided into genetic units distinguishable on aerial photographs, but in many areas the map symbol Cz is used to denote undifferentiated deposits and sandy soils.

Pisolitic and massive ferricrete and laterite (Czl), which formed under conditions of intense chemical weathering, form a thin drape over Cretaceous and older rocks. The most extensive deposits occur east of the main outcrops of McArthur Basin rocks where they probably lie most frequently over a relatively thin Cretaceous succession. Further inland, the capping of Czl has largely been stripped by erosion but is preserved on low mesas of Cretaceous rocks.

Deposits of loose sand (Czs), commonly with relief above the surrounding plain, formed by in situ disintegration of sandstone units, relics of which may be locally preserved. West of the Parsons Range Fault Zone, Czs forms over Roper Group such as Bessie Creek Sandstone. Southeast of Parsons Range, Czs forms over Cretaceous sandstone, while east of Parsons Range, narrow deposits of Czs lie on ridges of Strawbridge Breccia. These deposits contain scattered pebbles and cobbles, derived by disintegration of the basal sandy conglomerate of the Vaughton Stiltstone.

Alluvial gravel, sand, silt and clay (Qa) are found in active channels, flood plains, and outwash sheets around ranges. Fine-grained deposits in local depressions are included in this category. Areas of Qa, flanking rivers, fan laterally towards the coastal zone where they intermingle with coastal sediments.

Active deposits forming on intertidal and supratidal flats, and in tidal channels (Qc), cover extensive areas near the coast and extend 10 km inland in tidal reaches of major rivers. These are largely unvegetated, apart from stands of mangroves. They consist of unconsolidated, grey, clay, silt and sand with entrained shell debris.

Qc is 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 and recently active cheniers and sandy beach ridges (Qt) are comprised of shelly sand. They are scattered along much of the coast as narrow ridges a few metres in height, some are now located several kilometres inland.

Coastal aeolian dune fields (Qd) occur along the exposed coast in southern BLUE MUD BAY, where individual dunes reach 30 m in height, and along the northeast coast. Similar dune fields are developed on Groote Eylandt. In addition to modern active transverse and parabolic dunes, Schulmeister and Lees (1992) recognised three past dune phases on Groote Eylandt using thermoluminescence dating. The basal, now cemented dune field was formed prior to 100 000 yr BP, while parabolic dune fields stabilised between 6000 and 4800 yr BP, and less than 2000 yr BP.

The coastal deposits of BLUE MUD BAY are quite thin as they have only been accumulating in their current configuration since the Holocene sea level rise. During the Pleistocene low stands, the entire area of BLUE MUD BAY was probably dry land.

GEOPHYSICS
By K.A. Plumb

BLUE MUD BAY is covered by regional gravity and by airborne magnetic and radiometric data. The aeromagnetic data were obtained during contract surveys flown for NTGS during 1990-93. The surveys include ‘Marumba, NT, 1988/89’, ‘Mitchell Ranges, NT, 1990’, ‘Arnhem Bay/Gove, NT, 1991’ (all by Kevron Geophysics) and ‘Groote Eylandt, NT, 1993’ (Aerodata Holdings Ltd.). Surveys had east-west oriented flight lines, with a line spacing of 500 m and a mean survey elevation of 100 m. The data were processed by the contractors, and are available in digital form from NTGS, and as hardcopy as 1:100 000 scale total magnetic intensity (TMI) contour and flight path maps, and stacked profiles of TMI. The various datasets covering all Arnhem Land have since been microlevelled, stitched and gridded into a single dataset, and TMI reduced to the pole by AGSO. It is these latter datasets which have been used for the imagery creation and interpretation in this report.

The gravity dataset is available only from the AGSO Australia-wide regional gravity survey, at a station spacing of 11 km. This data is available in digital form and as contour maps of Bouguer and Free Air Anomalies.

Radiometrics

Figure 11 displays the regional radiometric features of eastern Arnhem Land, as a 3-band composite image of K – red, Th – green, and U – blue.

BLUE MUD BAY is dominated by radiometric signatures from Cainozoic deposits of sufficient thickness to mask the underlying bedrock. The most widespread of these are sand and laterite. Ferricrete/laterite is characterised on the image by green, blue, and magenta shades, reflecting enrichment in
Figure 11 Total count radiometric image for eastern Arnhem Land. BLUE MUD BAY is outlined.
Figure 12 Total magnetic intensity image for eastern arnhem Land. BLUE MUD BAY is outlined. High values magenta, low values blue.
Figure 13 Gravity image for eastern Arnhem Land. BLUE MUD BAY is outlined. False colour gravity is draped over NE-SW and SE-NW gradient filters of magnetics. High values red, low values blue.
Th and U. Much of the laterite surface away from drainage interfluves, is actually covered by thin windblown sand. However, the laterite signature is preserved through this cover, implying that this sand is an integral uppermost component of the laterite profile. The radiometrics clearly distinguish laterite, and its residual sand, from other widespread blankets of transported quartzose sands, which are low in radioactive elements (black pattern). All detectable K, Th, and U have been removed from the underlying leached zone (black).

Coastal alluvial deposits and salt flats, subject to periodic seasonal inundation, are identified by their red K-rich signature; XRD examination of samples has identified illite as the only potassic source. The K-rich signature of the active coastal flats extends upstream and is preserved over older exhumed vegetated coastal deposits, such as along the lower reaches of the Koolatong River. Active alluvial deposits are therefore readily distinguished from exhumed coastal deposits with marine influence. However, some alluvial systems, such as the upper Koolatong and Rose Rivers, are characterised by high-K signatures (red), as a reflection of K-feldspar or glauconite-rich sources.

Outcropping bedrock is distinguished mainly by variations in potassium content. As expected, the strongest response is from K-feldspar granites. The cores of outcrops of the post-tectonic Bukudal Granite show yellow to white patterns, reflecting K and Th enrichment, grading to red around the edges. In contrast, metamorphic and magmatic rocks of the Bradshaw Complex in ARNHEM BAY–GOVE are enriched in U, relative to younger granites, and are characterised by blue to magenta shades. Outcrops of this unit on BLUE MUD BAY are too small to register on the radiometric image. Grindall Formation is sericite-rich, and so the larger outcrops, such as beneath Coast Range, have a red K-rich pattern. Outcrop of Mirarrmina Complex is too poor to preserve characteristic patterns, and shows up as scattered red spots.

Felsic volcanics and hybridised maﬁc intrusives of the Donydji Group and Gadabara Volcanics are identified by similar red-yellow, K- and Th-rich signatures to those of post-tectonic granites. Associated illitic and feldspathic sandstones, such as Ritarrango Formation, show weaker, brown patterns. Signatures from Groote Eylandt Group are variable. Felsic volcanic units of Bustard Subgroup show characteristic red-yellow K- and Th-rich signatures, while associated sandstone shows dull red patterns, reflecting contained clay. Contained clay in sandstone of the overlying Alyangula Subgroup is patchy and radiometric signatures are weak.

Parsons Range Group is dominated by non-radioactive quartzose sands, although recessive shaly units within the group do show weak red K-rich signatures from contained illite.

Outcrops of Balma Group show characteristic red to yellow, K-rich signatures from illite and K-feldspar rich tuffs. The Roper Group displays red, K-enrichment from glauconite in the Crawford, Mainora, and Jalboi Formations. The quartzose units and associated maﬁc sills are characteristically black.

Magnetics

The regional range of values of magnetic intensity over Arnhem Land is generally low. The maximum range between highs and lows on BLUE MUD BAY including dykes is 1000 nT. Generally the range over short wavelength anomalies is 300–500 nT, while the difference between regional relative highs and lows is only 100–150 nT. Nonetheless, structural features may be enhanced by the application of various high-frequency ﬁlters, such as horizontal and vertical gradients. Figure 12 displays the regional magnetic features of eastern Arnhem Land by superimposing northeast and northwest gradient ﬁlters on a stretched false colour image of TMI, which has been reduced to the pole. The 1:1 000 000 scale magnetic image on the map face is extracted from this same image.

A range of enhanced images and ﬁlters has been used to interpret pre-Mesozoic subcrop in unexposed areas. This interpretation is depicted on the back of the map face and accompanying 1:1 000 000 scale solid geology map, while the cross-section has been constrained by two-dimensional modelling of magnetic proﬁles.

The most magnetic (300–500 nT) units are volcanic horizons within the Donydji Group, Bukudal Granite, and dolerite dykes. Modelling indicates that magnetic susceptibilities of the volcanics are actually an order of magnitude greater than average values for granite; the similar amplitude of the anomalies over the granite reﬂects the greater thickness of the latter. Dolerite sills intruding the Roper Group along western BLUE MUD BAY show well-deﬁned edge effects, although there are negligible anomalies over the ﬂatlying sills themselves. Most other rocks within the McArthur Basin sequence are essentially non-magnetic. Metamorphic basement rocks of Bradshaw and Mirarrmina Complexes are less magnetic than the volcanic and granitic units described above, but are higher than the overlying sedimentary rocks. Grindall Formation is essentially non-magnetic. ‘Magnetic basement’ beneath most of the McArthur Basin (Parsons Range Group upwards) is deﬁned by the Donydji Group or the granites, while the Bradshaw and Mirarrmina Complexes may be used as a general background value for modelling.

Bukudal Granite is characterised by a distinctive pattern of closely spaced (<0.5 km) north and north-northeast fractures or dykes; outcrop is insuﬃcient to identify their ground source. The granite bodies trend east, subparallel to the regional trends of the Bradshaw Complex observed in ARNHEM BAY–GOVE (Rawlings and others, 1997).

While the Bradshaw Complex is characterised by similar, but lower amplitude high-frequency fault and fracture patterns in ARNHEM BAY–GOVE, these features are not apparent in BLUE MUD BAY. Coastal outcrops are smaller than the diagnostic pattern itself, and masked by nearby sedimentary cover. Possible Bradshaw Complex in BLUE MUD BAY may be distinguished only by slightly elevated magnetic values, relative to the non-magnetic Grindall Formation.
Dipping volcanic and intrusive Donydj Group units in Mitchell Ranges provide some of the largest amplitude anomalies.

Most other sedimentary rocks of the McArthur Basin are essentially non-magnetic. The flat-lying Groote Eylandt Group is characterised by well-developed rectilinear patterns of northeast and northwest faults and dyke anomalies, identical with that which characterises the Katherine River Group further west in MILINGIMBI and MOUNT MARUMBA. The amplitude of these high-frequency anomalies is enhanced by basaltic units, allowing the Bartalumba Basalt and overlying Dalumbu Sandstone, to be distinguished from all units of the group below.

No Balma or Nathan Groups units show any appreciable magnetic susceptibility. However, high frequency filters, particularly horizontal gradient filters, clearly identify faults as small sharp gradients. These correlate well with mapped faults in areas of outcrop and allow concealed faults to be mapped beneath shallow cover. A characteristic pattern of closely spaced north and north-northeast trending gradients distinguishes Balma and Nathan Groups from the very flat Grindall Formation pattern around the shores of Blue Mud Bay. Although Parsons Range Group is also essentially non-magnetic, selected stratigraphic units within it may be traced by characteristic, very high frequency 'noise', probably reflecting scattered iron minerals in sandstone. Roper Group sediments are only weakly magnetic, but dykes and interlayered dolerite sills enhance the fault and fracture gradients.

Dyke anomalies are prominent over wide areas of BLUE MUD BAY. Outcrops of fresh dolerite are rare. Modelling over several dykes indicates tops near ground surface and susceptibilities typical of dolerite. Many dykes are emplaced into pre-existing faults, in which case dykes superimposed on faults have simply been shown as dykes on the map face.

**Gravity**

The gravity field over eastern Arnhem Land is relatively high, but quite flat. Bouguer anomaly values over BLUE MUD BAY range from only -170 mm/sec² to 375 mm/sec². The wide station spacing means that anomalies relate to deep sources or broad regional effects. Near surface features may be enhanced by calculating second vertical derivatives. Figure 13 displays a false colour image of Bouguer anomalies, draped over northeast and northwest gradient filters of magnetics.

Distinct negative anomalies of -25 to 0 µm/sec² are associated with the Bukudal Granite on the Caledon Shelf. In BLUE MUD BAY, 0 µm/sec² is the lowest value recorded for this unit. A north-northeast trending linear low of -170 mm/sec² (Parsons Range gravity low) is centred over the southwestern end of the Badalangarmirri Fault. The eastern flank of this anomaly extends over Parsons Range; thus it is probably a reflection of the thick Parsons Range Group. The westward flank overlies the Roper Group, which is also characterised by negative gravity anomalies elsewhere in McArthur Basin. Here, however, the Roper Group is too thin to produce the observed anomaly, and so it is assumed that Parsons Range Group beneath contributes to the anomaly.

Relative highs of 300-375 µm/sec² are associated with basement units, such as Bradshaw Complex, and 300 µm/sec² with the Donydj Group in Mitchell Ranges. This latter high might reflect the composition of the Donydj Group itself, or might simply reflect proximity to basement. Around Koolatong River in northern BLUE MUD BAY, the dolomitic Balma Group is accompanied by relative gravity highs. This character is marked by the Parsons Range gravity low farther south.

**Interpretation and modelling**

Interpretation of the subcrop of eastern Arnhem Land is based on magnetics, supplemented by gravity.

The magnetic anomaly pattern of eastern Arnhem Land is dominated by a large, steep, linear anomaly, which extends for over 100 km from north-central Parsons Range (beneath the Sheridan Fault), south-southwest through southern BLUE MUD BAY and across ROPER RIVER, to the edge of the Urapunga Tectonic Ridge (Figure 12). It has its maximum amplitude of 300 nT at Harris Creek in southern BLUE MUD BAY, decreasing gradually to both the north and south. While it lies on trend with magnetic highs associated with the Donydj Group in Mitchell Ranges, it is separate from those features. It dies out northwards before reaching the Donydj Group anomalies. These high-frequency near-surface anomalies terminate southwards beneath Parsons Range Group; and Donydj Group rocks have inadequate magnetic susceptibility to source the anomaly from depth.

The smooth, simple, and broad east-west profiles across the anomaly imply a single deep source. Simple depth estimation methods, such half height width, straight-line slope and half-slope width (Henderson and Zietz, 1948; Sharma, 1986), consistently give depths of 13-15 km to the top of the body. This lies below the base of the Walker Trough, as calculated from stratigraphy. Modelling the simplest, most geologically reasonable body at 15 km depth, defines a linear prismatic body of essentially infinite depth, widening to 25 km at 25 km depth. The modelled magnetic susceptibility (0.01 cgs units) lies at the lower end of the normal range for ultramafics (0.015), or the upper end for gabbro (0.007) or diorite (0.0085).

This body (Central Dyke of Figure 14) underlies the depocentre of the Walker Trough, where a full section of Balma Group overlies a full section of Parsons Range Group. This is presumably the deepest part of the Walker Trough, and emplacement of the Central Dyke is inferred to be contemporaneous with rifting. The body is interpreted to be a mantle upwarp related to either ultramafics below crustal thinning, or a complex of mafic dykes emplaced during rifting.

Small irregularities in the otherwise smooth magnetic profiles across the body may be modelled to reflect the overlying sedimentary cover within the Walker Trough (Map Section
A-B-C). For example, the \textit{Parsons Range gravity low} is truncated suddenly at Mitchell Ranges-Bath Range Fault system. Thus, it is interpreted that Parsons Range Group thins suddenly east of this fault system, an observation consistent with regional mapping. This is also consistent with magnetic modelling. The Donydji Group is similarly not present at the appropriate stratigraphic level in Coast Range.

A small magnetic high to the east of Mitchell Ranges and centred around Koolatong River, mirrors local structure; namely, a dome exposing the lowermost unit of Balma Group (Koolatong Siltstone). It may thus be taken to reflect magnetic Donydji Group rocks immediately below. This anomaly dies out quickly to the east, beyond the Koolatong Fault, which is taken to indicate rapid eastward thinning of Donydji Group. This is consistent with modelling of the major profile farther south (Map Section A-B-C), where Donydji Group actually cuts out at Koolatong Fault. Farther south, near the southern edge of BLUE MUD BAY, the eastern limit of Donydji Group lies at the trace of Bath Range Fault. Negative inflections in the magnetic profile between Koolatong and Coast Range Faults requires 4 km of non-magnetic Balma Group right up to Coast Range Fault, and so defining the eastern edge of Walker Trough.

West of Parsons Range, beneath Mesozoic and Cainozoic cover between the Badalngarmirri and Parsons-Gali Faults, small high-frequency magnetic trends indicate continuation of lowermost Balma Group from adjacent outcrop in ARNHEM BAY–GOVE. The western flank of the \textit{Parsons Range gravity low} (see section on Gravity) continues beneath this same area, indicating a westward continuation of Parsons Range Group below. The western flank of the low extends westward beyond Parsons-Gali Faults, beneath Roper Group cover. This is in agreement with a westward-thinning wedge of Parsons Range Group defined from both magnetics and gravity, lapping onto the Arnhem Shelf, to the west of Gali Fault, on ARNHEM BAY–GOVE. The smooth westward continuation of the \textit{Parsons Range gravity low}, beyond Parsons-Gali Faults, implies an absence of thick carbonates between Parsons Range Group and Roper Group in this area. No Balma Group equivalents crop out beneath Mount Rigg Group further to the west in MOUNT MARUMBA. Thus, Parsons Range-Gali Fault system is selected as the western limit of Balma Group.

The characteristic high-frequency fracture pattern associated with the Bukudal Granite is masked by Proterozoic cover, but not by Cainozoic and Mesozoic cover. Consequently, the subcrop limits of granite beneath surficial rocks can be identified with reasonable confidence. The granite is accompanied, in turn, by significant gravity lows, which allow its subsurface extent, beneath overlying Proterozoic sedimentary rocks, to be determined with confidence. The magnetic anomalies are typical of shallow-dipping, east-striking sheets with clearly defined floors. Thus, Bukudal Granite comprises several interlayered sheets of differing magnetic susceptibility, in east-trending synclines. The pluton extends for several tens of kilometres westwards as a thickening wedge (from gravity) beneath a relatively thin cover (from magnetics), to a magnetic dyke anomaly trending south-southeast from the Frederick Fault in ARNHEM BAY–GOVE, and southwards for several kilometres into the Gulf of Carpentaria beneath similarly thin sedimentary cover.

A coincidence of high magnetic and low gravity values beneath the western end of Bickerton Island indicates granite at shallow depth beneath Groote Eylandt Group. Along the mainland coast immediately to the northwest, a series of similar, linear, \textit{en echelon} magnetic anomalies show progressively decreasing values to the southwest. This indicates progressive downstepping of the granite ‘basement’ toward the west, related to the eastern edge of Walker Trough.

The boundary between Bradshaw Complex and Grindall Formation is difficult to determine due to poor outcrop and extensive cover of Groote Eylandt Group. Subtle magnetic differences between these units are discernible through this cover, and a boundary can be drawn beneath the Gulf of Carpentaria at a magnetic gradient across a northwest set of dykes and faults which extend from northern Groote Eylandt, through Isle Woodah, to the northern shore of BLUE MUD BAY (see Figure 12 and solid geology on mapface). However, it must be noted that the geological significance of this gradient is unknown.

\textbf{TECTONICS AND STRUCTURE}

\textit{By K.A. Plumb}

\textbf{Tectonic setting}

The structure of the McArthur Basin in Arnhem Land, as established by Plumb and Derrick (1975) and Plumb and Wellman (1987), is dominated by the north-trending Walker Fault Zone and coincident Walker Trough. These are bounded by the relatively undeformed Arnhem Shelf to the west and Caledon Shelf to the east — and truncated to the south by the east-trending Urupungu Fault Zone (Tectonic Ridge; Figure 14).

The Walker Fault Zone (WFZ) approximates the site of the syn-sedimentary Walker Trough. The WFZ is transected obliquely by a north-northeast belt of intense deformation, the Mitchell–Flinders Thrust Belt. Boundaries between major structural features are mostly inferred from geophysics (see GEOPHYSICS). Figure 14 significantly refines earlier models of the Walker Trough (Plumb and Wellman, 1987; Plumb, 1987; Plumb and others, 1990). Recent mapping in URAPUNGA (K. Plumb, personal observations, 1995), has reinforced the significance of the Urupungu Fault Zone as a basement high or tectonic ridge separating Walker and Batten Troughs (Plumb and Derrick, 1975; Plumb and others, 1980).

The WFZ is a deformed zone 300 km long and 50-80 km wide, within which more than 12 km of section accumulated locally in the asymmetric, syn-depositional Walker Trough. This compares with only 4 km on the marginal shelves (Plumb and Wellman, 1987). The Walker Trough is bounded by the Coast Range-Frederick-Gwakura Fault system in the east, and
the Parsons Range-Gali Fault system in the west. The Parsons Range, Balma and Habgood Groups are known only from within the WFZ. Correlatives of the rift formations on the adjacent shelves are dramatically attenuated or absent. Thickness changes are rapid across major faults, and conglomerate fans confirm syn-depositional faulting. The Balma-Habgood *rift-phase* effectively defines the Walker Trough in Figure 14.

A prominent north-trending magnetic anomaly, which dominates the southern part of the magnetic image in Figure 12, has been modelled as a linear prismatic mafic body lying 13-15 km below surface (the *Central Dyke* of Figure 14). Significantly, this body corresponds with the deepest part of the Walker rift sequence, where full sections of Balma and Parsons Range Groups are stacked. It lies below the base of the McArthur Basin succession and apparently reflects the emplacement of large mafic dykes into the crust.

**Chronological evolution of the Walker Trough**

**Donydji-Spencer Creek phase**

The earliest stratigraphic package of Donydji-Spencer Creek-Groote Eylandt-Katherine River Groups, deposited in an extensional terrain, but no specific rift structures can be defined at this stage. Geophysical interpretation indicates that Donydji and Katherine River Groups are continuous and of similar thickness across the Arnhem Shelf and WFZ.

On the Caledon Shelf, the Spencer Creek and Groote Eylandt Groups represent either attenuated equivalents or thin erosional remnants of their correlatives farther west. Geophysical interpretation indicates that Donydji Group thins rapidly eastwards towards the Arnhem Inlier. There is therefore an inferred early syn-sedimentary influence by the Gwakura, Koolatong and Frederick Fault systems on this package, prior to full development of the Walker Trough.

**Parsons Range phase**

The Parsons Range Group was deposited within an east-deepening half graben with an eastern margin controlled by the Mitchell Ranges-Bath Range Fault system (Figure 14). A feathered edge appears to lap onto the Arnhem Shelf in the west, and the unit thins rapidly northwards into ARNHEM BAY–GOVE.

Stratigraphic thickness increases from 3 km in the southwest, adjacent to the Parsons Range Fault, to 6 km at the northeastern limit of outcrop, against the Mitchell Ranges-Bath Range Fault system. Gravity data define a progressive eastwards subsurface truncation of the Parsons Range Group east of the Mitchell Ranges-Bath Range Fault system. The nearest outcropping inferred equivalent, the Coast Range Sandstone 30 km east, is only a few tens of metres thick.

The thickness of the Parsons Range Group in ARNHEM BAY–GOVE is much less. The thickness of the Badalingarmirri Formation in the ‘Gali Belt’ (between the Donydji and Gali Faults) is similar to the Parsons Range area, however, geophysical interpretation indicates that the underlying Mattamurra Sandstone is absent or greatly attenuated. West from the Gali Fault, geophysical interpretation defines a west-thinning wedge of Parsons Range Group lapping onto the Arnhem Shelf. Farther south, a continuous gravity low west from Parsons Range similarly reflects the same west-thinning wedge of Parsons Range Group beneath Roper Group, to the west of Parsons Range and Gali Faults. Only thin structural remnants of Mattamurra Sandstone or Badalingarmirri Formation are preserved in fault blocks within Mitchell Ranges. Northwards, along the partly concealed extension of Walker Fault Zone beneath the Arafura Basin, geophysics precludes a significant thickness of Parsons Range Group between the concealed Donydji Group and the outcropping Habgood Group.

**Balma-Habgood phase**

The inferred depositional setting of the Balma and Habgood Groups in northern BLUE MUD BAY and ARNHEM BAY–GOVE is an east-thickening half graben between Mitchell Ranges Fault and Coast Range-Frederick-Gwakura Fault system to the east, and small discontinuous grabens and syn-rift horsts to the west, wedging out at Gali Fault. A polarity reversal probably occurs in southern BLUE MUD BAY and ROPER RIVER, with the depositional geometry interpreted as a west-deepening half graben, bounded by the Parsons Range-Gali Fault system to the west.

The *Central Dyke* and the depocentre of Parsons Range Group appear to be coincident with this southern, broader, deeper graben. The bounding accommodation zone between these two rift components is probably the north-northeast trending Lela Fault and Bath Range-Ritarang Fault systems, which extend right across the trough.

Outcrop of the 4-5 km thick Balma Group extends uninterrupted from Parsons Range Fault in the southwest of BLUE MUD BAY to Koolatong Fault in the northeast. Conglomerate fans, sourced from Parsons Range and Donydji Groups, and associated with erosional surfaces in the Balma Group adjacent to Mitchell Ranges-Ritarang-Bath Range and Koolatong-Lela Fault systems, attest to syn-depositional faulting and the presence of central horsts of exposed Parsons Range and Donydji Groups. Further east, upper Balma Group units crop out right up to Coast Range Fault. However, immediately east of this fault, along Coast Range, only a few tens of metres of the correlative Jalm Formation are preserved. Magnetic modelling requires an almost complete thickness (4 km) of Balma Group to be present immediately to the west of Coast Range Fault. Coast Range Fault defines the eastern margin of Walker Trough (rather than Koolatong Fault - Plumb and Derrick, 1975; Plumb and others, 1980).

The Frederick Fault is modelled as the concealed eastern limit of thick Balma Group in southern ARNHEM BAY–GOVE. Farther north, the rift margin becomes difficult to trace and several alternatives may be inferred. One alternative is that movement on Frederic Fault has transferred northwards to Gwakura Fault, which marks the eastern limit of Habgood Group outcrop. In this model, a major
northwest magnetic gradient along the southwestern edge of Arnham Bay (marked by a late dyke) is taken as the principal transfer zone between Frederick and Gwakura Faults. Some transfer may also have occurred along a north-trending zone of en echelon faults linking Frederick and Gwakura Faults farther west. A northerly limit to the rift is inferred from a major northeast magnetic gradient a few kilometres north of Flinders Peninsula, interpreted to separate thick Habgood Group from shallow Donydji Group.

In southern ARNHEM BAY–GOVE, the current western limit of thick Balma Group, abutting the eastern edge of Mitchell Ranges, is assumed to define the western border of the principal rift of Walker Trough, or perhaps the edge of a central syn-rift horst (possibly the current Mitchell Ranges). However, farther north near Flinders Peninsula, where the majority of the sequence is concealed, this model is difficult to demonstrate. Geophysical interpretation suggests that lower Habgood and Donydji Groups structurally interdigitate within the Mitchell–Flinders Thrust Belt (MFTB). It is now impossible to establish the original thickness of Habgood Group, or how much was stripped off after thrusting.

West of Mitchell Ranges, between Donydji and Gali Faults, thin erosional remnants of lowermost Balma Group crop out above Parsons Range Group and continue southwards (from similar magnetic signatures) through to northern BLUE MUD BAY. Structural trends dictate that any possible westerly extension of Balma Group beyond the Parsons Range–Gali Fault system can only occur in BLUE MUD BAY and MOUNT MARUMBA, where it would be totally concealed by Roper Group. The continuity of the Parsons Range gravity low (discussed earlier) implies absence of significant thickness of dense carbonate between the Parsons Range Group and Roper Group in the west. In addition, no Balma Group equivalents crop out beneath the Mount Rigg Group in central MOUNT MARUMBA. On this basis, the Parsons Range–Gali Fault system is interpreted as the western limit of the Balma Group (Figure 14).

The southern extension of the Walker Trough into ROPER RIVER is concealed by Roper Group. To the west, the magnetic gradient related to Parsons Range Fault continues southwards as far as Urapunga Fault Zone. In eastern BLUE MUD BAY, magnetic gradients of the Coast Range Fault (and related normal faults) are truncated at their southern ends by the north-northwest Lela Fault. Immediately south of BLUE MUD BAY, at the edge of the Gulf of Carpentaria, the magnetic gradient associated with the Lela Fault intersects gradients (normal faults) parallel to the Coast Range Fault which, themselves progressively down-step to the west. This is interpreted as the edge of the Walker Trough at that point.

Weak but coincident magnetic and gravity gradients follow the coast to the southwest, until they merge into the Urapunga Fault Zone (Tectonic Ridge; Figure 14). The lack of a sharp gradient at the southeastern edge implies a feathered boundary, while a full thickness of Balma Group at the Parsons Range Fault implies a western faulted boundary. This in turn implies a west-thickening half-graben.

The location of an 'accommodation zone' separating these two reversed rifts is not immediately obvious. However, since the southern, west-thickening rift appears to be coincident with the broader, deeper graben overlying the Central Dyke and encompassing the depocentre of the Parsons Range Group, any 'accommodation zone' probably passes to the northeast of the Central Dyke and Parsons Range Group, and should extend right across the rift. The Lela Fault and its extension into ARNHEM BAY–GOVE, and the Bath Range–Kitarango Fault system, fit these criteria.

This overall geometry – north-northeast extensional faults and oblique north-northwest 'accommodation zones' – best fits an oblique extension or pull-apart model, although reliable kinematic indicators are lacking. This geometry is consistent with north-northwest extension or dextral transtension. This is a similar model to that proposed for the southern McArthur Basin by Jackson and others (1987), Plumb and others (1990) and Davidson and Dashlooty (1993).

Nathan-Mount Rigg phase

The Nathan and Mount Rigg Groups overlie the Balma and McArthur Groups, with regional unconformity. They extend across all shelves, fault zones and rifts without significant change in thickness. Their distribution is unrelated to the pre-existing rift framework. They were deposited in a broad post-rift sag basin.

Roper phase

The Roper Group similarly overlies all older units with regional unconformity. It was deposited in a younger sag basin, with a new depocentre in the far southwest of the McArthur Basin.

Deformation

Post-depositional deformation of the McArthur Basin in the WFZ is characterised by open folding and thrust and strike-slip faulting. Reactivation of older structures is common. Stratigraphic separations range up to six kilometres across individual faults. BLUE MUD BAY is dominated by the Badalingarmirri Fault and its overlying hanging-wall syncline. This is the higher level, southern extension of the Mitchell–Flinders Thrust Belt of ARNHEM BAY–GOVE (Rawlings and others, 1997). The latter is a 20 km-wide zone of north-northeast-striking thrust duplexes, accompanied by folding and regional cleavage, which extends from the northern Badalingarmirri Fault to Gwakura Fault in ARNHEM BAY–GOVE. Mirarminna Complex and Donydji, Parsons Range, and Balma Group rocks appear to have been thrust westwards over the Arnham Shelf during the hiatus between Nathan-Mount Rigg and Roper Groups. This deformational style is unique to eastern Arnham Land. The western edge of the thrust belt is defined by its sole thrust, the Donydji-Badalingarmirri Fault system. Deformation decreases eastwards, away from the sole thrust. The eastern boundary of the Mitchell–Flinders Thrust Belt, as shown in Figure 14, is taken at the disappearance of cleavage.
Figure 14 Principal tectonic elements of eastern Arnhem Land.
In contrast to the Walker Trough, the Arnhem and Caledon Shelves are characterised by thin, shallow dipping, attenuated successions, minimal lateral facies and thickness variations, and minimal deformation. Faults are widespread but show only small displacements.

Structure

Walker Fault Zone

The following summary is based largely on Plumb (1994). Folds in the north-trending Walker Fault Zone are broad and open, with wavelengths of the order of kilometres, and fold axes subparallel to major faults. Thrusting, extension, and strike-slip displacements are all apparent and many major fault systems have ‘dog-leg’ shapes - the composite of several oblique segments (see Figure 15). Reactivation through several events is common.

Criteria to determine sense of shear in fault zones include observed offsets, Reidel shear sets, en echelon quartz tension gashes, quartz-fibre orientations, sheared porphyroclasts, and C-S fabrics (Sibson, 1977; Ramsay, 1980; Simpson and Schmid, 1983; Hancock, 1985; McClay, 1987).

The Mitchell Ranges Fault (Figures 14 & 15) is a steep west-dipping backthrust of the Mitchell–Flinders Thrust Belt (MFTB). It delineates the eastern edge of Mitchell Ranges for more than 100 km from BLUE MUD BAY into ARNHEM BAY–GOVE. It merges southwards with the Bath Range Fault, which in turn continues for over 100 km, beyond the southern border of BLUE MUD BAY. Along the northern Bath Range, the north-northeast Bath Range Fault parallels stratigraphic strike and displays little apparent displacement; it appears to be simply a steep monoclinic flexure, above a thrust at depth. Farther south it trends north-northwest and has a probable sinistral strike-slip component; a prominent positive flower structure is developed over a restraining bend immediately south of the Walker River. At the northeastern edge of Parsons Range, the overstep between the Bath Range Fault and Mitchell Ranges Fault is marked by an intensely deformed zone of northwest-directed thrust duplexes. While this thrusting might be interpreted as D_m thrusting of the Post-Nathan Shortening (see below), it is better interpreted as local convergence within a restraining bend of the D_m sinistral strike-slip faulting. Small listric extensional faults from the Walker Trough Extension are preserved within this same zone, and adjacent conglomerate fans in the Balma Group attest to syndepositional uplift. It is also overprinted by younger dextral reactivations.

The northeast-trending Badalngarrmirri Fault (Figure 15) is the sole thrust of the MFTB, on which Parsons Range Group has been thrust westwards over Balma Group. To the north, it joins via a sinistral offset, with the Donydji Fault in ARNHEM BAY–GOVE. The southwest end of the Badalngarrmirri Fault is terminated by the northerly extension of the Parsons Range Fault. Contact relationships between tilted Parsons Range Group and gently dipping Roper Group along the Badalngarrmirri and Parsons Range Faults, require that Parsons Range Group was folded and upthrust before being onlapped by Roper Group. Thus, the Parsons Range Fault was active as either, a sinistral ramp (D_m, see below), or a later sinistral offset of the Badalngarrmirri Fault (D_m).

It has been suggested earlier that Parsons Range Fault has a more protracted history, acting as the western margin of the Walker Trough. However, the principal displacement now visible on the exposed near-vertical Parsons Range Fault at the southern end of Parsons Range relates to later, post-Roper Group transpression. Dextral strike-slip displacement is accompanied by locally intense southwest-directed oblique thrusting. Fractures along the Parsons Range Fault have been filled by post-Roper Group dykes.

The north-northeast Sheridan Fault displays reactivation. Its northern part, across the transition from Parsons Range to Mitchell Ranges, shows map-scale sinistral offset of several kilometres. Shear criteria suggest displacement was sinistral, with later dextral overprint. Farther south, at Walker River, the fault system is predominantly a positive flower structure, related to locally intense dextral transpression.

The north-northeast Koolatong Fault extends for over 100 km, beyond the northern and southern boundaries of BLUE MUD BAY. It is interpreted as a west-dipping backthrust, but it is commonly strike-parallel and stratigraphic displacements are not great. Near Koolatong River it is deflected sinistrally for several kilometres in a zone along strike with the Lela Fault to the south. At this intersection zone, conglomerate wedges in Balma Group indicate even earlier (syndepositional) movement on one or both faults, during extension of the Walker Trough, while both the Lela and Koolatong Faults are offset by young northeast dextral faults. Farther south, Lela Fault truncates Coast Range Fault and adjacent extensional faults, implying that Lela Fault marks the site of an accommodation zone within the earlier rift.

The north-northeast Coast Range Fault (Figure 14) is known mainly from its magnetic gradient and scattered sheared outcrops of Yarrawirrie Formation along its trend. It marks the eastern edge of the Walker Trough, and an original extensional origin is assumed. It was probably reactivated by minor thrusting during later shortening (Map Section B-C). To the northeast, its displacement (from magnetics) appears to die out. The main displacement is transferred eastwards several kilometres to a parallel fault that links, via a sinistral offset, the equivalent Frederick Fault in ARNHEM BAY–GOVE (see Figure 14).

Plumb (1994) identified three principal deformation events, D_1, D_2, and D_3, from outcrop studies within the MFTB. These are redesignated herein as the Walker Trough Extension, Post-Nathan Shortening and Post-Roper Inversion, respectively. A fourth event, the Post-Roper Extension and Dykes is recognised to predate the Post-Roper Inversion.

Walker Trough Extension (D_1)

Preservation of structures in outcrop related to primary extension is rare. However, in thrust rocks within the
overstep zone between the Bath Range Fault and Mitchell Ranges Fault (Figure 15), small east-dipping listric extensional faults striking 020° are preserved in Parsons Range Group within zones of minimal thrusting. These are cut by small reverse faults related to D₂. The zone lies immediately adjacent to Balma Group conglomerate fans referred to earlier. The extensional faults parallel the inferred Walker Trough marginal faults. They are therefore preserved reliefs from the syn-depositional Walker Trough Extension.

Other mildly-deformed zones in the same duplex contain semi-brittle, steep dextral faults striking 015°±20°. Plumb (1994) provisionally related these to D₁ extension, but reappraisal suggests transpression. Some D₁ dextral shears cut cleavage and other shears related to Post-Nathan Shortening, and relate to the Post-Roper Inversion.

Post-Nathan Shortening (D₃)

The Post-Nathan Shortening is the event that formed the MFTB and established much of the structural framework of eastern Arnhem Land. The MFTB in ARNHEM BAY–GOVE lies above the sole thrust and comprises 020°-trending thrust duplexes and imbricate stacks, separated by steep oblique ramps striking 340° to 000° and 045°. The MFTB passes southwards into a higher, less-deformed structural level in BLUE MUD BAY, represented by the broad hanging-wall syncline above the basal Badalgarmirri Fault. Plumb (1994) interpreted 340° trending sinistral faulting as a later closely related event, D₃a.

D₃a: The event is primarily shortening or thrusting, directed perpendicular to the MFTB. D₃a is clearly younger than the Habgood and Balma Groups. Relationships along the Badalgarmirri and Parsons Range Faults suggest thrusting preceded deposition of Roper Group. In central MOUNT MARUMBA, local areas of tight folding and thrusting occur within Mount Rigg Group, but never within adjacent Roper Group. D₃a is therefore inferred to have occurred during the break between the Nathan-Mount Rigg Groups and the Roper Group.

Cleavage formation is confined to a narrow 020°-trending belt from the northwest edge of Parsons Range and adjacent Mirrarinha Complex in BLUE MUD BAY, through Mitchell Ranges, to Flinders Peninsula in ARNHEM BAY–GOVE (Figure 14). Cleavage disappears southeasterwards, away from the sole thrust and open, regional folds then characterise Parsons and Balma Groups of BLUE MUD BAY. Sub-vertical cleavage, shallowly-plunging folds, and steep thrusts consistently trend about 015° throughout the MFTB.

Conjugate shear and joint sets display orthorhombic symmetry with a shortening direction (s,110°), sub-perpendicular to the Badalgarmirri Fault. This is consistent with rare shallow plunging slickensides within Mitchell Ranges in ARNHEM BAY–GOVE, indicating thrusting slightly oblique to the MFTB.

D₃b: Semi-ductile sub-vertical sinistral faults, trending north, are widespread throughout Mitchell Ranges and beyond. They sinistrally offset thrusts of D₂b (Mitchell Ranges Fault by Ritarango Fault and other faults in ARNHEM BAY–GOVE; Koolatong Fault by Lela Fault in BLUE MUD BAY). The 020°-trending Mitchell Ranges and Sheridan Faults show local sinistral displacements in their own right. Small sinistral faults are apparent at map scale throughout the Parsons Range and Balma Groups. Mesoscopic conjugate shear sets associated with D₂b consistently indicate s, shortening direction of 135°, significantly different from D₂a. This direction probably reflects secondary Reidel patterns of the sinistral faults. D₃b is thus considered to be the latest, brittle fracture phase of the Post-Nathan Shortening, generally overprinting D₂b thrusting.

Post-Roper Extension and Dykes

As previously noted, a major episode of extension and dyke emplacement occurred between Roper Group deposition and the Post-Roper Inversion. Dykes emplaced into pre-existing fractures generated during the Post-Nathan Shortening. All dyke sets cut the Roper Group and have consistently been offset by structures of the Post-Roper Inversion. Dykes are common within the Caledon and Arnhem Shelves, and continue into the WFZ without change. An overall pattern of east-west extension has been deduced, consistent with the regional extensional event identified in MILINGIMBI.

Dykes strike 315°, 340°, 000° and 020° to 045° in what appear to be separate sets in BLUE MUD BAY. However, dykes on the Caledon Shelf swing through arcuate traces from 000° in BLUE MUD BAY to 315° in ARNHEM BAY–GOVE. 315° dykes form a conjugate pattern with the less-abundant 020° to 045° set. North trending dykes in the WFZ have clearly emplaced along earlier structures, such as Parsons Range-Gali, Bath Range, and Lela Faults.

Patterns of apparent offsets by dykes are totally inconsistent. In the Grindall Point-Islie Woodah area, for example, a 000° dyke offsets a 340° dyke dextrally, but it is itself Offset sinistrally by a different 340° dyke. Other 340° dykes in turn offset 315° dykes and Groote Eylandt Group dextrally. While some apparent dyke offsets may relate to emplacement within the pre-existing fracture systems, other offsets may relate to late reactivation of dykes/fractures during the Post-Roper Inversion.

The walls of 020° dykes that intrude the Mattamurra Sandstone at the northern end of Parsons Range have conjugate fracture sets indicative of extension to the east perpendicular to the dykes. Many other north-trending dykes elsewhere have similarly extended perpendicular to strike. Dextral offsets on 340° dykes also reflect easterly extension. En echelon arrays developed along 315° dyke sets indicate a dextral component, again consistent with easterly extension. En echelon dyke array, emplaced into sinistral tension gashes along the northern extension of Lela Fault, imply a temporal connection between dyke emplacement and sinistral D₂b faulting. However, the dykes cut and post-date the main shear zone, and cut the nearby Koolatong Fault. They are considered to have emplaced into pre-existing fractures as they extended perpendicular to strike.
Plate 34 Shatter cones in the Arnold Sandstone, Goyder impact structure (GR NF045102). Lens cap for scale.

Post-Roper Inversion ($D_1$)

Throughout McArthur Basin, the Post-Roper Inversion is the dominant post-depositional structural event. Within BLUE MUD BAY there is transition from minor reactivation of Post-Nathan Shortening structures and dykes in the north, to dominance of Post-Roper Inversion structure in southern BLUE MUD BAY and beyond.

Mesoscopic, semi-brittle, conjugate shear sets in the MFTB offset $D_{1a}$ cleavage and consistently indicate that the principal compression ($s_3$) was about 080°, distinctly different from that of $D_{2a}$ or $D_{2b}$. At map scale, dextral offsets on northeast-striking faults are common throughout Parsons Range Group and Balma Group. Northeast dextral and, to a lesser extent, northwest conjugate sinistral cross faults, consistently offset 000° dykes and $D_1$ faults. Much of this conjugate array may involve reactivation of earlier $D_2$ extension fractures. Sinistral reactivation of 315° dykes is common in ARNHEM BAY–GOVE. North-northeast $D_2$ sinistral faults have commonly been reactivated dextrally. For example, the southern half of the Sheridan Fault system shows dextral offsets and internal deformation indicative of dextral transpression. Dextral transpressive reactivation of the north-trending Parsons Range Fault has similarly produced dextral strike-slip faulting and associated oblique thrusting from the northeast. $D_1$ conjugate fault sets postdate the Roper Group and dykes.

Caledon Shelf

The poorly exposed Caledon Shelf is only mildly deformed and structure must be inferred from magnetic patterns. Structure is dominated by younger, post-Roper Group events especially dykes from the Post-Roper Extension and Dykes event. These, and earlier structures, are either offset or reactivated during east-west shortening during the Post-Roper Inversion.

Arnhem Shelf

The Arnhem Shelf *sensu stricto* in BLUE MUD BAY is covered by Roper Group, which dips at shallow angles, except where upturned at the eastern edge of the shelf. Faults comprise a conjugate northeast and subordinate northwest set, and minor north-trending faults. Northeast faults show consistent dextral offsets of 000° dykes and faults related to the Post-Roper Inversion. Adjacent to the edge of the WFZ, the Roper Group is steeply upturned and sequences are repeated across north-northeast faults, probably related to dextral transpressive reactivation of pre-Roper $D_2$ thrusts.

Goyder Impact Structure

By P.W. Haines

Goyder impact structure is located near the western boundary of BLUE MUD BAY centred near GR NF050100. It is named after Goyder River, which drains the area. The structure consists of a circular uplift 3 km in diameter composed of Arnold and Hodgson Sandstones. Shatter cones (Plate 34) were found in fractured Arnold Sandstone in the radially-faulted core. The outer edge of the central uplift is defined by a fault-disrupted ring of tangentially-dipping Hodgson Sandstone, much of which has disintegrated to loose sand. The intervening Jalboi Formation is poorly exposed in the eastern half of the uplift.

The impact structure is described in detail by Haines (1996), who identified shock-induced planar deformation features in quartz from the central shatter cone locality. Central outcrops represent the deeply eroded remnants of the central uplift of a complex impact structure with the original dimensions of the crater rim being 7 to 25 km. The impact probably occurred prior to the Cretaceous, with the maximum age constrained only by the Mesoproterozoic impacted rocks.
SUMMARY OF GEOLOGICAL HISTORY

By P.W. Haines

The geological history of BLUE MUD BAY is summarised in point form below.

1. Pre-1870 Ma: Deposition of the turbiditic Grindall Formation, probably contemporaneously with other similar extensive turbiditic successions across northern Australia.

2. 1870 Ma: Peak tectonic activity and metamorphism of the Barramundi Orogeny. Development of Bradshaw and Mirarrmina Complexes, and folding and metamorphism of the Grindall Formation.

3. 1870-1840 Ma: Extrusion of unnamed felsic volcanics (Pz) now exposed in the Coast Range area.

4. 1840-1830 Ma: Intrusion of Bukudal Granite coeval with similar granite in ARNHEM BAY-GOVE and the Pine Creek Inlier. This event effectively concluded the stabilisation of the North Australian Craton.

5. 1830-1800 Ma: Uplift and erosion in most areas. Deposition of the fluvial Bustard Subgroup in the southeast, accompanied by felsic volcanism (Bickerton Rhyolite) occurred during the later part of this interval at about 1815 Ma.

6. 1800-1725 Ma: Widespread platformal deposition and volcanism across the McArthur Basin, represented in BLUE MUD-BAY by Alyangula Subgroup and Dhunganda Formation (lower Donydji Group). Widespread mafic flood volcanism is represented locally by the Bartalumba Basalt.

7. 1725-1710 Ma: Deposition of fluvial and shallow-water deposits, associated with emplacement of bimodal volcanics and shallow level intrusives, including Ritarango Formation and Fagan Volcanics (upper Donydji Group). Probable eastern equivalents of the magmatic units are the Gadaban Volcanics and felsic dykes of the Coast Range area.

8. 1710-1670 Ma: Deposition of the thick siliciclastic-dominated Parsons Range Group in the rift-like Walker Fault Zone and probable thin equivalent, Coast Range Sandstone, on the eastern flank.

9. 1670-1600 Ma: Deposition of the mostly shallow-water Balma Group within the fault-controlled Walker Trough. The Jalma Formation, on the eastern flank of the trough, probably deposited as an attenuated equivalent.

10. 1600 Ma: Brief hiatus marked by unconformity across most of McArthur Basin. Deposition may have been continuous within the depocentre of the Walker Trough in parts of BLUE MUD BAY.

11. Mesoproterozoic (Calymmian): Deposition of shallow-water stromatolitic and ooidal carbonates of the Nathan and Mount Rigg Groups within a sag-basin setting.


13. Mesoproterozoic (Calymmian-Ectasian): Deposition of the cyclic shallow-marine Roper Group in a sag basin; only preserved in the far west of BLUE MUD BAY, but deposition was likely widespread.

14. Mesoproterozoic: Regional east-west extensional event (Post-Roper Extension and Dykes) accompanied by intrusion of mafic sills and dykes into all parts of the McArthur Basin stratigraphy. Sills mainly form within the Roper Group.

15. Late Mesoproterozoic: Major regional northwest directed shortening event (Post-Roper Inversion).

16. Late Mesoproterozoic-Cretaceous: no stratigraphic record; presumably the area was very stable and underwent slow erosion. Goyder impact structure was probably formed sometime during this interval. Neoproterozoic and early Palaeozoic deposition recorded to the north in ARNHEM BAY-GOVE probably extended into BLUE MUD BAY but has not been preserved.


18. Cainozoic: Gradual erosion of Cretaceous deposits to reveal the pre-Cretaceous landscape. Formation of duricrust and erosion of lateritic deposits and surfaces. Deposition on flood plains and of coastal deposits continues to the present day.

ECONOMIC GEOLOGY

By B.A. Pietsch and D.J. Rawlings

Manganese

One of the world’s largest economic manganese resources is located on the western coastal plain of Groote Eylandt straddling BLUE MUD BAY and ROPER RIVER. The ore body occurs within flat-lying Cretaceous rocks, which are largely covered by thin Cainozoic clay, sand and lateritic material. The deposit extends 22 km north-south, is 6 km wide, and up to 9 m thick (average 3 m).

The ores are present as manganese oxides, chiefly pyrolusite and cryptomelane. Also present in minor amounts are romanechite, todorokite and trace amounts of vernadite, braunite, lithiophorite, binnesite and chalcockinite (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 siliceous ore zone. Quartz is sometimes found in the nucleus of ooliths or pisoliths.

The ore minerals were deposited to form various textural types. The most distinctive ore texture is ooliths and pisoliths; these are variably cemented and in areas of extreme secondary cementation, no primary textures are preserved. In some areas, massive to concretionary textures are developed both above and below the pisolithic ore where no primary pisoliths originally occurred.

The ore horizon can be subdivided into several vertically distributed 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 and others, 1990).

A generalised vertical stratigraphy is shown in Figure 16. The oldest pisolithic sequence deposited is generally the ferruginous pisolite; this was originally a manganiferous pisolite but underwent secondary iron replacement. The entire pisolithic sequence was deposited in a shallow marine environment. Various cycles of reverse and normal grading of pisoliths and ooliths are present in the sequence; these are especially well preserved in the thick uncemented ore sequence in G Quarry. Pisoliths can be up to 25 mm in diameter. Though cross-bedding and hardground aggregates are also found in places (Bolton and others, 1990). The deposit is described in more detail by Bolton and others (1990) and Pietsch and others (1997).

**Base metals**

There has been little in the way of base metals exploration in the Arnhem Land region. However, significant potential exists for the discovery of McArthur River-style (stratiform sediment-hosted base metal) deposits and other styles of mineralisation along the Walker Fault Zone. The dolomitic Balma and Hubgood Groups are time correlatives of the McArthur Group in the southern McArthur Basin, and it can be shown that wrench-faulting was active during sedimentation. Parts of these sequences were formed by the accumulation of mixed dolomitic-siliceous carbonate sediments in restricted water bodies in possible third-order basins, contained within a rapidly subsiding fault-bounded trough.

**Groundwater**

There has been limited groundwater exploration in BLUE MUD BAY, owing to the sparse population and absence of a pastoral industry. Many of the small Aboriginal communities rely on bore-derived water for consumption and minor crop growing, but the groundwater system is still very much under-utilised. Most bores are sited over structures in Proterozoic units or in the thinned Cretaceous and Cenozoic sections, owing to suitable permeability. Many bores have also been sited in aquifers through relatively modern beach and aeolian sand deposits. The Water Division of the Power and Water Authority should be contacted for any specific information regarding groundwater resources in the region.

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APPENDIX

DEFINITIONS OF NEW STRATIGRAPHIC UNITS AND REDEFINITION OF SOME EXISTING UNITS

The definitions below have been approved by the Commonwealth Territories Division of the Stratigraphic Names Subcommittee and have been filed with the Central Registry of Stratigraphic Names. The requirements and procedures for new definitions are set out in Staines (1985). Definitions for most other formal units in BLUE MUD BAY are presented in Plumb and Roberts (1992) and Rawlings and others (1997), however, Roper Group formations currently lack formal definitions.
BADALNGGARRIRRI FORMATION (redefinition of unit)

Proposer: Ian Sweet (after Plumb and Roberts, 1992)

Derivation of name: From Badalnggarrirri Creek, which drains an area west of the Mitchell Ranges in eastern MIRINGADIA.

Synonymy: None

Distribution: Main outcrops are in the Parsons Range and southern Mitchell Ranges in BLUE MUD BAY, covering around 900 km². Other outcrops (1) lie west of the Mitchell Ranges (the Gali Belt, covering around 300 km²), and (2) forming a narrow outcrop belt about 1 km wide, along the eastern edge of the Mitchell Ranges, both in ARNHEM BAY–GOVE.

Type section: In the eastern Parsons Range, a composite section made up of three parts. This replaces the reference area nominated by Plumb and Roberts (1992) (along long. 135°50′E). The lowest part, from the top of the Mattamurra Sandstone at lat. 13°15′51″S, long. 135°31′44″E, extends to the top of informal member 4 (see Comments), at lat. 13°16′52″S, long. 135°32′4″E. The middle part of the section extends from 13°17′5″S, long. 135°29′51″E (base of informal member 5) to 13°18′43″S, long. 135°29′45″E (top of Fairy Glen Sandstone Member). The upper portion of the type section runs from 13°18′37″S, long. 135°30′25″E (base of informal member 11) through to the top of the formation at 13°19′29″S, long. 135°50′32″E.

Thickness: 2850 m in the composite type section, thinning to the west and southwest, to about 2200 m and to 1900 m, 40 km and 60 km to the southwest, respectively.

Lithology: Interbedded medium-grained quartzarenite, ferruginous arenite (presumed to have been glacioconical and pyritic, now mostly weathered to iron oxides), laminated green to grey and black mudstone, wavy laminated and hummocky cross-stratified sandstone and very fine-grained sandstone, and minor stromatolitic dolostone and chert.

Depositional environment: Storm-dominated marine shelf, ranging from basinal (below storm-wave base), through to lower to upper shoreface and shoreline environments.

Geomorphic expression: Due to the alternating quartzarenite/mudstone-siltstone stratigraphy, the formation forms a distinctive set of alternating ridges and valleys, each about 100 m in width and 1 km across. Collectively, these ridges and valleys extend over 60 km, and form much of the aridic Parsons Range.

Relationships and boundary criteria: Base placed at a prominent photogeological boundary marking the change from strongly cross-bedded quartzarenite of the uppermost Mattamurra Sandstone to olive green mudstone of the Mount Fawcett Member of the Badalnggarrirri Formation. Plumb and Roberts (1992) included an interval of 90 m of ferruginous sandstone in the Badalnggarrirri Formation in the type area, but this has been included in the Mattamurra Sandstone for three reasons: 1. It does not appear to be a laterally continuous unit, but rather due to local secondary iron precipitation; 2. It is indistinguishable from Mattamurra Sandstone in most outcrops; and 3. the main lithological change is above this sandstone — between it and the overlying mudstone and chert. The Mattamurra Sandstone-Badalnggarrirri Formation contact may be an unconformity, at least locally, as at one locality stromatolitic chert crescurs apparently lithified sandstone, and infills cracks up to 0.5 m deep. The upper contact, with the Marura Siltstone, is conformable, and is placed at the abrupt change from quartzarenite (top of informal member 13) to mudstone; a stromatolitic chert is commonly present a few metres above the contact, within the Marura Siltstone.

Age: Palaeoproterozoic: maximum age is well constrained by the age of the uppermost formation of the Donyndji Group, the Fagan Volcanics, at ~1710 Ma (Pietsch and others, 1994); minimum age is less well constrained, but must be greater than ~1620 Ma, the age of the Yarrarwarrie Formation in the overlying Balma Group (Pietsch and others, 1994), and is most likely older than 1640 Ma, the age of the Barney Creek Formation (Page and Sweet, 1998), a correlate of the central Balma Group below the Yarrarwarrie Formation (Haines, 1994).

 correlates: No known correlates, although the Surprise Creek Formation in the Mount Isa Inlier (Derrick and others, 1980) is very similar in its lithology, and stratigraphic and tectonic setting.

Comments: The Badalnggarrirri Formation has been subdivided into 14 units, reflecting the alternating sandstone–mudstone lithologies. Three of these, the Mount Fawcett Member, Gali Member, and Fairy Glen Sandstone Member, have been formally defined and delineated in BLUE MUD BAY, whereas the others, which are easily mappable at photoscale (1:50 000) but not easily represented on 1:250 000 maps, are described only in this report.

BALMA GROUP (name published by Haines, 1994)

Proposer: P. W. Haines

Derivation of name: Balma Community in BLUE MUD BAY (lat. 13°14′S, long. 135°51′E).

Synonymy: Previously mapped as McArthur Group by Plumb and Roberts (1965). However, it has no formations in common with the McArthur Group of the southern McArthur Basin (which has priority of usage) and although interpreted to correlate, at least in part, with the McArthur Group, the precise nature of such correlations is speculative. Correlations with the Habgood Group to the north are easier than those with the McArthur Group. This inconsistency is alleviated establishing a new group.

Constituent formations: In ascending order: Koolatong Siltstone, Strawbridge Breccia, Vaughton Siltstone, Conway Formation, Zamia Creek Siltstone, Yarrarwarrie Formation, Baiguridi Formation and Bath Range Formation. These units were named by Plumb and Roberts (1965) and defined by Plumb and Roberts (1992).

Distribution: Largely restricted to BLUE MUD BAY. Minor outcrops occur near the southern edge of ARNHEM BAY–GOVE.

Type section: Type sections as for each constituent formation (see Plumb and Roberts, 1992).

Lithology: Shallow water dolostone, mudstone and sandstone. Minor tuffaceous rocks and limestone.

Thickness: Estimated composite thickness of about 4500 m.

Geomorphic expression: Resistant units crop out as low strike ridges. Other units crop out sparsely as low rubbly rises and in creek bank exposures.

Structural attitude: Most areas (except near major faults) are gently folded with low dip angles. Faulting is common.

Relationships: Conformably overlies the Fleming Sandstone of the Parsons Range Group. Overlain by the Bulbirini Dolomite of the Nathan Group, but the contact relationship could not be determined due to poor outcrop. Locally intruded by dykes, based largely on geophysical evidence.

Age: Tuffaceous rocks from the Yarrarwarrie Formation and basal Bath Range Formation have given SHRIMP U-Pb zircon ages of 1621±21 Ma and 1599±11 Ma respectively (Pietsch and others, 1994). These provide maximum ages for the time of sedimentation.

Correlatives: The McArthur Group to the south and the Habgood Group to the north.
COAST RANGE SANDSTONE (new name)
Proposer: P. W. Haines

Derivation of name: Coast Range (lat. 13°30’S, long. 135°48’E), BLUE MUD BAY.

Synonymy: Previously mapped as part of the now abandoned 'Gootse Eylandt Beds' (Plumb and Roberts, 1965).

Distribution: Eastern BLUE MUD BAY. Crops out at the Coast Range, Mount Grindall, Round Hill Island, the unnamed peninsula west of Julma Bay, and near Gaa Gaa community.

Type section: Northern Coast Range at lat. 13°24’S, long. 135°50’E, about 1 km east of the point where the only access track first meets the range. Lower boundary stratotype at GR NF905180 and upper boundary stratotype top at GR NF902190. This is the most accessible location with top and bottom exposed, and demonstrates all major subunits recognized in the area.

Thickness: Estimated to be about 30-40 m thick in the Mount Grindall area. About 20 m or less along the Coast Range including type section. Locally removed by the basal unconformity of the Julma Formation near the southern end of the Coast Range.

Lithology: White, medium- to coarse-grained, thick-bedded, quartz-rich sandstone. Local lower unit of pale brown, poorly-sorted, coarse- to very coarse-grained sandstone and granule conglomerate at type section. Commonly pebbly, with a lenticular basal pebble or cobble conglomerate.

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

Depositional environment: Shallow marine, high-energy, transgressive unit.

Relationships and boundary criteria: Not assigned to any group. Lies unconformably on the Grindall Formation, Bradshaw Complex, unnamed porphyritic felsic dykes, and unnamed felsic volcanic unit. Boundary picked at marked angular unconformity below basal conglomerate or pebbly sandstone. Inferred to overlie the Woohah Sandstone near Grindall Point (nature of contact unknown). Overlain unconformably by the Julma Formation. Top picked below at sudden incoming of fine-grained, flaggy sandstone, or locally below basal cobble conglomerate. Intruded by mafic dykes.

Age: Probably late Palaeoproterozoic given tentative constraints provided by older and younger units. A maximum constraint is provided by the older porphyritic felsic dykes, which are tentatively correlated on petrologic and geochemical grounds with the 1700-1710 Ma felsic suite of Rawlings (1994). The overlying Julma Formation is tentatively correlated with the Balma Group, the top of which is dated at ~1600 Ma (Plievich and others, 1994).

Correlatives: Tentatively correlated with the Parsons Range Group based on lithology and stratigraphic position.

FAIRY GLEN SANDSTONE MEMBER (new name)
Proposer: Ian Sweet

Derivation of name: From Fairy Glen, a small valley around a permanent waterhole on the Walker River, at lat. 13°23.7’S, long. 135°22.7’E, FLEMING.

Synonymy: None

Parent formation: Member of the Badalgarmirimi Formation, Parsons Range Group.

Distribution: Outcrops all lie within the Parsons Range, from 4 km south of the headwaters of the Mata Murtta River, in an arcuate belt extending 65 km west, southwest and south, to the southern Parsons Range.

Type section: 16 km northeast of Fairy Glen, the base is at lat. 13°18’20”S, long. 135°29’51.55”E; the top is at lat. 13°18’27”S, long. 135°29’54.88”E.

Thickness: Maximum of 100 m in the eastern Parsons Range, including at type locality, thinning to 50 m and less in the southwest.

Lithology: Medium-grained, swaley and hummocky cross-stratified medium- to fine-grained ferruginous sandstone; very fine- to fine-grained, slightly ferruginous, lithic, and clay-rich sandstone more common in the central and southern Parsons Range outcrops.

Depositional environment: Shallow marine; probably lower to mid-shoreface, based on domination by swaley and hummocky cross-stratified sands.

Geomorphic expression: Forms a distinctive dark reddish-brown-coloured capping on a south- to east-dipping cuesta.

Relationships and boundary criteria: Both lower and upper contacts, although relatively sharp, are believed to be conformable. Base is placed at the change from medium-grained quartzarenite (of informal unit 1a), to ferruginous, porous sandstone. The top is marked by an abrupt change of slope, coinciding with the change from ferruginous sandstone to laminated mudstone, the latter rarely exposed.

Age: Palaeoproterozoic: maximum age is well constrained by the age of the uppermost formation of the Donytji Group, the Fagani Volcanics, at ~7170 Ma; minimum age is less well constrained, but must be greater than ~1620 Ma, the age of the Yarrawirrie Formation in the overlying Balma Group (Fietsch and others, 1994), and most likely older than ~1640 Ma, the age of the Barney Creek Formation (Page and Sweet, 1998), a correlative of the central Balma Group (Haines, 1994).

Correlatives: No known correlatives.

Comments: The Fairy Glen Sandstone Member was not distinguished during previous mapping of the Parsons Range Group by Plumb and Roberts (1965, 1992), but was described in measured sections as an interval of ferruginous (lithiclastic) sandstone.

GADABARA VOLCANICS (new name)
Proposer: D. J. Rawlings

Derivation of name: Gadabara District, an aboriginal clan area to the north of Grindall Point in the northeastern part of BLUE MUD BAY.

Synonymy: Previously undifferentiated 'Bickerton Volcanics' of Plumb and Roberts (1965).

Distribution: Outcrop is confined to Round Hill Island, adjacent to Grindall Point in the northeastern part of BLUE MUD BAY.

Type locality: At the southern tip of Round Hill Island (lat. 13°19’S, long. 136°06’E; GR PF181269). No specific section is nominated due to lateral variation in rock-types. Lower boundary stratotype at GR PF173284 where volcanic breccia of Gadabara Volcanics overlies migmatic gneiss of the Bradshaw Complex. The boundary with the overlying Coast Range Sandstone is not well exposed, and a top boundary stratotype is not defined.

Lithology: Salmon pink, but sometimes orange or brown, altered felsic igneous rock (Phyolite). About half of the exposure is made up of coherent pink rock, the other half by volcanic breccia. Coherent rock, which takes the form of dykes, sills and lava flows, is generally microcrystalline and aphyric to slightly porphyritic (small K-feldspar), with accessory fragments of sandstone and granite, and locally common amygdales. Abundant thin (<1 m) banded dykes intrude the Bradshaw Complex on the western side of the island (lower boundary stratotype), and the volcanic breccia on the other sides of the island. Lava flows locally exhibit coarsely banded flow banding, which appears to dip steeply away from the centre of the island, the inferred pre-existing volcanic edifice. They also contain occasional large rafts of contorted sandstone, presumably derived from the underlying Woohah Sandstone. Volcanic breccia, which tends to underlie or is intruded by the coherent rock, ranges from fine-grained...
volcanic sandstone to block and boulder volcanic breccia. Clasts are almost exclusively angular- or pillow-shaped pink-orange rhyolite as described above, with a variable component of clasts derived from the 'basement'. Mud-grade volcanioclastic material makes up the matrix. These breccias range from crudely stratified to unstratified.

**Thickness:** Approximately 50 m at type locality.

**Depositional environment:** Volcanic and shallow intrusive igneous rocks associated with probable subaqueous volcaniclastic rocks.

**Geomorphic expression:** Outcrop is relatively resistant and comprises blocks, boulders and rubble.

**Relationships and boundary criteria:** Intrudes and overlies the Bradshaw Complex and Woodah Sandstone and is in turn overlain unconformably by the Coast Range Sandstone.

**Age:** Palaeoproterozoic (Statherian). Not well constrained. They appear to intrude and lie stratigraphically above the Woodah Sandstone, indicating they are probably younger than the -1810 Ma Bickerton Rhyolite to the south (Pietsch and others, 1997). The unconformably overlying Coast Range Sandstone is tentatively correlated with the Parsons Range Group, which has a minimum age of -1640 Ma (the age of the overlying McArthur Group in the south; Haines, 1994). They are similar to the -1710 Ma Yanunghi Volcanics in ARNHEM BAY-GOVE (Rawlings and others, 1997), and occupy a similar stratigraphic position.

**Correlatives:** Possibly the Yanunghi Volcanics (ARNHEM BAY-GOVE) and Fagan Volcanics (ARNHEM BAY-GOVE and BLUE MUD BAY). This is based on similar stratigraphic position and petrology (Rawlings and others, 1997; Rawlings, 1994).

**Comments:** Outcrop now assigned to this formation was previously (Plumb and Roberts, 1965) mapped as 'Bickerton Volcanica', formalised by Plumb and Roberts (1992). Pietsch and others (1997) were able to demonstrate that the various outcrops assigned to this formation are non-correlatives, and in many cases are significantly different in age. The name was subsequently abandoned by Pietsch and others (1997) and the various outcrops were remapped as a series of new formations, including the Galahara Volcanics.

**GALI MEMBER (New name)**

**Proposer:** Ian Sweet

**Derivation of name:** From Gali outstait, a small settlement on the banks of Badalingmirmir Creek, lat. 12°44′36″S, long. 135°26′19″E, MIRRNGADIA.

**Synonymy:** None

**Parent formation:** A member of the Badalingmirmir Formation, Parsons Range Group.

**Distribution:** Main outcrops lie within the Parsons Range, extending from 3 km south of the headwaters of the Mitta Mitta River in the eastern Parsons Range, in an arcuate belt 50 km west, southwest and south, to a point about 15 km south-southeast of Mount Fawcett (FLEMING); the only other outcrops are in the valley in which Gali outstait lies (MIRRNGADIA).

**Type section:** 16.5 km northeast of Mount Fleming, the base is at lat. 13°17′15″S, long. 135°29′45″E; the top is at lat. 13°17′32″S, long. 135°29′48″E.

**Thickness:** Maximum of 360 m in the eastern Parsons Range, including at type section, thinning to 0 m in the southwest.

**Lithology:** Laminated to thin- and wavy-bedded, and hummocky cross-stratified mudstone and fine to coarse siltstone; interbeds of thin to medium bedded, fine-grained clayey sandstone in the upper part.

**Depositional environment:** Storm-dominated shelf; lower to upper shoreface.

**Geomorphic expression:** Recessive relative to the quartzarenite members above and below, hence forming a narrow valley, but the upper part of the member forms rounded low hills as a result of the resistant clayey sandstone interbeds.

**Relationships and boundary criteria:** Lower contact is marked by an abrupt change from quartzarenite below, to mudstone. It is a sharp contact, but is presumed conformable. The upper contact is probably gradational, with interfingering relationships of the clayey sandstone beds with quartzarenite. The upper boundary is placed at the first resistant medium-grained quartzarenite bed.

**Age:** Palaeoproterozoic: As for the parent formation, the maximum age of the member is well constrained by the age of the uppermost formation of the Donnyj Group, the Fagan Volcanics, at -1710 Ma; minimum age is less well constrained, but must be greater than -1620 Ma, the age of the Yarrawirrie Formation in the overlying Balma Group (Pietsch and others, 1994), and most likely older than -1640 Ma, the age of the Barney Creek Formation (Page and Sweet, 1998), a correlate of the central Balma Group (Haines, 1994).

**Correlatives:** None known correlatives.

**Comments:** The Gali Member was not distinguished during previous mapping of the Parsons Range Group by Plumb and Roberts (1965; 1992).

**JALMA FORMATION (new name)**

**Proposer:** P. W. Haines

**Derivation of name:** Jalma Bay (lat. 13°13′5″S, long. 135°6′0″E) in BLUE MUD BAY.

**Synonymy:** Plumb and Roberts (1965) included the Jalma Formation at the top of the now abandoned 'Groote Eylandt Beds'.

**Distribution:** Outcrops restricted to the Coast Range, Grindall Point and Gan Gan areas in BLUE MUD BAY.

**Type section:** Along the Coast Range at lat. 13°5′1″S, long. 135°48′E. Base at GR NF865051 and top at NF858055. This section is the only location where part of the upper recessive interval is exposed.

**Lithology:** Main part of formation consists of brown to purple, medium-grained, thin- to medium-bedded, ferruginous sandstone. Probably pyritic at depth. Fine-grained, thin-bedded, flaggy sandstone near base. Local basal polymict cobble conglomerate south of type section. Upper recessive unit of laminated mudstone (exposed only at type section).

**Thickness:** Complete sections only present along the Coast Range where the thickness varies from about 70 m to 130 m. Estimated to be about 110 m at the type section.

**Geomorphic expression:** Lower part is expressed as low rounded hills. Upper part is recessive and valley-forming.

**Relationships and boundary criteria:** Not assigned to any group. Unconformably overlies the Coast Range Sandstone and locally the underlying Grindall Formation where the unconformity cuts to that level. At the type section, the base is picked at the contact between medium-grained, thick-bedded, white, quartz-rich sandstone (Coast Range Sandstone) and recessive fine-grained, flaggy sandstone above. Actual point of contact obscured here. Overlain unconformably (regional evidence of truncation at contact) by the Balbirini Dolomite but the actual point of contact is obscured by younger cover. At the type section, the top is designated as the base of the ridge of prominentstromatolitic chert that represents the lowermost Balbirini Dolomite.

**Depositional environment:** Probably shallow marine.

**Age:** Poorly constrained. Late Palaeoproterozoic or early Mesoproterozoic based on its relative position in the regional sequence.
Correlatives: May correlate with the Mount Bonner Sandstone, which occupies a similar stratigraphic position in ARNHEM BAY–GOVE (Rawlings and others, 1997). Possibly an attenuated lateral equivalent of the Balma or Parsons Range Groups.

**MOUNT FAWCETT MEMBER (New name)**

**Proposer:** Ian Sweet

**Derivation of name:** From Mount Fawcett, one of the higher points in the western Parsons Range, at lat. 13°26’14”, long. 135°9’9”E, FLEMING.

**Synonymy:** None

**Parent formation:** A member of the Badalgarmirrini Formation, Parsons Range Group.

**Distribution:** Outcrops all lie within the Parsons Range, paralleling the southern bank of the Matta Matta River in the eastern Parsons Range, in an arcuate belt extending 45 km west, southwest then south, to a point about 7 km southeast of Mount Fawcett.

**Type section:** The base is at lat. 13°15’51”S, long. 135°31’44”E; the top is at lat. 13°16’0”S, long. 135°31’48”E.

**Thickness:** Maximum of 265 m in the central Parsons Range, and 250 m in type section, thinning to 0 m about 7 km southeast of Mount Fawcett.

**Lithology:** Laminated to thin-bedded olive to grey mudstone and siltstone, coarse- to very coarse-grained glauconitic sandstone, minor stromatolitic dolostone, generally silicified to chert.

**Depositional environment:** Shallow marine, probably intertidal and shallow subtidal.

**Geomorphic expression:** Forms a narrow valley between resistant sandstone ridges.

**Relationships and boundary criteria:** Both lower and upper contacts are sharp. The lower contact may be unconformable, at least locally, e.g., 23 km west of the type section, where stromatolitic chert encrusts lithified sandstone at the top of the Mathamurra Sandstone. The upper contact is probably conformable, and is placed at the change from recessive siltstone/mudstone to boldly outcropping medium-grained quartzarenite.

**Age:** Palaeoproterozoic: As for its parent formation, the maximum age for the Mount Fawcett Member is well constrained by the age of the uppermost formation of the Donydi Group, the Fagan Volcanics, at ~1710 Ma; minimum age is less well constrained, but must be greater than ~1620 Ma, the age of the Yarrawirrie Formation in the overlying Balma Group (Haines, 1994), and most likely older than ~1640 Ma, the age of the Barney Creek Formation (Page and Sweet, 1998), a correlative of the central Balma Group (Haines, 1994).

**Correlatives:** No known correlatives.

**Comments:** The Mount Fawcett Member was not distinguished during previous mapping of the Parsons Range Group by Plumb and Roberts (1992).

**NGILIPITJI CONGLOMERATE MEMBER (new name)**

**Proposer:** P. W. Haines

**Derivation of name:** Ngilipitji community (GR NF568023), BLUE MUD BAY.

**Synonymy:** Previously undifferentiated Yarrawirrie Formation. Plumb and Roberts (1992) mention a local basal conglomerate to the Yarrawirrie Formation but did not differentiate it as a member.

**Parent formation:** A member of the Yarrawirrie Formation, Balma Group.

**Distribution:** Crops out mainly in BLUE MUD BAY, where it is exposed from the area of the Ngilipitji airstrip, north to the northern margin of the sheet, and extends on to the southern edge of ARNHEM BAY–GOVE around longitude 135°45”E.

**Type section:** At lat. 13°22’5”, long. 135°34’30”E along the south bank of an unnamed creek in BLUE MUD BAY. Base at GR NF624226.