EXPLANATORY NOTES

PETERMANN RANGES
SG 52-7

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ABSTRACT

PETERMANN RANGES is situated in the southwest corner of the Northern Territory, and contains elements of two major geological domains – a basement terrain of Mesoproterozoic granite and gneiss of the Musgrave Block, and overlying sediments of the Neoproterozoic to Palaeozoic intracratonic Amadeus Basin. Within the Musgrave Block, a major north-verging structure, the Woodroffe Thrust, separates rocks of higher metamorphic grade in the south from lower grade rocks in the north. The oldest exposed rocks are felsic, mafic and rare aluminous gneisses with a protolith age of 1600-1550 Ma. These rocks were metamorphosed to medium pressure granulite to amphibolite facies during the Musgravian Event at 1200-1170 Ma and were subsequently overprinted by lower pressure assemblages possibly reflecting near-isothermal decompression. This 1200 Ma event was accompanied by the intrusion of syn-tectonic charnockite and voluminous syn-to post-tectonic granites which intruded throughout the terrain at 1190-1120 Ma. These granites comprise about 90% of the Musgrave Block outcrop on PETERMANN RANGES.

Further igneous activity occurred at 1080-1050 Ma, including the intrusion of the mafic-ultramafic Giles Complex and dolerite dykes of the Alcurra Dyke Swarm at c. 1078 Ma. A suite of granite and charnockite in the eastern Mann Ranges intruded at c. 1070 Ma, whilst felsic and less abundant mafic volcanics in the northwest of the mapsheet were extruded at c. 1050 Ma. This volcanism is interpreted to be related to a rift environment, in which coarse gritty sand and conglomerate was also deposited, forming the Bloods Range beds. This rift may reflect the earliest stage of the opening of the Amadeus Basin. Further mafic dykes probably intruded at 1000-970 Ma.

Widespread subsidence in the early Neoproterozoic led to the deposition of the quartz sand of the Dean Quartzite, followed by silts and carbonates of the Pinyinna beds. The Dean Quartzite now forms the dominant ridges and peaks of the Petermann Ranges and Olia Chain. The Pinyinna beds were probably deposited at a similar time to the intrusion of dolerite of the Amata Dyke Swarm at c. 820 Ma. Intermittent deposition punctuated by minor tectonism occurred in the Amadeus Basin through the late Neoproterozoic, but with the exception a small outcrop of Winnall beds these sediments are largely absent from PETERMANN RANGES.

Intense north-directed oblique compression associated with the 580-520 Ma Petermann Orogeny resulted in deformation and metamorphism throughout PETERMANN RANGES. South of the Woodroffe Thrust, the region was metamorphosed during mylonitic deformation at high pressure granulite to garnet amphibolite facies conditions, at pressures of 12-13 kbars and temperatures of 700-750°C. Channelised fluid flow accompanying high strain led to zones of partial melting and the development of gneissic fabrics. Immediately north of the Woodroffe Thrust, metamorphic conditions were medium pressure amphibolite facies (650°C, 6-7 kbars), resulting in partial melting of granites. The metamorphic grade decreases to lower amphibolite to upper greenschist facies to the north. Deformation of the basal Amadeus Basin sequence was intense, with early isoclinal folding preserved in the Olia Chain, followed by prolonged north-directed thrusting and transport of a large basement nappe along the Piltardi Detachment Zone. Exhumation of the southern terrain along the Woodroffe Thrust, associated with lower grade (amphibolite to greenschist facies) shear zones, resulted in the juxtaposition of the different crustal levels.

The topography generated by the Petermann Orogeny led to the deposition of the Mount Currie Conglomerate as a proximal foreland deposit. Scattered mesas of white sandstone in the northeast of the mapsheet reflect a marine transgression in the Ordovician. The majority of PETERMANN RANGES is covered with Cainozoic sediments, comprising sand, colluvial and alluvial deposits and calcrite, with minor to rare sandstone, ferricrete and talus deposits.

No economic mineral deposits have been discovered on PETERMANN RANGES, although anomalous Cr, Ni and Pt occur associated with Giles Complex, subeconomic base metal mineralisation occurs within the Pinyinna beds, and minor gold and copper mineralisation occurs locally along the Piltardi Detachment Zone. Granite Suites north of the Woodroffe Thrust are relatively enriched in U and Th. Groundwater resources are poorly known, with scattered data suggesting a high variability in water quality.

INTRODUCTION

PETERMANN RANGES lies in the southwestern corner of the Northern Territory, bordering Western Australia and South Australia (Figure 1). The map is bounded by latitudes 25°00' and 26°00' S and longitudes 129°00' and 130°30' E. This report accompanies the second edition geological map, and results from work conducted by the Northern Territory Geological Survey (NTGS) from 1988-96. In 1988-90, work was concentrated on PETERMANN. In 1995 the project was extended to cover the entire 1:250 000 mapsheet with fieldwork being completed in 1996.

First edition mapping of PETERMANN RANGES was conducted by AGSO (Australian Geological Survey Organisation, formerly Bureau of Mineral Resources (BMR)) from 1962-69 (Forman 1966a, 1972). NTGS second edition mapping was conducted using 1:25 000 colour air photography flown in 1985, 1990, 1992 and 1995. Some regions on the mapsheet were not visited due to their cultural significance to the Traditional Owners, including a 20 x 10 km region encompassing Mt Mann within the Mann Ranges. However, interpretation of thin sections from these regions made by BMR in the 1960s combined with airborne geophysics have allowed a broad distribution of rock types to be depicted on the map. Analysis and interpretation of petrological, geochemical, geochronological and geophysical data acquired during the project aided the interpretation of field observations. Igneous rock names follow the IUGS nomenclature scheme (Le Maitre 1989). The 1996 AGSO Timescale is used in this report. The AMG datum used is AGD 66 (see map face for a guide to UGR grid references).

Work by BMR in the 1960s was the first comprehensive

* Names of 1:250 000 and 1:100 000 mapsheet areas are given in large and small capitals respectively; eg, PETERMANN RANGES, COCKBURN.
mapping of the area. Before this time, most information was restricted to specific localities within the mapsheet, and was gathered by early explorers and prospecting parties. A list of expeditions, prospectors and geological exploration up to 1970 was provided by Forman (1972). No geological studies or mineral exploration have been undertaken in the region since the late 1960s. However, in more recent times, some interest has been shown in the prospectivity of the area, and several exploration licence applications are under veto or pending approval from Traditional Owners, under the requirements of the Land Rights Act (1976).

Access, land use and population

PETERMANN RANGES is accessed from Alice Springs via the Stuart and then Lasseter Highways, passing through Uluru-Kata tjuta National Park (AYERS ROCK) (Figure 1). A wide, formed gravel road, known as the Docker River Road, traverses the northern part of the mapsheet until it crosses the northern boundary near the Hull River. It then continues northwards through Docker River (Kaltukatjara, BLOODS RANGE) and on to Giles Meteorological Station in Western Australia. The Mann Ranges along the southern edge of the mapsheet are more easily accessed from tracks that divert northwards from the Mulga Park - Wingellina road in South Australia. This major road links many of the larger Aboriginal communities in the Pitjantjatjara Lands of northern South Australia. Figure 2 shows the major subsidiary tracks that provide access within the mapsheet area. The remainder of the mapsheet is accessed on minor hunting tracks or by off-road travel.

The entirety of the mapsheet is Aboriginal Freehold, known as the Petermann Aboriginal Land Trust. There are no permanently occupied Aboriginal Communities in the sheet area, but approximately twenty outstations which are occupied at various times are scattered across the region (Figure 2). The largest of these are Walatyjata and Umutju, which include several dwellings, whilst most consist of a single structure. The primary land use is traditional hunting and gathering, with some minor tourism and camel mustering. The dominant languages of the region are Pitjantjatjara and Ngaatjatjarra.
Climate and vegetation

This region belongs to the arid zone of Hooper et al. (1987). The nearest places with rainfall statistics are Giles Meteorological Station (WA) and Yulara (AYERS ROCK), which have 253.7 mm per annum (averaged over 40 years) and 311.9 mm per annum (averaged over 23 years) respectively (figures supplied by the Bureau of Meteorology). It is useful to consider these rainfall figures in comparison to the mean annual potential evaporation, which is in the order of 2,700 mm. The winters are relatively cool, with a fairly large diurnal range in temperature. The mean daily minimum for July is 3.4°C and mean daily maximum is 20.3°C. The summers are hot, with extensive periods where the temperature exceeds 40°C each day. Rainfall occurs predominantly in summer, but also falls in winter. Summer rains occur as isolated, sometimes heavy storms. Generally winter rains are steadier. The natural cycle for this region is for very erratic rainfall patterns and extended dry spells are common.

The vegetation survey of the Northern Territory, published in 1990 by the then Conservation Commission of the NT (Wilson et al 1990), has divided the vegetation of the area into ten broad communities that generally reflect variations in landscape and soil type. They do not exactly match the geomorphic units described later in this report due to the scale of the vegetation survey map (1:1 000 000), which greatly decreases the degree of resolution, and also due to local variations in vegetation patterns.

The most extensive are the sand plain and dune field communities of desert oak (Allocasuarina decoraesmatea) and hard spinifex (Triodia basedowii), which occupy the northeast and southeast corners, and a wide belt through the central and western parts of the sheet area. The community of dead finish (Acacia tetragonophylla) and witchetty bush (Acacia kempaeana) with scattered ghost gum (Eucalyptus papuana) over a herb or grassland is also a major vegetation type, and largely coincides with the belt of granite hills that trends southeast across the mapsheet. Surrounding these hilly areas are expanses of plains with mulga (Acacia aneura) open shrubland over woollybutt (Eragrostis eriopoda) grassland. An extensive community on sand plains to the north of the Petermann Ranges and the western part of the Olia Chain is a hard spinifex open grassland with blue mallee (Eucalyptus gamophylla) overstorey. The Mann Ranges in the south of the mapsheet support an open grassland strongly dominated by porcupine grass (Triodia irrtans). The ridges of the Petermann Ranges are occupied by spike-flowered spinifex (Triodia spicata) grassland with holly grevillea (Grevillea
wickehamii), Acacia spp. and ghost gum. Scattered across the
mapsheet are: small isolated patches of hard spinifex grassland
with mulga between dunes; Plectrachne melvillei grassland
with mulga and witchetty bush; and weeping spinifex (Triodia
clelandii) grassland with a mixed species open woodland.

Geomorphology

Seven broad geomorphic units can be recognised and
described for PETERMANN RANGES: (1) Southern
Uplands, (2) Northern and Central Uplands, (3) Hills, (4)
Penepalns, (5) Frontage Plains and Floodplains, (6) Sand
Plains and Dune Fields and (7) Claypans. The broad
distribution of these units is shown on Figure 3.

Southern Uplands - These comprise the Mann Ranges,
with the highest point of the mapsheet at 1225 m above sea
level in the eastern part. Mt Mann stands at 1169 m. The ranges
rise approximately 500 m above the level of the plains to the
north. Some lower, outlying uplands in the southern part of
the sheet are also included in this unit. The uplands form quite
dissected and irregularly shaped, steep-sloped hills, with
abundant bouldery outcrop and smooth rock faces on the crests
and slopes (Figure 4). Soils are thin to non-existent, and
vegetation cover is low, with the majority of the area being
treeless. On the map sheet, the drainage from these ranges is
north directed, and rapidly dissipates into the plains to the
north.

Northern and Central Uplands - These comprise the
Petermann Ranges and the series of isolated peaks of the Olia
Chain such as Stevenson Peak, Butler Dome, and Foster Cliff
(Figure 5). The maximum height of the Petermann Ranges is
958 m at Mt Curdie. Most of the ranges stand about 200-
300 m above the level of the plains to the north. The highest
point in the Olia Chain is Butler Dome (1107 m), although all
the large peaks are greater than 1000 m. These uplands are

![Figure 3 Generalised geomorphic units on PETERMANN RANGES](image)
distinguished from those in the south by their morphology. Escarpments, footslopes, and dip slopes are common features. Broad, gently sloping summits on some of the larger features are probably a remnant of the Palaeogene-Neogene upland surface, as is the bevelled crest on many of the quartzite ridges in the Petermann Ranges. These ranges are cut by a series of wide, north-flowing sandy creeks (e.g., Shaw, Irving, Chirnside creeks).

**Hills** - The Pottoyu Hills (average 750-800 m above sea level, and about 100 m above the plains to the south) and the less rugged southern part of the Olia Chain form this unit. Some of the more substantial isolated granite outcrops, such as Duffield Rocks and Mt Jenkins, are also included. This unit forms exclusively on granitic lithologies. The hills are relatively rounded and covered with outcrop consisting of boulders and tors, with lower slopes formed of gritty colluvial soils. The area is closely dissected, with numerous narrow, shallow valleys around a dominantly dendritic drainage pattern. In some places the drainage is strongly joint-controlled and has a trellis pattern. Most of the major drainage in the northern part of the mapsheet originates within these areas.

**Peneplains** - These areas are remnant older land surfaces that have undergone some erosion in the form of stripping, but to a large extent are mostly unmodified. They generally lack defined drainage and the major mode of material transport is by sheetwash. These plains are largely dominated by mulga, which commonly shows a distinct grooving pattern, clearly evident on air photos, but less obvious on the ground. Generally the soils are sandy clay loam in texture, and may have a thin sandy veneer where they occur adjacent to sand plains.

**Frontage plains and floodplains** - These areas are distinguished from the stable plains because they are geomorphically more active and diverse. The Mann Ranges have no large drainage systems originating from their northern side, but after significant rain events the narrow frontage plains receive runoff and sediment via the series of alluvial fans flanking the slopes. Several large creeks or rivers flow
northwards from the Pottowy Hills, through the Petermann Ranges, and disgorge onto the northern plains where they eventually disappear beneath the sand plains. These creeks have wide, sandy to loamy floodplains, and the creeks themselves are wide and shallow in section. Overbank deposits of finer sand and clay are laid down after the infrequent major flooding events.

Sandplains and Dunefields - This is by far the most extensive geomorphic unit in the sheet area. It occupies most of the northeast and north-central parts, and a wide belt stretching from the southeast corner to almost the entire length of the western boundary. The dunes and plains are largely stabilised by their vegetation cover, although some drifting of sand may occur on dune crests. In the northeast corner, the dominant orientation of dunes is northeast. In the more central part of the map sheet, the dominant orientation is north-northwest. The average height of the dunes varies from about 8-12 m. The dominant dune morphologies are mesh and brided types, particularly in the northeast. Longitudinal dunes are rarer, and mostly occur in the central and western parts of the sheet area.

Claypans - Claypans are scattered in a wide band amongst the dunes north of the Mann Ranges. They may be a surface expression of palaeodrainage dating from wetter climatic conditions earlier in the Cainozoic, before the influx of aeolian sand. The claypans consist of a flat, cracked when dry, impermeable clay surface on a generally circular depression, surrounded by banks of sand. Calcrete surfaces are also commonly associated with the claypans and surrounds. After rain, evaporation is the dominant mechanism for the dissipation of surface water.

REGIONAL GEOLOGICAL SETTING

PETERMANN RANGES contains elements of two major geological domains - a basement terrain of Mesoproterozoic granite and gneiss of the Musgrave Block, and overlying sediments of the Neoproterozoic to Palaeozoic intracratonic Amadeus Basin. The Musgrave Block is a large east-west trending Proterozoic mobile belt which extends along the Northern Territory - South Australia border and into Western Australia (Figure 6). The oldest exposed rocks in the Musgrave Block are Mesoproterozoic gneisses which have intrusive, volcanic and rare sedimentary precursors (Moore and Goode 1978) and protolith ages which range from 1600-1300 Ma (Gray 1978, Camacho and Fanning 1995). These gneisses were metamorphosed to granulite and amphibolite facies during the Musgravian Event at c.1200 Ma (Gray and Compston 1978, Maboko et al 1991). The western Musgrave Block may have undergone a more complex Mesoproterozoic evolution, with additional granulite events at c.1300 and 1080-1060 Ma (Clarke et al 1995a, White et al 1998). Voluminous granitic magmatism occurred synchronously with and immediately following the Musgravian Event in the interval 1200-1140 Ma (Camacho and Fanning 1995). A second major phase of magmatism occurred between 1080-1050 Ma (Sun et al 1996) with the intrusion of the extensive Giles Complex layered mafic and ultramafic bodies, the Alcurra Dyke Swarm (Edgose et al 1993) and additional granites and charnockites. Extrusive equivalents of the Giles Complex, the Tollu Volcanics, occur in the western Musgrave Block. Further mafic dyke intrusion occurred at 800 Ma (the Amata Dyke Swarm; Maboko 1988; Zhao et al 1994). The Musgrave Block is cut by several south dipping crustal scale structures which were active during the 580-520 Ma Petermann Orogeny (Maboko et al 1992, Lambeck and Burgess 1992). These
include the Woodroffe Thrust, which separates Musgravian granulite facies gneisses from amphibolite facies gneisses to the north (Major 1973) and the more steeply dipping Mann Fault, which is variously interpreted as having undergone normal, reverse and/or dextral strike-slip movement (Major and Conor 1993, Stewart 1998).

The Amadeus Basin is a large east-west trending intracratonic structure extending across the southern part of the Northern Territory and into Western Australia. It is approximately 800 km long and 300 km wide and contains a thickness of up to 14 km of Neoproterozoic to Palaeozoic sediments (Lindsay and Korsch 1991). The sedimentary sequence records at least nine episodes of deposition separated by regional unconformities (Shaw et al 1991). It forms part of the Centralian Superbasin (Walther et al 1995), and at times during its history was probably contiguous with the Officer, Ngalia, Georgina, Wiso and Canning Basins (Shaw et al 1991, Walther et al 1995). The shape of the basin varied with each depositional cycle, and the present margins of the basin can be attributed to the two major orogenetic events affecting the sequence: the southern margin to the 580-520 Ma Petermann Orogeny and the northern margin to the 400-300 Ma Alice Springs Orogeny. Both margins underwent extensive deformation during these events. The sequence on PETERMANN RANGES forms part of the southwestern margin of the basin.

In the northwestern Musgrave Block, a sequence of felsic and mafic volcanics and quartz-muscovite schists comprising the Mount Harris Basalt and Bloods Range Beds were deposited at 1070-1040 Ma and overlie the granitic basement beneath the basin units of the Amadeus Basin. This sequence has traditionally been regarded as a rift sequence underlying the Amadeus Basin (Lindsay and Korsch 1991). The basin unit of the southwestern Amadeus Basin is the Dean Quartzite (Forman 1966a, Lindsay and Korsch 1991) which is correlated with the Heavitree Quartzite in the northern Amadeus Basin (eg, Shaw 1991). The Dean Quartzite is conformably overlain by a sequence of siltstone and dolomite comprising the Pinyinna beds, which are interpreted to be equivalent to the Bitter Springs Formation elsewhere in the Amadeus Basin (Forman 1966a, Lindsay and Korsch 1991). The late Neoproterozoic development of the southwestern Amadeus Basin involved the deposition of sandstone-dominated sediments comprising the Inindia Beds and Winnall beds, punctuated by periods of non-deposition and minor tectonic movements (Shaw et al 1991).

The Petermann Orogeny occurred at 580-520 Ma (Maboko et al 1992, Camacho and Fanning 1995, Clarke et al 1995b) and resulted in the dissection of the Musgrave Block by numerous major structures including the Woodroffe Thrust and Mann Fault, which are interpreted to displace the Moho (Lambeck and Burgess 1992). The Petermann Orogeny also resulted in significant exhumation of deep crustal rocks, with the most exhumation occurring between the Woodroffe Thrust and Mann Fault (Stewart 1997, 1998). The region to the north of the Woodroffe Thrust is dominated by the Petermann Nappe (Figure 6), in which a large basement slab at least 5 km thick has been carried north along a major detachment which incorporates the basal units of the Amadeus Basin. Within the central Musgrave Block, mylonitic deformation occurred under high pressure granulite to eclogite facies conditions (Clarke et al 1995a, Camacho et al 1997), whilst the terrain north of the Woodroffe Thrust was metamorphosed at greenschist to amphibolite facies conditions. The Petermann Orogeny was less intense in the eastern Musgrave Block, where its effects were limited to greenschist facies metamorphism north of the Woodroffe Thrust (Edgoose et al 1993).

The Cambrian Mt Currie Sub-basin, which occurs along the southwestern margin of the Amadeus Basin has traditionally been regarded as a proximal foreland basin into which conglomerate and coarse arkose were shed from the high topography produced by the Petermann Orogeny. The Palaeozoic sediments of the southern part of the basin were deposited on a platform that developed following the Petermann Orogeny. As a consequence, the sequence is much thinner here, with numerous periods of non-deposition in contrast to the sequence deposited in the deeper trough to the north (Lindsay and Korsch 1991). The effects of the Alice Springs Orogeny in the southwestern Amadeus Basin were relatively mild, resulting in some gentle folding of Palaeozoic rocks.

Since the Carboniferous, central Australia has been within the stable part of the Australian craton, with no further significant crustal movements. Permian basins containing sediment of a probable glacial or fluvio-glacial origin locally overlie the northern Musgrave Block and western Amadeus Basin, particularly in Western Australia.

**STRATIGRAPHY**

The lithological units of the Musgrave Block and Amadeus Basin, exposed on PETERMANN RANGES are summarised in Table 1.

**MUSGRAVE BLOCK**

**MESOPROTEROZOIC**

Musgravian granulite facies gneisses (Egn)

The distribution of Mesoproterozoic (Musgravian) granulite facies gneisses on PETERMANN RANGES is generally restricted to the eastern part of the Mann Ranges, although localised outcrops also occur in the southwest of COCKBURN and east of Walpygtjajita outstation on DUFFIELD. The gneisses are dominated by felsic gneiss with minor aluminous and mafic gneisses in the eastern Mann Ranges, and by interlayered felsic and mafic gneisses with intrusive charnockites near Surveyor-Generals Corner. In the description of the petrography of the gneisses, the term M₁ will be used to denote minerals associated with Musgravian metamorphism, whilst M₂ signifies minerals associated with high grade Petermann Orogeny fabrics. On the PETERMANN RANGES mapface, gneissic fabrics developed during the c.1200 Ma Musgravian Event are
denoted in green, whilst gneissic fabrics developed during the c.560 Ma Petermann Orogeny are denoted in dark purple.

**Felsic granulite (Egn₁)***

The Musgravian granulite facies gneisses of the Mann Ranges are dominated by homogeneous felsic gneiss which is typically medium grained and equigranular, with ≤5% mafic minerals typically comprising orthopyroxene, biotite and magnetite with or without garnet. The gneissic layering is very clear on weathered surfaces but is often poorly defined on fresh surfaces. In the eastern Mann Ranges south of the Mount Charles Thrust, where there is no mylonitic reworking, the gneiss often weathers into smooth rounded faces and boulders.

Within the felsic granulites, the M₁ assemblage is overprinted by corona textures dominated by garnet, hornblende, secondary biotite and secondary Fe-Ti oxides. M₁ biotite often has coronas of M₂ hornblende and/or garnet, and garnet coronas locally form vermicular intergrowths with opaques. Primary magnetite also contains garnet coronas, whilst orthopyroxene generally has coronas of M₂ hornblende and biotite. In the hills surrounding Puka outstation (ES890250), the felsic granulite is overprinted by an almost pervasive mylonitic fabric, resulting in the development of garnet-hornblende-clinopyroxene bearing assemblages, with no preserved granulite facies mineralogy.

The precursor to the felsic granulite is not clear, and geochemical inhomogeneities suggest that there may be various precursors. However, most of the felsic granulite is interpreted to have an intrusive igneous precursor. Localised interlayering with mafic granulite and pelite in the eastern Mann Ranges suggest that the felsic gneiss here may have a volcanic precursor. Northwest of Walal claypan at FS246258 the felsic gneiss contains folded mafic layers <1 m thick which contain plagioclase phenocrysts in a hornblende and clinopyroxene-rich matrix. These layers are interpreted to be either mafic volcanics or shallow level dolerites.

Zircons from a felsic gneiss from the eastern Mann Ranges south of the Mt. Charles Thrust (FS186250) have been dated by SHRIMP U-Pb at 1548 ± 28 Ma with metamorphic rims at 1170 ± 10 Ma. In addition, a homogeneous population of inherited zircons in the Walal Granite at FS275242, which may have been derived from the adjacent felsic gneiss, have magmatic cores dated at 1592 ± 27 Ma with metamorphic rims at 1190 ± 35 Ma.

**Peraluminous and mafic gneiss***

Peraluminous gneiss interlayered with mafic granulite only occurs within the eastern Mann Ranges south of the Mt Charles Thrust, as discontinuous zones up to 50 m wide within the quartzofeldspathic gneiss. Their distribution is not represented on the map, but they are well exposed in creek sections at FS195243 and FS150259. The peraluminous gneiss can be distinguished from the enclosing quartzofeldspathic gneiss in that it is more compositionally heterogeneous, contains abundant garnet and has narrow dark blue kyanite-rich layers and localised biotite-rich layers. Abundant partial melts occur defining a strong gneissic fabric which is locally transposed into a later mylonitic fabric.

The peraluminous gneiss contains a granulite facies assemblage which is locally strongly overprinted by high pressure mylonitic fabrics. The M₁ assemblage is generally poorly preserved but typically contains quartz, K-feldspar, plagioclase, garnet, biotite, ilmenite and magnetite with or without orthopyroxene. Where Petermann Orogeny deformation is less intense, sillimanite is preserved within peraluminous gneisses (Olive 1983). Rare corundum and hercynitic spinel occur enclosed in magnetite within narrow highly aluminous layers. Orthopyroxene often occurs with plagioclase in coronas and symplectites that separate M₁ garnet from quartz.

The M₁ assemblage is overgrown by a finer grained M₂ assemblage dominated by garnet, biotite and fibrous kyanite. Kyanite is concentrated in narrow aluminous layers containing intergrown kyanite and magnetite with or without biotite, often enclosing M₁ corundum, spinel and magnetite. M₁ biotite often has coronas of garnet, whilst M₁ ilmenite and magnetite has coronas of intergrown garnet, fibrous kyanite and biotite. Within late-M₁ orthopyroxene-plagioclase symplectites, plagioclase contains abundant fibrous kyanite and small grains of M₁ garnet that overgrow M₁ garnet at contacts with plagioclase. Kyanite also occurs along plagioclase grain boundaries where the later mineral has been recrystallised in the mylonitic fabric.

Mafic granulite layers, within peraluminous gneiss, are rarely more than 5 m in width and contain leucosomes which define a gneissic fabric. These mafic granulites contain a granoblastic assemblage of orthopyroxene, clinopyroxene, opaques and plagioclase, with minor quartz and biotite. Hercynitic spinel occurs within some magnetite grains. This granoblastic assemblage is overprinted by garnet which forms coronas that separate plagioclase from opaques and pyroxene, and by the growth of fibrous kyanite within plagioclase.

The precursors of the peraluminous and mafic gneisses are not clear although their compositional heterogeneity suggests a supracrustal origin. Similar magnetite-bearing peraluminous gneiss near Kulgera were interpreted by Edgoose et al. (1993) to be metamorphosed acid volcanics that had undergone syn-depositional alteration. The interlayering of the peraluminous gneiss with mafic gneiss on PETERMANN RANGES may therefore indicate bimodal volcanism. Alternatively, the peraluminous and mafic gneisses may represent pelitic sediments locally intruded by mafic sills.

**Interlayered mafic and felsic gneiss (Egn₂)***

Outcrops of granulite facies gneiss in the southwestern corner of COCKBURN comprise interlayered felsic and mafic gneiss, intruded by more homogeneous charnockite. East of Wanajaktioutku outstation, the gneiss is strongly overprinted by a mylonitic fabric, whilst in hills immediately north of Surveyor Generals Corner they preserve granulite facies assemblages.

North of Surveyor Generals Corner, a compositionally layered gneiss is intruded by a weakly porphyritic granite, which also has a gneissic fabric. Within the layered gneiss,
<table>
<thead>
<tr>
<th>UNIT, WITH MAP SYMBOL AND LITHOLOGY</th>
<th>DISTRIBUTION</th>
<th>COMMENTS, AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PALAEozoic (540-251 Ma)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larapinta Group (Ola)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White sandstone, locally bioturbated, with minor siltstone and conglomeratic sandstone</td>
<td>Scattered mesas in northern OLA CHAIN</td>
<td>Almost flat-lying, unconformably overlies deformed granite. Thickness uncertain but is &gt;10 m. Trace fossils (eg, Diplacrerion) suggest Ordovician age</td>
</tr>
<tr>
<td>Mount Currie Conglomerate (Ccm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphipora member (Eca)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conglomerate, dominated by clasts of sandstone. Very minor basalt and rhyolite</td>
<td>Extreme northwestern corner of OLA CHAIN</td>
<td>Poorly outcropping, largely consisting of rubble on rounded hills. Maximum thickness on AYERS ROCK probably 6-7 km. Fluvial sedimentation, probable Cambrian age</td>
</tr>
<tr>
<td>Ignaceous Provenance (Ecb)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conglomerate, dominated by clasts of rhyolite and lesser basalt, granite, sandstone and quartzite</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UNCONFORMITY</strong> Petermann Orogeny c.580-520 Ma</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NEOPROTEROZOIC (1080-540 Ma)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winnall beds (Etwi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White sandstone, minor siltstone</td>
<td>Extreme northwestern corner of OLA CHAIN</td>
<td>Poorly outcropping on rounded hills. Unconformably overlain by Mount Currie Conglomerate</td>
</tr>
<tr>
<td><strong>UNCONFORMITY? Souths Range Movement c.600 Ma</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amata Dyke Swarm (Edm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolerite dykes, gabbro</td>
<td>Throughout the map sheet within the granitic basement</td>
<td>Correlated with dykes dated at 824 ± 4 Ma in South Australia. At one locality it appears to intrude the Pinyinna beds</td>
</tr>
<tr>
<td>Pinyinna beds (Epi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey quartz-muscovite phyllite, crystalline dolostone</td>
<td>Throughout the Petermann Ranges and Ola Chain</td>
<td>Correlated with Bitter Springs Formation. Age probably c.820 Ma. Top of sequence not exposed. Thickness is &gt;100 m, possibly significantly more</td>
</tr>
<tr>
<td>Dean Quartzite (Edo)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystalline quartz sandstone, rare quartz conglomerate and quartz-kyanite-muscovite layers</td>
<td>Prominent strike ridges comprising Petermann Ranges and Ola Chain</td>
<td>Correlated with Heavitree Quartzite in northern Amadeus Basin. Age poorly constrained, but probably c.850 Ma. Thickness probably 50-100 m, but is typically structurally thickened</td>
</tr>
<tr>
<td><strong>Erosional Disconformity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MESOproterozoic (1600-1000 Ma)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnamed dolerite (Rdu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivine dolerite, ?gabbro</td>
<td>In eastern Mann Ranges and Pottoyu Hills, extent of distribution uncertain</td>
<td>Correlated with Type C mafic dykes of Glikson et al (1996), age poorly constrained at c.1000 Ma. May be correlateable with dykes in southwest Arunta Block dated at 980-970 Ma (Wyborn et al 1998)</td>
</tr>
<tr>
<td>Bloods Range beds (Eh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grity quartz-muscovite schist, schistose quartz conglomerate, kyanite-muscovite-epidote-quartz schist, rare phyllite and quartzite</td>
<td>Near Mt Berteaux on northwestern Pottoyu, and locally between basement and Dean Quartzite on PETERMANN</td>
<td>Probably a similar age to the underlying rhyolite. May represent fluvial deposition of gritty quartz sandstones and granite conglomerates in a fluvial environment. Possible rift sediments</td>
</tr>
<tr>
<td>Wankari volcanics (Rvw)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felsic volcanics with small orange K-feldspar phenocrysts, minor mafic volcanics</td>
<td>Vicinity of Giles Creek near Mt. Berteaux and in northwestern corner of POTTOYU</td>
<td>Zircons dated at 1041 ± 2 Ma using Pb-Pb evaporation technique. Correlated with Mt. Harris Basalt and felsic volcanics on BLOODS RANGE</td>
</tr>
<tr>
<td><strong>angatja granite (Pgsa)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charnockite ( Pgsc )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porphyritic orthopyroxene-clinopyroxene granite</td>
<td>Eastern Mann Ranges, north of Mt Charles Thrust</td>
<td>Locally strongly mylonitised in Mt Charles Thrust</td>
</tr>
<tr>
<td>Eastern Mann Ranges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dated at 1171 ± 5 Ma (Zircon Pb-Pb evaporation) Intrudes Alcurra Dyke Swarm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNIT, WITH MAP SYMBOL AND LITHOLOGY</td>
<td>DISTRIBUTION</td>
<td>COMMENTS, AGE</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Rapakivi granite</td>
<td>Eastern Mann Ranges</td>
<td>Occurs as dykes intruding Alcurrn Dyke Swarm and quartzfeldspathic gneiss. Mineralogically similar to charnockite</td>
</tr>
<tr>
<td>ALCURRA DYKE SWARM (Pd)</td>
<td>Widely distributed across mapsheet</td>
<td>Correlated with dykes in SA dated at 1078 Ma. In the Mann Ranges they are typically recrystallised to garnet-clinoxyroxene bearing assemblages</td>
</tr>
<tr>
<td>GILES COMPLEX (Pug)</td>
<td>On South Australian border on southern COCKBURN</td>
<td>Correlated with Giles Complex in SA dated at 1078 ± 3 Ma by Sun et al (1996)</td>
</tr>
<tr>
<td>WALAL GRANITE (Pgw)</td>
<td>In the vicinity of Walal claypan, east of the Mann Ranges</td>
<td>Age uncertain. The granite intrudes and contains xenoliths of granitic facies quartzfeldspathic gneiss. Zircons are largely inherited, although some are as old as 1190 Ma may be magmatic in origin. Differs geochemically from Angatja and Umujo Suites</td>
</tr>
</tbody>
</table>

### UMUTJU GRANITE SUITE

<table>
<thead>
<tr>
<th>UNIT, WITH MAP SYMBOL AND LITHOLOGY</th>
<th>DISTRIBUTION</th>
<th>COMMENTS, AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mantapayika Granite (Pgum)</td>
<td>In scattered outcrops extending north of the Mann Ranges to the Woodroffe Thrust</td>
<td>Hornblende-biotite granite dated at 1120 ± 9 Ma. Clinopyroxene granite dated at 1147 ± 3 Ma. (Pb-Pb zircon evaporation)</td>
</tr>
<tr>
<td>Porphyritic granites</td>
<td></td>
<td>Zones of high strain and fluid flow in Mantapayika Granite which underwent mylonitisation during the Petermann Orogeny. Protolith age is 1159 ± 22 Ma, metamorphic age is 561 ± 11 Ma (SHRIMP U-Pb zircon)</td>
</tr>
<tr>
<td>Hornblende-garnet gneisses</td>
<td>In scattered outcrops extending north of the Mann Ranges to the Woodroffe Thrust</td>
<td></td>
</tr>
<tr>
<td>Migmatic garnet-hornblende-biotite felsic gneiss (represented as stipple on accompanying map)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puka Granite (Pgup)</td>
<td>In hills northwest of Puka outstation in Mann Ranges</td>
<td>Dated by Pb-Pb zircon evaporation at 1145 ± 6 Ma</td>
</tr>
<tr>
<td>Hornblende- and clinopyroxene-bearing granites, variably porphyritic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charnockite (Pgsp)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weakly porphyritic orthopyroxene-clinopyroxene granite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walytjatjatja Granite (Pgw)</td>
<td>Extensive through the Mann Ranges on DUFFIELD and COCKBURN and on outcrops to the north</td>
<td>Locally mylonitised and overprinted by garnet-rich assemblages. Texture variable, with phenocrysts comprising between 40% and &lt;3% of the rock. Intrusive age at Mt Cockburn is 1177 ± 10 Ma (Pb-Pb zircon evaporation)</td>
</tr>
<tr>
<td>Porphyritic clinopyroxene granite with rounded blue-grey phenocrysts of K-feldspar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnamed clinopyroxene granite (Pguc)</td>
<td>In hills 15 km east of Puka, in eastern Mann Ranges</td>
<td>Dated by Pb-Pb zircon evaporation at 1172 ± 6 Ma</td>
</tr>
</tbody>
</table>

### MANTARURR GRANITE SUITE

<table>
<thead>
<tr>
<th>UNIT, WITH MAP SYMBOL AND LITHOLOGY</th>
<th>DISTRIBUTION</th>
<th>COMMENTS, AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utanta Granite (Pgum)</td>
<td>Western side of Butler Dome</td>
<td>More felsic than other granites in Mantarurr Suite</td>
</tr>
<tr>
<td>Felsic coarsely porphyritic biotite granite</td>
<td>Highly radiogenic, contains allanite and minor fluorite</td>
<td></td>
</tr>
<tr>
<td>Wala Wuru Granite (Pgum)</td>
<td>Stevensons Peak region, southeastern Butler Dome</td>
<td>Distinctive large rectangular to subrounded K-feldspar phenocrysts</td>
</tr>
<tr>
<td>Megacrystic granite with a fine grained biotite-rich matrix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kulu Granite (Pgumk)</td>
<td>South of Foster Cliff</td>
<td>Magmatic ages of 1168 ± 14 Ma (SHRIMP U-Pb zircon) and 1165 ± 11 Ma (SHRIMP U-Pb sphene)</td>
</tr>
<tr>
<td>Coarsely porphyritic biotite-sphene-epidote-muscovite granite</td>
<td>Locally contains gneissic xenoliths</td>
<td></td>
</tr>
<tr>
<td>Foster Cliff Granite (Pgmf)</td>
<td>Extensively throughout Olia Chain, particularly in Foster Cliff region and south and west of Stevensons Peak</td>
<td>Locally migmatitic, particularly in the south</td>
</tr>
<tr>
<td>Finely porphyritic to equigranular biotite-sphene-epidote granite, minor aplite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnamed leucogranite (Pgmd)</td>
<td>Scattered outcrops ~10km southeast of Butler Dome</td>
<td>Locally has intrusive relationships with Foster Cliff Granite, but relative timing is not clear. May be late stage aplite phase of Mantarurr Suite</td>
</tr>
</tbody>
</table>
Table 1 (Continued)

<table>
<thead>
<tr>
<th>UNIT, WITH MAP SYMBOL AND LITHOLOGY</th>
<th>DISTRIBUTION</th>
<th>COMMENTS, AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>POTTOYU GRANITE SUITE (Pgn)</td>
<td>Throughout the Pottoyu Hills, outcrops immediately south of the Pottoyu Hills, and north of the Petermann Ranges</td>
<td>Typically has very distinctive rounded phenocrysts, locally up to 6 cm in diameter. Micasheet and hornblende rich south of the Pottoyu Hills. SHRIMP U-Pb zircon ages of 1192 ± 13 and 1144 ± 12 Ma, suggesting possible prolonged series of intrusions</td>
</tr>
<tr>
<td>Mutyati Granite (Egpn)</td>
<td>South of the Pottoyu Hills on POTTOYU</td>
<td>Geochemically similar to the Pottoyu Suite</td>
</tr>
<tr>
<td>Syn-tectonic charnockite (Pgc)</td>
<td>Southwestern COCKBURN</td>
<td>Intrudes interlayered mafic and felsic gneisses (Egn2) Correlated with syn-tectonic charnockite in Tomkinson Ranges dated at 1198 ± 6 Ma (Sun et al 1996)</td>
</tr>
</tbody>
</table>

Musgravian Event 1200-1170 Ma

<table>
<thead>
<tr>
<th>PRE-1200 Ma GNEISSES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibolite facies gneiss (Egn,)</td>
<td>North of Woodroffe Thrust, south of Poster Cliff on BUTLER DOME</td>
</tr>
<tr>
<td>Interlayered mafic and felsic gneisses (Egn,)</td>
<td>Southwestern COCKBURN</td>
</tr>
<tr>
<td>Felsic granulite (Pgn,)</td>
<td>Within Mann Ranges, southern BUTLER DOME and DUFFIELD</td>
</tr>
<tr>
<td>Peraluminous and mafic gneiss</td>
<td>Eastern Mann Ranges, south of Mt Charles Thrust</td>
</tr>
</tbody>
</table>

two-pyroxene bearing granulite of felsic to intermediate composition is interlayered with more mafic layers 2-10 cm thick. The mafic layers are often lensoid or boudinaged in the gneissic fabric and may represent an early generation of mafic dykes. The mafic layers contain clinopyroxene, orthopyroxene and plagioclase, which are overprinted by narrow garnet coronas, and by abundant fibrous kyanite within plagioclase.

In the layered mafic and felsic gneiss east of Wanatjukutjukku outstation, the contacts between the gneiss and the adjacent Walytjatjata Granite are generally mylonitic. Intrusive contacts were not observed in the field, however scattered occurrences of gneiss within regions dominated by Walytjatjata Granite suggest that locally the gneiss may form large xenoliths or rafts within the granite. The gneiss contains strong layering defined by leucosomes which are folded and transposed into a later mylonitic fabric (Figure 7). Generally, no Musgravian granulite facies minerals are preserved within these gneisses although some primary clinopyroxene and ilmenite locally occurs. These minerals are overprinted by a garnet-clinopyroxene-rutile bearing assemblage which forms coronas and symplectites in regions of low strain and defines a pervasive mylonitic fabric elsewhere. Leucocratic layers are dominated by quartz and perthitic K-feldspar. Small fibres of kyanite locally occur within recrystallised plagioclase.

This unit has close affinities with the interlayered mafic and felsic granulites abundant in adjacent regions of Western Australia (Stewart 1997). The geochemistry of these gneisses is similar to Y-depleted granulite at Mt Aloysius in Western Australia, which has a protolith age of 1550 Ma and a metamorphic age of 1200 Ma (Gray 1978, Sheraton and Sun 1995).

A series of low outcrops of fine to medium grained rock of a felsic to intermediate composition occurs at ES167441 and have been tentatively assigned to Egn,. In these outcrops compositional layering is overprinted by a later mylonitic fabric defined by quartz, feldspar, hornblende, biotite, garnet, opaques and possible tourmaline. No conclusive evidence exists as to whether the layering represents primary sedimentary heterogeneity or whether it is an annealed gneissic fabric. These outcrops are best interpreted to represent a large enclaves of metasedimentary origin.
Syn-tectonic orthopyroxene granite (Bgc)

Large bodies of homogeneous weakly porphyritic gneissic orthopyroxene granite intrude the interlayered mafic and felsic gneisses on southwestern COCKBURN. These granites contain gneissic layering that is less well developed than in the enclosing gneisses, and therefore are likely to be syn-tectonic intrusions associated with the Musgravian Event. Similar large bodies of orthopyroxene granite intruding granulite facies gneisses have been described in the Tomkinson and Hinckley Ranges in adjacent regions of South Australia by Glikson et al. (1996) and have been dated at 1198 ± 6 Ma by Sun et al. (1996a). Near Surveyor Generals Corner, where the granite has not been significantly reworked by the Petermann Orogeny, phenocrysts of K-feldspar are bluish-purple in colour and up to 2 cm in diameter and generally comprise 5-10% of the rock. Fresh faces are distinctively glassy with a dark appearance. The granite contains orthopyroxene and biotite, with or without clinopyroxene, and is overprinted by coronas of garnet around pyroxene and biotite and the growth of fibrous kyanite within plagioclase. A similar weakly to moderately porphyritic granite intrudes the layered gneisses near Wandaikutjuukku outstation, and is a medium grained rock dominated by quartz and perthitic K-feldspar with <5% mafic minerals. The quartz and feldspar have recrystallised at grain boundaries and the mafic minerals have completely recrystallised to aggregates of Fe-Ti oxides, clinopyroxene and fine grained biotite with quartz and feldspar which are enclosed by fine grained garnet-bearing symplectites.

Amphibolite facies gneiss (Bgn.)

Musgravian gneiss is relatively rare north of the Woodroffe Thrust on PETERMANN RANGES. The largest area of quartzofeldspathic amphibolite facies gneiss is exposed in outcrops 20 km south-southwest of Foster Cliff on BUTLER DOMES. The gneiss contains multiple generations of leucosomes and two pervasive fabrics. It is typically equigranular and contains an assemblage of biotite, oxides, titanite, epidote, quartz, K-feldspar and plagioclase with or without allanite and garnet. The early gneissic fabric (S1) is defined by segregation into biotite and feldspar-rich layers on the scale of a few millimetres, with diffuse parallel leucosomes. Coarse biotite-bearing leucosomes up to 3 cm in thickness are locally discordant to S1 and contain allanite up to 6 mm in diameter. Small diffuse leucocratic zones within the gneiss also contain allanite, suggesting that the allanite-bearing melts reflect in situ partial melting. These leucosomes are tightly folded with an axial planar S2 fabric defined by biotite-titanite-epidote ± garnet assemblages. Biotite-bearing leucosomes locally occur parallel to S1 (Figure 8). Where S1 is strongly developed, evidence for the early gneissic fabric is often destroyed. A complex intrusive contact with the Mantarurr Granite Suite in which the gneiss forms large xenoliths within granite is exposed at FS410530.

The homogeneous gneissic composition of this gneiss is consistent with an intrusive igneous precursor. SHRIMP U-Pb dating of a gneiss from FS355510 indicates a protolith age of 1584 ± 23 Ma, and a metamorphic age of 1176 ± 40 Ma. The c.1180 Ma metamorphic age is interpreted to reflect the timing of development of the S1 fabric, whilst the S2 fabric is considered likely to reflect deformation associated with the Petermann Orogeny.

1190-1120 MA GRANITES

Granites which intruded immediately after the Musgravian Event between 1190-1120 Ma dominate the Musgrave Block on PETERMANN RANGES. Felsic intrusions of this age have been recorded throughout the Musgrave Block (Maboko et al. 1991, Camacho and Fanning 1995, Glikson et al. 1996) and have been termed the Kulgera Suite by Major and Conor (1993).

Figure 7 Mafic granite from the interlayered mafic and felsic gneiss (Bgn.). The layering is folded with axial planar fabric containing garnet and clinopyroxene.
Walal Granite (PgW)

Porphyritic granite associated with medium grained equigranular aplite crops out in the region of Walal claypan, near the South Australian border on Butler Dome. This porphyritic granite is characterised by coarse phenocrysts of purple-brown K-feldspar in a medium grained groundmass. In regions of low strain the phenocrysts are often subhedral and exhibit simple twinning, whilst in regions of high strain the rock shows a distinctive banding. Its composition ranges between granodiorite and granite, with mafic minerals making up 10-25% of the granite.

Walal Granite contains relict clinopyroxene that formed part of the primary assemblage, and which is largely replaced by biotite, hornblende and opaques (predominantly ilmenite). Elsewhere (eg, FS276253 and FS227264) the granite contains primary orthopyroxene, which forms part of an igneous assemblage which also contains hornblende, biotite, quartz, K-feldspar, plagioclase and opaques. Coronas of garnet occur around biotite and ilmenite and less abundantly around hornblende and pyroxene. Following garnet growth, a second, finer grained generation of biotite and hornblende formed and defines a moderate fabric accompanying extensive recrystallisation of quartz and feldspar. Aligned inclusions within garnet suggest that garnet growth occurred early within the progressive development of this secondary biotite-hornblende fabric. Where the late fabric is not as well developed, secondary biotite and hornblende occur as narrow coronas around garnet and earlier biotite and hornblende. Narrow coronas of titanite occur locally around ilmenite. The dominant feldspar within the porphyritic granite is plagioclase, which is often antiperthitic and contains deformed twin lamellae. Large simple twinned K-feldspar is often extensively consumed on their margins by myrmekitic plagioclase.

The porphyritic granite is typically associated with a medium grained equigranular aplite. This rock-type also contains purple-brown K-feldspar, which locally forms larger phenocrysts (eg, the southern side of the Walal claypan; FS255240). The aplite contains <5% mafic minerals comprising clinopyroxene, hornblende, biotite and garnet. The presence of xenoliths of porphyritic granite in aplite and aplite veins in granite, indicate that the aplite is a later intrusion. Contacts between porphyritic and equigranular intrusions are broadly concordant, but locally discordant to the dominant fabric.

Both lithologies are intruded by coarse K-feldspar-rich veins (typically 5-20 cm in width) which contain ~50% coarse purple K-feldspar, ~5% mafic minerals (probably hornblende) and have the same fabric as the granodiorite and aplite.

Abundant mafic xenoliths, with less common felsic xenoliths occur throughout the Walal Granite. The felsic xenoliths contain an earlier gneissic fabric, and are assumed to be derived from felsic granulate. The mafic xenoliths contain no obvious earlier fabric, and where they are deformed by the same fabric as in the enclosing granite they contain a garnet-bearing metamorphic assemblage.

The age and significance of the Walal Granite is unclear. Cathodoluminescence imaging and SHRIMP II analysis of a sample from hills to the east of the Walal claypan (FS275242) revealed a complex zircon population with a core at ca.1590 Ma, possible metamorphic rims at ca.1510 Ma, and a second generation of metamorphic rims at ca.1190 Ma. Pb-Pb zircon evaporation analysis of a sample from the northern edge of the claypan (FS252247) revealed a similar population of complex inherited zircons with cores at ca.1590 Ma. The presence of gneissic xenoliths constrains the intrusion of the granite to post-1200 Ma. The Walal Granite has a number of textural and geochemical similarities with the unnamed clinopyroxene granite within the Umatuji Suite, including local presence of primary clinopyroxene and purple-brown colour of feldspar phenocrysts. As the unnamed clinopyroxene granite is dated at 1.177 Ma, this is the preferred approximate age of the Walal Granite. However, the possibility remains that this granite may be related to the 1.070 Ma Angatja Granite Suite.

Figure 8 Amphibolite facies gneiss (PgW) with multiple generations of leucosome. The leucosome parallel to the pencil is interpreted to be parallel to S2.
UMUTJU GRANITE SUITE

The Umutju Granite Suite is an extensive suite of granites which dominates the basement outcrop on PETERMANN RANGES south of the Woodroffe Thrust. In spite of many textural variations through this region, the granite bodies have been grouped into a single complex due to their close geochemical and chronological affinities. The suite has been divided into four main granite types, largely on the basis of geochemical and textural distinctions.

Walytjatjara Granite (Pguw)

The Walytjatjara Granite comprises an extensive suite of predominantly porphyritic granite which dominates the western Mann Ranges and low outcrops to the north of Mt Le Hunte and Mt Samuel. The most common lithology is coarse porphyritic clinopyroxene-bearing granite, which contains distinctive large rounded blue-grey phenocrysts of K-feldspar (Figure 9). Phenocrysts are spherical to elliptoidal, typically 2-3 cm in diameter, and comprise between 40% and <5% of the rock. Phenocrysts of plagioclase feldspar occur locally. Mafic minerals typically make up 15-20% of the rock and form coarse aggregates which are elongated in the fabric. Locally, the granite is equigranular and medium grained, and becomes less homogeneous near the western end of the Mann Ranges around Watatjatjaturu outstation. In this region, medium grained equigranular granites are more common than elsewhere, some samples are geochemically anomalous and locally there are brown rather than bluish-grey phenocrysts.

The primary igneous mineral assemblage generally contains clinopyroxene and ilmenite and is typically largely consumed by a secondary mineral assemblage associated with the development of mylonitic fabrics. In relatively low strain regions, the secondary assemblage comprises symplectites of garnet, clinopyroxene and K-feldspar which separate primary clinopyroxene and ilmenite from plagioclase. The presence of K-feldspar in the symplectites suggests biotite may also have been consumed by these reactions. Small garnets locally occur within recrystallised plagioclase.

Primary mafic minerals are also recrystallised along grain boundaries to garnet, clinopyroxene, biotite and K-feldspar with minor quartz. Where the granite is strongly mylonitised, the mafic mineralogy has entirely recrystallised to fine grained garnet, clinopyroxene, biotite and ilmenite, with or without hornblende, strung out in the mylonitic fabric.

A number of outcrops of granite north of the Mann Ranges (eg, ES284430 and ES243399) are distinctive in that K-feldspar phenocrysts are strongly recrystallised and orange in colour. Locally, corroded remnants of blue-grey feldspar occur within the orange K-feldspar, implying that these outcrops belong to the Walytjatjara Granite and that the change in feldspar colour is a product of subsequent recrystallisation.

Near Mt Cockburn, Walytjatjara Granite is cut by the Cockburn Shear Zone, which comprises a 50 m thick mylonite with coarse hornblende and garnet porphyroblasts overprinted by a biotite-hornblende-titanite fabric. Within the mylonite, the granite contains numerous leucosomes, which have been strongly deformed, transposed and stretched by mylonitic deformation. Similar shear zones also occur in the Walytjatjara Granite in the vicinity of Mt Le Hunte.

A granite with coarse blue grey phenocrysts from near Mt Cockburn (ES410301) gives a Pb-Pb zircon evaporation age of 1175 ± 10 Ma, which is interpreted to reflect the age of intrusion.

Mantapayika Granite (Pguum)

The granite that occurs as scattered outcrops to the north of the Mann Ranges is variable both in texture and degree of deformation, ranging from almost undeformed granite to migmatite. It is similar to the Walytjatjara Granite, although it is generally younger, more texturally variable and has a slightly different geochemical signature.

Figure 9 Typical outcrop of the Walytjatjara Granite, with large rounded blue-grey phenocrysts of K-feldspar
Porphyritic clinopyroxene and hornblende granite

The Mantapayika Granite is typified by a porphyritic granite with rounded to subhedral blue grey K-feldspar and/or plagioclase phenocrysts. However there is considerable variation in both the texture and appearance of the granite across this broad region.

Clinopyroxene granite with blue-grey K-feldspar phenocrysts is the dominant lithology within a 20 km radius of Umutju outstation (ES680620), and occurs less abundantly through the remainder of the Mantapayika Granite. It typically contains corroded primary clinopyroxene with or without ilmenite. The primary mafic assemblage has largely recrystallised to garnet, hornblende, biotite and titanite, with or without clinopyroxene, which form vermicular intergrowths with quartz and felspar. In higher strain zones these minerals define a mylonitic fabric. The granite typically has a dark appearance and is often almost indistinguishable from the Walytatjata Granite, although it is geochemically distinct and generally less porphyritic. A sample from the porphyritic clinopyroxene granite in a remote outcrop at ES957543 has a Pb-Pb zircon evaporation age of 1147±9 Ma.

Scattered throughout the Mantapayika Granite, but particularly in the west in the region of the Wingellina to Docker River road, is white, equigranular to weakly porphyritic hornblende granite. This granite is generally indistinguishable geochemically from the porphyritic clinopyroxene granite, but is recognisable in the field by white to pale grey colour, lack of large phenocrysts, and spotty appearance. It often has small white phenocrysts of plagioclase (and locally also K-feldspar), typically <1 cm in size, but elsewhere is equigranular. The mafic mineralogy is dominated by hornblende, garnet, ilmenite and biotite, often forming discrete clusters which may pseudomorph primary igneous minerals. Locally, primary igneous hornblende is preserved. A sample from this hornblende granite at ES839681 has a Pb-Pb evaporation age of 1120 ± 9 Ma, and this granite is tentatively correlated with similar granite further west (eg, at ES247669 and ES264481).

At Border Hill (ES015512) the Mantapayika Granite is medium grained and equigranular to weakly porphyritic, and the mafic minerals have entirely recrystallised to an assemblage of garnet, clinopyroxene and ilmenite with minor biotite, which occur as fine grained aggregates of minerals elongated in the fabric. Hornblende is absent.

Hornblende-garnet migmatitic gneiss

Discrete zones through the Mantapayika Granite have undergone partial melting during high strain, resulting in the obliteration of the granitic texture and the formation of migmatitic containing gneissic layering (Figure 10). The percentage of granite which has undergone high strain and migmatisation increases to the north, particularly in the northern regions of Cockburn and amongst the scattered outcrops east of Umutju on Duffield. Here the gneiss forms large anastomosing networks, with gradational contacts into less deformed granite.

The migmatitic gneiss has no preserved igneous texture, and typically comprises biotite-rich felsic gneiss, with coarse hornblende and garnet porphyroblasts and abundant partial melts defining the gneissic fabric. The leucosomes commonly contain coarse hornblende up to 1.5 cm in length. The gneissic fabric is tightly folded and transposed into an axial planar fabric defined by biotite and hornblende. The axial planar fabric locally intensifies into mylonite which typically has an east-plunging mineral lineation.

The mineralogy of this gneiss comprises biotite, hornblende, garnet, titanite, quartz, plagioclase, K-feldspar and ilmenite, with or without allanite and monazite. Pyroxene is absent. An early metamorphic assemblage associated with the gneissic fabric contains coarse grained garnet, hornblende and biotite with or without titanite. This is generally overprinted by a later, finer grained assemblage containing biotite, hornblende and titanite with no garnet, which is associated with the development of the axial planar fabric. Hornblende, quartz, plagioclase and ilmenite locally form coronas consuming garnet.

Interpretation of the significance of this migmatitic gneiss is hampered by lack of exposed field relationships due to the
scattered nature of the outcrop. However, at a number of localities (eg, ES532440 and ES240651) gradational contacts are exposed between foliated Mantapayika or WalytjaJatata Granite and hornblende-garnet migmatic gneiss. These gradations occur over a distance of only 1-3 m, and correspond to a significant increase in strain. The gneiss also has strong geochemical affinities with the surrounding porphyritic granite. The most plausible interpretation is that the hornblende-garnet migmatic gneiss represents zones of high strain of Petermann Orogeny phase, which served as conduits for channelised hydrous fluids, lowering the granite solidus and allowing partial melting and complete recrystallisation to occur. Further evidence that the hornblende-garnet gneiss represents strained Mantapayika Granite is provided by SHRIMP U-Pb zircon date of gneiss 35 km west of Mt Jenkins (ES334658). This sample yielded zircons with a magmatic age of 1139 ± 22 Ma with metamorphic rims dated at 561 ± 11 Ma, confirming that the gneissic fabric developed during the Petermann Orogeny. This is further supported by a K-Ar age of 565 ± 9 Ma for hornblende from within a leucosome at ES203655. However, it remains possible that some isolated outcrops of gneiss within this terrain may have older precursors.

**Puka Granite (Pgup)**

A variety of granites in the vicinity of Puka outstation in the Mann Ranges are texturally distinct from the WalytjaJatata Granite, but are similar geochemically. Within this unit, the granites are clinopyroxene-hornblende-bearing and charnockitic.

At an outcrop on the South Australian border near Puka outstation (ES907240), a coarsely megacrystic clinopyroxene granite occurs, which is tentatively assigned to the Puka Granite. It contains large rounded to circular plagioclase phenocrysts, which are grey-purple in colour, and up to 9 cm in diameter. The mafic mineralogy comprises primary clinopyroxene and Fe-Ti oxides which are extensively consumed by a later assemblage of hornblende, garnet, biotite and ilmenite. Twinned plagioclase phenocrysts contain fine kyanite and zoisite.

In the region north and northwest of Puka, is a medium to coarse grained hornblende granite, which is typically equigranular although locally it contains rare rounded phenocrysts of plagioclase up to 2-3 cm in diameter. Coarse grained primary hornblende and ilmenite have coronas of garnet, and are enveloped by a biotite-garnet-hornblende fabric of variable intensity. Mafic minerals comprise 10-20% of the granite and locally occur in coarse aggregates up to 1 cm in length. Plagioclase and K-feldspar occur in approximately equal proportions. Zones of hornblende- and garnet-bearing melt, aligned in the regional fabric, are developed at location ES867288. The granite is broadly similar in appearance to equigranular and weakly porphyritic rocks of the WalytjaJatata Granite. At location ES893317, a sample of hornblende granite yielded a Pb-Pb evaporation age of 1145 ± 6 Ma indicating the age of intrusion.

**Charnockite (Pgup1)**

Isolated outcrops of medium grained, weakly porphyritic charnockite lie approximately 14 km northeast of Puka outstation at locality ES985353. This charnockite contains primary hornblende, orthopyroxene, clinopyroxene and quartz, with small phenocrysts of plagioclase up to 3 mm in size. The hornblende has variably broken down to secondary biotite and garnet, whilst garnet reaction rims have formed around orthopyroxene and ilmenite. The charnockite is unfoliated.

**Unnamed clinopyroxene granite (Pguc)**

A body of porphyritic granite and granodiorite containing primary clinopyroxene occurs 10-15 km east of Puka outstation. Its extent is unclear as access to some areas was not available for reasons of cultural significance. The granite is distinctive in that it typically has brown to purple-brown K-feldspar phenocrysts up to 6 cm in length. In relatively low strain zones, these phenocrysts are almost euhedral and show simple twinning, whilst in high strain zones they form rounded augens. The granite locally contains up to 20% mafic minerals, which typically comprise corroded primary clinopyroxene which is largely recrystallised to an assemblage of hornblende, biotite and garnet, with or without secondary clinopyroxene. Hornblende may also occur as a primary igneous mineral. In some samples, clinopyroxene has partially broken down to biotite and hornblende prior to garnet coral development, implying hydration prior to high pressure metamorphism. The K-feldspar phenocrysts are locally strongly perthitic.

This unnamed clinopyroxene granite is geochemically distinct from the Puka Granite but nonetheless shows broad geochemical affinities with the Umutju Suite. A sample of porphyritic granite from 14 km east of Puka outstation (FS031253) was dated using the Pb-Pb zircon evaporation method and yielded an age of 1172 ± 6 Ma.

**POTTOYU GRANITE SUITE (Pgg)**

The Pottoyu Granite Suite occurs throughout the Pottoyu Hills and in hills to the north of the Petermann Ranges. Two units are shown on the map: Mulyati Granite and undifferentiated Pottoyu Granite Suite. The suite is dominated by foliated coarsely porphyritic biotite granite, with large rounded K-feldspar phenocrysts which often display rapakivi textures. In addition to the dominant coarse porphyritic granite, numerous weakly porphyritic, equigranular and aplitic phases occur. The mafic mineralogy of the granite consists of biotite with less abundant titanite and opaque phases, with or without epidote, allanite, chlorite and hornblende. Hornblende generally only occurs in regions of high strain accompanying amphibolite facies metamorphism.

The phenocrysts within the coarsely porphyritic rapakivi granite are spherical and typically 1-3 cm in diameter, although locally they are up to 8 cm in diameter. They often exhibit growth zoning, and locally contain narrow zones of dark
inclusions and mantles of plagioclase feldspar (Figure 11). The coarsely porphyritic granite has complex intrusive relationships with medium to fine grained equigranular and aplitic granite phases. Most commonly the equigranular granite phases form dykes and sills, often broadly parallel with the fabric, but elsewhere they occur as xenoliths. Variations in the size and abundance of phenocrysts occur gradationally through the porphyritic granite.

In the Pottoyu Hills, strain increases to the south with a corresponding increase in metamorphic grade. In outcrops to the south of the Pottoyu Hills, phenocrysts are recrystallised and stretched into the fabric. Fabric-parallel leucosomes containing coarse hornblende occur, and the rock has a gneissic appearance with segregation of mafic and felsic minerals (Figure 12).

The Pottoyu Granite is mylonitic within and immediately to the north of the Pilgardi Detachment Zone, with a decrease in strain to the north. North of the PDZ, the granite locally has a higher proportion of mafic minerals, including biotite, titanite, epidote and ilmenite and has a strong mineral elongation lineation. In this region the granite typically does not contain hornblende, although hornblende and garnet do occur in a granite at ET982278.

SHRIMP U-Pb dating of two samples from the Pottoyu Suite give differing ages. A sample from the southern part of the Pottoyu Hills 14 km east of Pitalu outstation on PETERMANN (ET661071) gives an age of 1144 ± 12 Ma, whilst a sample of porphyritic granite from the western side of Irving Creek 2 km south of Little Puta Puta outstation on PETERMANN (ET880196) gives 1192 ± 13 Ma. These dates broadly agree with Rb/Sr ages of 1190 Ma for coarse porphyritic granite 4 km southwest of Katamala Cone (FS070902), and 1150 Ma for medium grained leucocratic granite 11 km southwest of Mt. McCulloch (ES910963) (Forman 1972). These ages suggest that the Pottoyu Suite represents a series of intrusions over a prolonged period of time.

Mulyati Granite (Pgpm)

A large area of homogeneous, equigranular medium to fine grained leucogranite occurs in remote scattered outcrops in
the southern half of POTTOYU, within the southern hangingwall of the Wankari Detachment Zone. It is geochemically very similar to the porphyritic granite within the Pottoyu Suite, and is probably co-genetic. It typically has an orange appearance on fresh surfaces due to abundance of K-feldspar. The mineralogy is quartz, K-feldspar and plagioclase, with less than 5% mafic minerals comprising Fe-Ti oxides and biotite. Biotite defines a weak fabric, and rare corroded remnants of titanite or allanite occur. K-feldspar (microcline) is significantly more abundant than plagioclase. Similar smaller leucogranite intrusions occur throughout the Pottoyu Suite, but are not indicated on the map.

MANTARURR GRANITE SUITE

The Mantarurr Granite Suite comprises a texturally variable suite of biotite-rich granites which occur throughout the Olia Chain. This suite can broadly be divided into the following five groups, largely on the basis of textural and compositional differences.

Wala Wuru Granite (Pgmnw)

The Wala Wuru Granite comprises coarsely porphyritic granite which occurs at Stevensons Peak, south of Stevensons Peak and on the southeastern slopes of Butler Dome. The granite is characterised by large rectangular to subrounded phenocrysts in a relatively fine grained biotite-rich matrix (Figure 13). The proportion of the rock comprising phenocrysts varies from 5% to >50%, but is typically 10-30%. The phenocrysts comprise white to very pale orange K-feldspar commonly 1-3 cm in diameter. The matrix is dominated by fine grained biotite, titanite, epidote and ilmenite disseminated through fine grained quartz and feldspar. The granite usually contains only a single fabric defined by biotite, although a diffuse earlier layering occurs locally.

Utanta Granite (Pgmnw)

The Utanta Granite, which is distinctively more felsic than other porphyritic granites in the Mantarurr Suite, crops out on the western side of Butler Dome. This granite is coarser grained than the Wala Wuru Granite, with K-feldspar phenocrysts up to 3 cm in diameter in a coarse grained matrix in which mafic minerals occur as clusters of biotite and ilmenite associated with less abundant muscovite and garnet. Minor fluorite and allanite often occur. This granite is high in U, Th and K and is defined by a distinct geophysical signature. Sharp intrusive contacts occur with the Wala Wuru Granite, but no timing relationship is evident.

Kulu Granite (Pgmnk)

The Kulu Granite is a coarsely porphyritic biotite granite that occurs extensively to the south of Foster Cliff. It contains coarse phenocrysts of both K-feldspar and plagioclase which are typically 1-3 cm in diameter, but locally up to 5 cm in diameter. K-feldspar phenocrysts are generally larger than plagioclase, which displays a pale green colour. The matrix is medium grained and consists of quartz, feldspar, biotite, epidote, titanite and muscovite, with less abundant ilmenite and garnet. Muscovite occurs in the peak metamorphic assemblage associated with the biotite fabric, and also as a later secondary mineral. Garnet occurs as small grains in equilibrium with biotite and epidote. This granite contains numerous xenoliths of felsic gneiss exhibiting an earlier layering (Figure 14). SHRIMP U-Pb dating of magmatic zircons from the Kulu Granite at FS335534 yielded an age of 1168 ± 14 Ma, whilst titanite from the same rock yielded an identical 1165 ± 11 Ma.

Foster Cliff Granite (Pgmf)

Finely porphyritic to locally equigranular biotite granite is widespread through the Olia Chain. In particular, it occurs extensively to the west and south of Stevensons Peak, east of

Figure 13 Typical Wala Wuru Granite (Pgmnw)
Butler Dome and in the Foster Cliff region. This granite generally contains abundant small phenocrysts of K-feldspar, typically 3-5 mm in diameter. The phenocrysts occur within a fine grained biotite-rich matrix comprising quartz, feldspar, biotite, epidote, titanite, ilmenite, muscovite (generally secondary) and accessory allanite. This lithology also contains other granitic phases, particularly aplite and medium grained biotite leucogranite.

In a number of localities (e.g. FS182689) the finely porphyritic granite contains two fabrics - an early compositional layering overprinted by the more pervasive biotite fabric. Leucocratic veins and pegmatite bodies locally occur parallel to this earlier fabric, which may have developed during the waning stages of the Musgravian deformation. Melt-bearing shear bands occur in the granite at FS412696.

Unnamed leucogranite (Pglm)

Numerous outcrops of a medium grained equigranular biotite-bearing leucogranite occur 10 km southeast of Butler Dome. This granite is typically moderately strained, with well preserved granitic texture and no gneissic layering. The mafic mineralogy is primarily biotite and Fe-Ti oxides with or without garnet, and comprises about 5% of the rock. The leucogranite has sharp intrusive contacts with the Foster Cliff Granite, into which it intrudes. Both the leucogranite and Foster Cliff Granite are cut by minor pegmatites which are locally folded. Similar leucogranite also occurs associated with the Foster Cliff Granite to the south and west of Stevensons Peak. The leucogranite is geochemically distinct from the rest of the Mantarrr Suited, and probably represents either a late aplite phase or alternatively a totally unrelated granite.

GILES COMPLEX (Pug)

The Giles Complex is an extensive suite of massive layered mafic to ultramafic intrusions emplaced within the granulite facies terrain of the central to western Musgrave Block (Glikson et al 1996) and which has been dated at 1078 ± 3 Ma (Sun et al 1996). Outcrops of the Giles Complex predominantly occur in regions of South Australia and Western Australia immediately to the south and southwest of PETERMANN RANGES. However, a medium to coarse grained pyroxenite with minor gabbro outcrops on a hill on the South Australian border (ES210266), and forms the northeastern extension of the Claude Hills peridotite/gabbro intrusion. The pyroxenite is comprised entirely of orthopyroxene and clinopyroxene, whilst outcrops at the eastern base of the hill also contain plagioclase. The rock does not contain a pervasive fabric, but pseudotachylites which occur throughout the rock indicate that it has been deformed. The unit is locally capped by calcrete, laterite, chaledony and pale brown jasper, and an economic chrysoprase deposit occurs 5 km to the west-southwest in SA. Gravity and magnetic data indicate significant subsurface extent within the Northern Territory south of the Mann Fault (Lewis 1989).

Angatja Granite (Pga)

A suite of hornblende granite and rapakivi granite intrudes the felsic granulites and Alcurra Dyke Swarm in the eastern part of the Mann Ranges. Granite of a very similar age and appearance have been described in the western Musgrave Block and Tomkinson Ranges by Glikson et al (1996), and are believed to be intimately associated with the intrusion of the Giles Complex. The origin of the granite suite has been attributed to a combination of crustal melting of granulite due to intrusion of voluminous mafic to ultramafic magmas, and derivation from mafic magmas through crustal assimilation and fractional crystallisation (Sun et al 1996).

Charnockite (Pgac)

Moderately porphyritic orthopyroxene-bearing granite occurs north of the Mt Charles Thrust in the eastern Mann Ranges. Locally it has the dark appearance characteristic of charnockite, particularly in zones of low strain, and contains 5-10% mafic minerals which often form coarse aggregates.
aligned in a mylonitic fabric. Elsewhere it is strongly mylonised. Where igneous minerals are preserved, they comprise orthopyroxene, clinopyroxene, quartz, plagioclase, K-feldspar and biotite. Some biotite appears to have formed after orthopyroxene but prior to development of the mylonitic fabric. These minerals are generally overprinted by a mylonitic fabric in which mafic minerals have recrystallised to aggregates of garnet, secondary clinopyroxene and biotite, with or without hornblende. Phenocrysts of strongly perthitic blue-grey to purple-brown K-feldspar are typically 0.5-1 cm in diameter and locally have rims of plagioclase. Some plagioclase is weakly antiperthitic.

**Porphyritic hornblende granite (Bgah)**

Coarsely porphyritic hornblende granite has sharp intrusive contacts with the granulite facies gneiss of the eastern Mann Ranges, and also intrudes shallowly south dipping mafic dykes of the Alcurra Dyke Swarm. The contact between the granite and the gneiss is complex, with numerous dykes of granite intruding the gneiss, and xenoliths of gneiss within granite. The contact is well exposed at FS195242. The granite is compositionally homogeneous, with coarse rectangular to ellipsoidal white to pale blue K-feldspar phenocrysts typically 2-3 cm in diameter which are elongated in the fabric (Figure 15). It contains 20-25% mafic minerals forming coarse aggregates, comprising coarse hornblende of possible igneous origin and finer grained aggregates of garnet, biotite and secondary hornblende which define a mylonitic fabric. Pyroxene is absent. The granite is often conspicuously less coarsely porphyritic at intrusive contacts with the gneiss. Xenoliths of both mafic and felsic composition are common, often containing a gneissic fabric. Magmatic zircons from the granite at FS190264 have been dated at 1071 ± 5 Ma using the single grain Pb-Pb evaporation method.

**Rapakivi granite**

Fine grained felsic dykes containing coarse K-feldspar phenocrysts displaying distinct rapakivi textures intrude granulite and the Alcurra Dyke Swarm in the eastern Mann Ranges, and appear to also intrude the porphyritic hornblende granite (Bgah). The rapakivi granite contains a fine grained igneous assemblage containing clinopyroxene with less abundant orthopyroxene and biotite, overprinted by garnet, hornblende, secondary clinopyroxene and biotite. This granite is geochemically indistinguishable from the nearby c. 1070 Ma charnockite and porphyritic hornblende granite.

**Mafic Dyke Swarms (Edl, Edu, Edm)**

Mafic dyke swarms are variably abundant within the basement throughout PETERMANN RANGES. Most mafic dykes have been strongly deformed and recrystallised during the Petermann Orogeny, making it difficult to distinguish between differing dyke swarms on the basis of textural or mineralogical features. However evidence suggests that three generations of mafic dykes occur on PETERMANN RANGES and that they can be correlated with the mafic dykes documented by Gilks et al (1995) in the Tomkinson Ranges.

**South of the Woodroffe Thrust**

Throughout much of the Mann Ranges, mafic dykes are too highly strained to allow different generations to be reliably distinguished. However, regions of lower strain in the eastern Mann Ranges, particularly south of the Mt Charles Thrust, allow relationships between mafic dykes to be determined. The three generations of mafic intrusions in this region are as follows:

1. Shallowly south-dipping dolerite dykes. These dykes form a sheeted swarm which truncates the gneissic layering in the eastern Mann Ranges, and is intruded by Angatja Granite.
2. Narrow north-northwest trending olivine dolerite dykes, which intrude Angatja Granite.
3. Large gabbroic bodies up to 100 m in diameter which intrude granites of Angatja Granite.
The shallowly south-dipping dykes are typically 1-3 m in width and are fine grained, particularly at the margins. They contain narrow, simply twinned laths of plagioclase in a fine grained intergranular groundmass of clinopyroxene, orthopyroxene and minor ilmenite, with rare larger orthopyroxene phenocrysts. These dykes cross cut the gneissic fabric of the felsic granulite (Figure 16) and are intruded by the 1070 Ma Angatja Granite. They have εNd of -0.5 to -1.3, and are therefore considered likely to be related to the Alcurra Dyke Swarm (Edgoose et al 1993; previously known as the Kulgera Dyke Swarm) which intruded at ~1080 Ma and typically have εNd of -3.3 to +1.9 (Zhao and McCulloch 1993b).

The north-northwest trending olivine dolerite dykes are less abundant than the south dipping dykes and are typically 1-4 m in width. They are characterised by plagioclase laths with interstitial aggregates of olivine, orthopyroxene and clinopyroxene forming an intergranular texture. These dykes generally have similar εNd to the Alcurra Dyke Swarm (+0.3 to +0.6) but intrude after the Angatja Granite Suite. They have strong textural similarities with Type-C mafic dykes of Glikson et al (1995) which have a poorly constrained Sm-Nd age of c.1000 Ma and one published εNd value of +1.9 (Glikson et al 1996), and are therefore considered likely to be the same age. They probably also relate to north trending unnamed dolerite dykes in the southwestern Arunta Block which have SHRIMP U-Pb zircon and baddeleyite ages of 976 ± 3 and 972 ± 8 Ma respectively, with an εNd of +2.3 (Wyborn et al 1998).

The age of the mafic dykes that intrude the Muntapayika Granite is poorly constrained, but a large boudin of medium to coarse grained olivine dolerite at E817635, and a remote outcrop of medium grained olivine dolerite at E8575922, both have geochemical characteristics consistent with the Alcurra or c.1000 Ma dyke swarms. The presence of primary olivine suggests that these dykes are more likely to be related to the c.1000 Ma dykes.

The large gabbroic bodies in the eastern Mann Ranges have coarse grained ophitic to subophitic textures and contain a magmatic assemblage of clinoxyrohene, orthopyroxene, plagioclase and minor magnetite with hercynitic spinel inclusions. These intrusions have high εNd (+4.9) which is comparable to high positive εNd values of the Amata Dyke Swarm in the Musgrave Ranges (Zhao et al 1994). These bodies are also texturally similar to the Type-B dykes of Glikson et al (1995) in the Tomkinson Ranges which they considered to be equivalents of the Amata Dyke Swarm. A sample of mafic dyke from the western Mann Ranges (E8379318) also has geochemical characteristics consistent with the Amata Dyke Swarm. The Amata Dyke Swarm has a Pb-Pb baddeleyite age of 824 ± 4 Ma (Tomkinson Ranges; S-S. Sun, unpublished data cited in Glikson et al 1996), and Sm-Nd ages of 790 ± 40 and 797 ± 49 Ma (Musgrave Ranges; Zhao and McCulloch 1993a). The Pb-Pb baddeleyite age of 824 ± 4 Ma for the Amata Dyke Swarm is within error of a Pb-Pb baddeleyite age of 827 ± 6 Ma for the Gairdner Swarms in South Australia, and a Pb-Pb zircon age of 827 ± 9 Ma for a gabbro near Broken Hill (Wingate et al 1998) suggesting that they form part of a very extensive region of mafic magmatism throughout south-central Australia.

Most mafic dykes south of the Woodroffe Thrust are partially or completely recrystallised by the widespread mylonitic fabrics. In the Mann Ranges, dykes which have not been deformed contain kyanite within plagioclase, and garnet coronas around pyroxene at contacts with plagioclase. In dykes which have partially recrystallised in the mylonitic fabric, garnet and secondary clinopyroxene define the fabric and form coronas around orthopyroxene and clinopyroxene. In addition, recrystallised plagioclase contains abundant garnet and kyanite. Dykes which have completely recrystallised within the mylonitic fabric contain an assemblage of garnet, clinopyroxene, hornblende, sodic plagioclase, quartz and rutile, with or without scapolite. These dykes are particularly concentrated in the western Mann Ranges. Within many of these dykes, diffuse enclaves of partial melt occur often interconnected by narrow veins. These zones of partial melt are prevalent within zones of high strain in which the enclosing granite is also migmatite. North of the Mann Ranges in the Umutju region, assemblages in the recrystallised dykes are similar, although hornblende is more abundant and titanian occurs instead of rutile. No melting occurs within the dykes in this region.
North of the Woodroffe Thrust

North of the Woodroffe Thrust, mafic dykes are typically highly recrystallised to amphibolite or biotite-amphibole schist, and the original igneous mineralogy is rarely preserved.

On northern Potteroyu, a number of large bodies of olivine gabbro and associated dolerite dykes intrude the Potteroyu Granite. Gabbros contain an igneous assemblage of olivine, clinopyroxene, orthopyroxene and plagioclase with less abundant magnetite. They have subophitic texture in which laths of plagioclase are embedded in pyroxene and magnetite. Olivine occurs as abundant poikilitic inclusions within pyroxene and magnetite. Locally olivine has radial coronas of orthopyroxene or clinopyroxene, often with outer coronas of hornblende containing subhedral garnet. These coronas reflect subsolidus reactions. The gabbro has eNd values near zero (+0.1), which suggests an association with 1080 or 1000 Ma dyke swarms. The abundance of olivine within the gabbro suggests an affinity with the c. 1000 Ma dykes.

A second and more widespread generation of dykes on Potteroyu trend broadly parallel to the regional foliation and have recrystallised in the fabric to form hornblende-plagioclase amphibolite. Such dykes are typically 2-6 m in width although locally are up to 20 m wide. The high positive eNd (+3.09) on one amphibolite dyke from ET 312238 is consistent with eNd values from the 820 Ma Amata Dyke Swarm. Similar amphibolites also occur through PERTERMANN and BUTLER DOME and are assigned to this generation. Typically these metamorphosed dykes contain hornblende and plagioclase, with greater biotite content as strain increases. Locally they contain minor garnet.

In the region of Alyapa outstation on southeastern PERTERMANN, coarse gabbroic dykes are boudinaged in the fabric and form small hills up to 60 m in diameter. These dykes typically do not contain a fabric except at the margins. They have ophitic texture in which laths of plagioclase are embedded in coarse optically continuous clinopyroxene and orthopyroxene. Pyroxene has largely retrogressed to hornblende, with minor oxides, rutile and garnet. The geochemistry of these dykes shows affinity with the 820 Ma Amata Dyke Swarm.

Basement Quartzite (Bqg)

Occurrences of quartzite within granitic basement are found throughout the Potteroyu Hills and Olia Chain. These were previously interpreted by Forman (1972) as Dean Quartzite, however their structural position within granite, combined with their differing composition and lack of preserved bedding, precludes this interpretation.

Basement quartzite is particularly common in outcrops 15-25 km south of Foster Cliff on BUTLER DOME (Figure 17). These outcrops are usually between 10 and 400 m wide, possibly due to structural repetition. Where contacts with the Mantarurr Granite Suite are preserved they appear sharp and broadly concordant with the regional fabric. Up to three quartzite layers may occur over an interval of 200 m. The quartzite contains no evidence of bedding but has a non-pervasive fabric of variable intensity and locally contains an intense stretching lineation. The quartzite preserves much greater structural complexity than the enclosing granite and gneiss. Subhedral garnet up to 1 cm in diameter occurs locally within the quartzite, and muscovite occurs along foliation planes. At locality FS352480 a micaeous schist containing highly weathered porphyroblasts up to 4 mm occurs in sharp contact with highly recrystallised quartzite containing minor sulphide casts. Although some of the quartzite could be vein quartz in origin, the porphyroblastic schist suggests the possible presence of some interleaved metasediment in the region.

A >50 metre thick outcrop of basement quartzite also occurs 8 km north-northwest of Butler Dome at FS313710. It comprises strongly lineated quartzite interlayered with highly weathered porphyroblastic schist. The porphyroblasts are up to 1.5 cm in diameter but are completely weathered to clay minerals. Quartzite up to 50 m in width also occurs within the Potteroyu Granite Suite, often at high angles to the fabric, and can be traced discontinuously along strike for 5 km. One of these quartzites forms a prominent hill 8 km west-northwest of Katamala Cone.

The origin of these basement quartzite enclaves is not clear. The majority occur as discrete sharply defined coarsely crystalline layers within granite, and can best be interpreted

Figure 17 Typical outcrop of basement quartzite, ~15 km south of Foster Cliff
as deformed and recrystallised vein quartz. This is particularly the case for the quartzite south of Foster Cliff which occurs along the trend of a major structure visible on magnetic images which is interpreted as a fault or shear zone. However where porphyroblastic schist is associated with quartzite it is possible that they represent large rafts of an older sedimentary sequence within granite. These older sediments could potentially relate to quartzite of the Sentinel beds on KULGERA (Edgoose et al 1993).

**MESOPROTEROZOIC VOLCANICS AND SEDIMENTS**

**Wankari volcanics (Pvw)**

A sequence of fine grained porphyritic felsic volcanics with minor interlayered mafic units outcrops on the eastern bank of Giles Creek at ET064215, and in scattered outcrops in the northwestern corner of POTTYOYU. The felsic volcanics are strongly foliated and contain phenocrysts of K-feldspar up to 4 mm. The matrix has entirely recrystallised in the foliation and comprises quartz, K-feldspar, plagioclase, biotite, muscovite, opaques and minor epidote. Amphibolite outcropping north of the quartz-muscovite schist east of Giles Creek (ET060210) contains rounded recrystallised plagioclase phenocrysts up to 4 mm, with a matrix containing hornblende, epidote, quartz, opaques, plagioclase and possibly K-feldspar. Hornblende defines a strong fabric, and hornblende and epidote also occur within the recrystallised plagioclase phenocrysts. The outcrop is too poor to determine the relationship of this unit with nearby felsic volcanics and quartz-muscovite schist, but it is tentatively interpreted to be a metamorphosed intermediate to mafic volcanic. Zones of massive epidote-rich rock which are associated with the Bloods Range beds extending east of Giles Creek (eg, ET192190) may represent silicified and epidotised basalt, but this interpretation is not definitive.

Five kilometres across the Western Australian border from Mt Berteaux, a sequence of >50 m of felsic and mafic volcanics occurs along strike from the scattered outcrops near Giles Creek. These volcanics appear to stratigraphically underlie quartz-muscovite schist of the Bloods Range beds, although this interpretation is equivocal due to the structural complexity of the Wankari Detachment Zone. In this region, the volcanic rocks comprise predominantly felsic porphyryfolic volcanics with less abundant mafic units with recrystallised phenocrysts of plagioclase, and rare muscovite schist. The succession is therefore interpreted as a bimodal volcanic sequence underlying the Bloods Range beds, and is tentatively correlated with the Mount Harris Basalt and associated volcanics on BLOODS RANGE (Forman 1966a). SHRIMP U-Pb dating of zircons from a felsic volcanic rock near Giles Creek at ET064215 yielded an age of 1051 ± 22 Ma, whilst Pb-Pb evaporation of magmatic zircons from the same sample yielded an age of 1041 ± 2 Ma. If this bimodal volcanism is associated with the initiation of the Amadeus Basin as suggested by some authors (eg, Lindsay and Korsch 1991), then the Amadeus Basin may have been initiated up to 200 million years prior to the deposition of the Dean Quartzite.

**Bloods Range beds (Ebl)**

Quartz muscovite schist of the Bloods Range beds (Forman 1966a) occurs along an east trending series of low ridges and isolated outcrops extending 20 km along the Wankari Detachment Zone from the Western Australian border through Mt Berteaux on northwestern POTTYOYU. They also occur locally between the Pottuy Granite and the overlying Dean Quartzite through the Petermann Ranges on PETERMANN, although these occurrences are too small to be represented on the map. The sequence consists primarily of gritty to pebbly quartz-muscovite schist with minor muscovite-bearing quartzite and kyanite-muscovite-phlogopite-quartz schist. These rock types are interpreted to represent impure gritty to pebbly quartz sandstone with minor conglomerate, which were probably deposited rapidly in an active fluvial environment, and subsequently metamorphosed during the Petermann Orogeny.

An erosional disconformity is interpreted to exist, at least locally, between the Bloods Range beds and overlying Dean Quartzite and therefore the original thickness of the Bloods Range beds on PETERMANN RANGES cannot be precisely estimated. At Mt Phillips, a sequence of gritty to pebbly quartz-muscovite schist, up to 30 m thick, occurs between the Pottuy Granite and Dean Quartzite. On the western side of Mt Berteaux they comprise a section >200 m in thickness, although the sequence may be structurally repeated by thrusting within the Wankari Detachment Zone. The sporadic preservation and variable thickness of the Bloods Range beds may indicate they infilled pre-existing topography, with subsequent erosion prior to deposition of the Dean Quartzite removing all but the thickest parts of the sequence. The contact between Bloods Range beds and Dean Quartzite is generally well exposed with no angular relationship. Although the contact locally contains a strong fabric and abundant quartz veining, particularly at Mt Berteaux, the contact does not appear to have acted as a detachment during deformation.

Mineralogically, the Bloods Range beds are dominated by quartz-muscovite ± phlogopite schist, with varying amounts of epidote, ilmenite and K-feldspar, and localised occurrences of kyanite and tourmaline. Plagioclase is rare. The quartz-muscovite schist often contains numerous granules and pebbles of quartz, typically 0.5-1 cm in diameter, but locally up to 5 cm, often elongated in the lineation, and these are interpreted as quartz pebbles in the original sediment. Locally the schist also contains rare clasts of K-feldspar up to 1 cm. Remnant laminations and bedding can be seen as colour variations within the schist, and this is generally subparallel to the schistose fabric (Figure 18).

Rare aluminous layers within the Bloods Range beds contain coarse blades of kyanite up to 12 cm in length (Figure 19), together with muscovite, phlogopite, epidote, ilmenite and quartz. These layers are best exposed one km west of Mt Berteaux. Quartz content is variable, with minor occurrences of quartzite. Darker phlogopite-rich layers have a phyllitic appearance, and narrow phlogopite-rich lenses occur within quartz-muscovite schists. The sequence also contains massive epidote alteration with ilmenite, quartz and rare grossular-rich garnet, in zones up to 10 m wide which
occur parallel to the fabric. Thick boudinaged quartz veins occur throughout the sequence, particularly in zones of high strain, and contain coarse ilmenite with inclusions of rutile. Folded and boudinaged pegmatite veins also occur in the Wankari region and are interpreted to be derived from nearby partial melting during the Petermann Orogeny.

East of Giles Creek within the Wankari Detachment Zone the strain increases dramatically, and the Bloods Range beds comprise strongly crenulated and folded muscovite-rich schist with vein-quartz rodded in a strong lineation. In this high strain zone, schist of the Bloods Range beds is difficult to distinguish from sheared Dean Quartzite.

The age of the Bloods Range beds in this region is poorly constrained. They are interpreted to overlie the 1050 Ma Wankari volcanics, and underlie the 2850 Ma Dean Quartzite. Poor relationships on PETERMANN RANGES preclude a definitive interpretation as to whether the Bloods Range beds associated with rift volcanics, or whether they represent fluvial sedimentation preceding deposition of Dean Quartzite and are unrelated to earlier bimodal volcanism.

AMADEUS BASIN
NEOPROTEROZOIC

Dean Quartzite (Ede)
The Dean Quartzite (Forman 1966a) forms prominent ridges in the Petermann Ranges and Olia Chain, and is correlated with the Heavitree Quartzite in the northern Amadeus Basin. Within the Olia Chain it unconformably overlies granitic basement, whilst in parts of POTTOYOU and PETERMANN it disconformably overlies quartz-muscovite schist of the Bloods Range Beds. The true sedimentary thickness of the Dean Quartzite is difficult to estimate due to structural repetition by isoclinal folding and thrusting. Forman (1966a, 1972) estimated the thickness on PETERMANN RANGES to be about 300 m, and possibly over 1000 m elsewhere in the southwestern Amadeus Basin. However, these estimates fail to account for widespread and intense structural thickening of the sequence, and the original thickness is likely to be about

Figure 18 Typical exposure of Bloods Range beds near Mt Berteaux, with numerous small quartz pebbles and granules and with colour variations defining S/S₁.

Figure 19 Coarse kyanite within an aluminous muscovite schist, Bloods Range beds, 1 km west of Mt Berteaux.
50-100 m, which is the thickness of quartzite comprising the cliffs at Mt Phillips and Mt Berteaux. The original sedimentary thickness of the quartzite may also vary across the mapsheet.

The Dean Quartzite comprises recrystallised, thick bedded to massive quartz sandstone. It is generally planar bedded, with occasional trough cross-beds with very rare ripple marks and graded beds, and is generally clean, well sorted and compositionally homogeneous. Rare quartz conglomerate occurs within the sequence, and contains rounded quartzite clasts up to 4 cm in a coarse quartz sandstone matrix of rounded grains. These conglomerate beds are typically <2 m thick with a sharp base, and appear to be laterally discontinuous.

The contact between the Dean Quartzite and the underlying granites is generally modified by high strain along the contact. Within the Olia Chain, the basal 1-3 m of the quartzite is typically muscovite-rich quartz mylonite with abundant folded and boudinaged quartz veins overlying mylonitised granite. Within the Petermann Ranges on PETERMANN and POTTOYU the basal beds are not as strongly deformed. In general the base of the Dean Quartzite appears to be a well sorted clean quartzite, similar to quartzite in the rest of the sequence.

The Dean Quartzite is essentially monominerallic, with minor muscovite and oxides and rare kyanite. Kyanite-bearing layers occur as discontinuous lenses, generally <10 cm in width, containing blades of kyanite up to 1 cm in length with numerous quartz inclusions, with a matrix of quartz, muscovite, oxides and locally minor rutile and tourmaline. Kyanite rich layers are most abundant in the Stevenson Range. In the Petermann Ranges near ET930112, layers of schist both within and at the base of the Dean Quartzite contain coarse biotite, and kyanite blades commonly 1.5-2 cm in length, but in places large aggregates of kyanite up to 15 cm long are found. Staurolite has also been recorded within the Dean Quartzite at Katamala Cone (Forman 1972).

Pinyinna beds (Ppi)

The Pinyinna beds were first defined by Forman (1966a) at a type area in the Pinyinna Range (BLOODS RANGE), where at least 200 m of grey, brown and white laminated micaceous siltstone is overlain by grey and pink laminated dolostone, sometimes stromatolitic, and grey limestone. Forman (1966a) correlated the Pinyinna beds with the Bitter Springs Formation in the northern Amadeus Basin, describing the beds as an infolded and altered portion of the Bitter Springs Formation within the Petermann Nappe structure. The Pinyinna beds conformably overlie the Dean Quartzite, and on PETERMANN RANGES the stratigraphic contact appears to be gradational, with approximately one metre of interlayered phyllite and quartzite (Figure 20). The thickness of the Pinyinna beds on PETERMANN RANGES is unknown due to the absence of a complete sequence, but it is likely to be greater than 100 m.

On PETERMANN RANGES, the Pinyinna beds are poorly exposed. Most outcrop is preserved in the hinges of tight to isoclinal synclines where it is protected by enclosing limbs of Dean Quartzite. This mode of outcrop occurs throughout the Olia Chain and within the Piltardi Detachment Zone. More widespread outcrops of Pinyinna beds occur in the Petermann Ranges between ridges of Dean Quartzite, in which the surface expression is low calcere rises with loose fragments of phyllite and rare dolostone outcrops.

The dominant lithology in the Pinyinna beds on PETERMANN RANGES is grey to purple-grey thinly laminated phyllite, containing a strong fabric that is typically crenulated. The mineralogy is muscovite-quartz or muscovite-phlogopite-quartz, although rare pseudomorphs of rounded porphyroblasts occur which may be replacing cordierite. Traces of K-feldspar are present. In many outcrops, the phyllite has undergone significant ferruginous alteration, with localised development of gossans, particularly at Butler Dome.

Overlying the phyllite is crystalline pale grey to yellow-brown dolostone. This is found only within the Pinyinna beds in the Petermann Ranges, and no dolostone is exposed in the Olia Chain. Gradational contacts between phyllite and dolostone over a distance of 2-3 metres are locally exposed in the Piltardi Detachment Zone north of Mt. Phillips. Dolostone containing fibrous tremolite occurs at ET888104.

The age of the Bitter Springs Formation in the northern Amadeus Basin is well constrained at around 800 Ma, due to the presence of basaltic layers which have geochemical affinities with the 820-800 Ma Amata Dyke Swarm (Zhao and McCulloch 1993a). Whilst no basaltic layers have been recorded in the Pinyinna beds, the presence of a mafic dyke intruding poorly outcropping Pinyinna beds at ET6502374 places a minimum, and probably depositional, age at c.820 Ma.

Winnall beds (Pwi)

Poorly outcropping white quartz sandstone and yellow-brown siltstone in the extreme northeastern corner of the mapsheet were previously mapped as Inindia Beds by Forman (1972). However, recent mapping on AYERS ROCK (N. Duncan pers. comm. 1997) has established that this sequence belongs to the late Neoproterozoic Winnall beds (Ranford et al. 1966). In this locality Winnall beds are unconformably overlain by Mount Currie Conglomerate to the south.

PALAEOZOIC (CAMBRIAN)

Mount Currie Conglomerate (Cc)

The Mount Currie Conglomerate was first defined by Forman (1966a) as a sequence up to 7 km thick of coarse conglomerate within the Mount Currie Sub-basin along the southwestern margin of the Amadeus Basin. An isolated exposure of Mount Currie Conglomerate occurs in low hills in the far northeastern corner of PETERMANN RANGES. It outcrops poorly, and largely consists of rubble on hill slopes, but better exposures occur along strike to the east in AYERS ROCK. The clasts within the Mount Currie Conglomerate in this area are subrounded to rounded, with a median diameter of 15-20 cm and larger clasts up to 70 cm. The Mount Currie Conglomerate on PETERMANN RANGES has been divided
into two members on the basis of clast composition. The basal sequence comprises well rounded clasts of sandstone, probably sourced from the underlying Winnall beds. This is overlain by a sequence dominated by clasts of porphyritic rhyolite that are undeformed and strongly epidotised. They comprise predominantly felsic volcanics, which are undeformed and strongly epidotised. Less common clasts include quartzite, undeformed granite, quartz stockworks, conglomerate and undeformed fine grained mafic volcanics with epidote-rich amygdales. The origin of the Mount Currie Conglomerate is still uncertain, but it is likely that it was deposited in a proximal foreland resulting from uplift during the Petermann Orogeny (Forman 1966a, Lindsay and Korsch 1991).

PALAEOZOIC (ORDOVICIAN)

Larapinta Group (Ola)

Sandstone considered by Forman (1966a, 1972) to be Ordovician in age outcrops on low hills in the northern half of OLIA CHAIN. Exposures that lie north and south of the Docker River road west of Armstrong Creek (FT070262, FT062239, FT079210) are clearly Ordovician, with abundant bioturbated bedding surfaces and trace fossils, in particular Diplocraterion. These outcrops unconformably overlie strained porphyritic granite and typically have a basal unit 1-2 m in thickness comprising poorly sorted pebbly sandstone, locally with quartz conglomerate at the base. The clasts consist of angular vein quartz 20 mm in diameter, set in an immature medium grained sandy matrix. This basal unit is overlain by up to one metre of purple siltstone, followed by 1-2 m of well bedded, ferruginous, bioturbated medium grained sandstone in beds 30 cm thick. This interval also contains some bands of yellow, silicified material, possibly after altered carbonate. A dominantly yellowish, limonitic siltstone, containing gastropods and other unidentifiable fragments of fossils occurs at the top of the ferruginous sandstone. Overlying this sequence is >3 m of clean, well-bedded medium grained quartz sandstone showing no bioturbation and containing current ripples and cross bedding. The top of the sequence is not exposed.

Exposures emerging from the sand dunes near FT345042, contain no signs of fossiliferous material or bioturbation and therefore their age is less certain. The rocks are white, medium grained sandstone with what is interpreted to be a leached dolomitic/calcareous matrix. They may also have a feldspathic component. Some intervals consist of gritty sand with a clay matrix. Abundant trough cross beds occur in the cleaner intervals. Interspersed in the sequence are thin (~10 cm) pale clay intervals containing fragments of weathered feldspar. This sequence was probably deposited fairly rapidly in an active environment sourced from nearby granite and quartzite.

CAINozoIC

The older Cainozoic sediments are those remaining from an earlier cycle of weathering and erosion, and in some instances the older landscape is also preserved. Generally they formed under a different (dominantly wetter and milder) climatic regime from that which has prevailed for most of the Quaternary. Interpretation of magnetic data indicates the possibility of two Cainozoic basins in the southern part of the sheet, where a more subdued magnetic response indicates thick cover material (Lewis 1989). One possible basin lies under sand to the northeast of Mt Mann, and the other is under sand southwest of Mt Samuel. These areas contain scattered outcrop of basement rocks, suggesting the basins are irregularly shaped and shallow. A drillhole immediately north of the South Australian border, 12 km southwest of Mt Samuel at approximately ES221267 contained >55 m of unconsolidated Cainozoic (possibly Quaternary) sediments comprising ?fluviatile gravel and sand overlain by clay, dolomitised and silicified lacustrine limestone, calcrete and aeolian sand (Miller 1966). This basin was interpreted to deepen to the northeast. Cainozoic basins occur in the area of Uluru-Katatjuta National Park to the east (AYERS ROCK) where they have been intersected in water bores.

Sedimentary rocks (Czs)

Two occurrences of Tertiary sediments occur immediately north of the Petermann Ranges on the western side of Shaw Creek (ET708233 and 715220). The outcrops consist of flat lying quartz sandstone with a thickness of >10 m, unconformably overlying Dean Quartzite and Pottosy Granite. The northernmost outcrop consists of clean, trough cross-bedded quartz sandstone, with rare bioturbation in the form of worm burrows. The southern outcrop, which occurs on the flank of a low ridge of Dean Quartzite, contains casts of vascular plants and silicified wood. Trough cross-bedding and terrestrial plant fossils are consistent with deposition in a fluvial environment.

Forman (1972) described an occurrence of flat-lying sandstone near Foster Cliff (FS645169) occurring beneath a distal colluvial fan conglomerate (Czt) that was deposited conformably on the scoured surface of the sandstone.

Ferricrete (Czf)

Exposures of ferricrete are largely concentrated in two areas - in southeast Petermann, and central east BUTLER DOME. Most exposures occur around the margins of extensive granite outcrop in these two areas. The flat ferricrete benches form a distinct break in slope from the level of the upland plains to lower-lying areas of granite outcrop. They probably represent the remnants of once more extensive ferricrete plains which have been largely stripped to expose underlying rocks. The laterite typically is consolidated and consists of pisoliths cemented with a strongly oxidised Fe-rich matrix. Vadose calcrete often occurs associated with these ferricrete deposits.
Shallow soils over subcrop (Cz/S)

Scattered areas of soils over shallow subcrop are generally associated with basement rocks. On aerial photographs the structural trends in the rocks are often visible through these thin surficial deposits which consist largely of weathered rock fragments ranging from grit to clay size. A weakly zoned soil profile often develops, and vadose calcrete is locally present. Vegetation cover is sparse. The process of development of these soils is still continuing, but as their initial age is unknown they are designated Cainozoic.

Talus (Czt)

Most of the larger quartzite peaks and ridges of the Olia Chain and Petermann Ranges are flanked by talus deposits from both actively-forming and defunct colluvial fans. The defunct fans are readily distinguished from actively-forming talus as they are generally separated from modern slopes by incised drainage. They consist of sub-rounded pebble- to boulder-sized material derived from the local rock types and are sometimes partly lithified. In some areas they form a shallow mask over subcrop, with the underlying rock often exposed in the banks of incised gullies. The recent talus and scree deposits generally obscure outcrop or mantle the older slope deposits. They consist of pebble to boulder-sized material, often irregularly shaped and angular, with size decreasing downslope. The deposits spread a short distance onto the surrounding plains, or may be partially obscured by sand banked up against the lower slope of the hills.

QUATERNARY

Unconsolidated deposits mantle nearly 70% of PETERMANN RANGES. The vast majority of this material is transported sand (Qs), present as sand sheets and dune fields. Largely stable colluvial and eluvial soil surfaces (Qr), alluvium associated with the larger drainage systems (Qa), scattered groundwater deposits (calcrete, Qe) and playa deposits (Qp) make up the remainder of these Quaternary sediments.

Qs, Qr, Qa, Qc, Qp

Aeolian sand (Qs) in both plains and dune fields covers more than 50% of PETERMANN RANGES. Large dune fields occur in the northeastern, and the southern parts of the sheet, and are surrounded by extensive sand plains. The sand is uniformly medium to fine grained quartz sand with a small portion of fine clay material that imparts the red colour. The incursion of the sand plains of central Australia is placed at about 18,000 ybp, during the last major glacial period, however the distribution of aeolian material would have begun during the earlier glacial cycles of the Quaternary. The interdune areas (swales) may have a clay subsoil, which is commonly vegetated by mulga. Where large enough these swales have been mapped out as colluvium (Qr). Their presence indicates that the sand sheets may not be very thick, and that where winnowed into dunes, in places the underlying palaeoplain has been exposed in the swales.

Extensive colluvial plain deposits (Qr) occur in the central and western part of the sheet, as well as flanking the areas of ranges. They are easily distinguished by the presence of a grooved pattern in the mulga woodland that inhabits them (eg, Wakelin-King 1999). Investigations elsewhere in central Australia show these areas consist of a sandy clay loam in places with a thin sandy veneer. The groving in the mulga indicates sheetflow, with confined drainage being largely absent. These plains represent a modified palaeo-surface and may not have formed entirely through the colluvial processes that shape them today. Conceivably they were once widespread plains with a dominantly lateritic surface and well developed drainage system, as is the case in many parts of central Australia.

Alluvial deposits (Qa) are confined to stream bed and overbank areas along the major drainages and proximal outwash deposits from hills and ranges. Stream profiles are wide and shallow, with coarse sandy, gravelly to pebbly material. The overbank material is composed of fine sand and clay.
Calcrete (Qc) is probably much more widespread than indicated on the map, as in many areas it is obscured by sand or occurs as shallow subcrop. It forms as a precipitate from groundwater, but may also be spatially associated with calcium-bearing basement rocks. The deposits consist of fine grained to amorphous calcite, with some larger grains in veins or patches. Veins of chaledony are common. Electron spin resonance dating of calcretes in AYERS ROCK (Jacobsen et al 1988) identified two ages of calcrete development— an older phase (34,000-75,000 ybp) that was largely associated with the extensive Lake Amadeus playa system, and a later phase (22,000-27,000 ybp) that developed above the water table by the upwards movement of water through the soil profile. Calcrete in PETERMANN RANGES is probably the latter type, with the possible exception of the area around playas in the south.

Playa deposits (Qp) are largely concentrated in the broad band of scattered playas in the southern part of the sheet. They are interpreted to be the remnant surface expression of an ancestral drainage system that has ceased to function in the drier climatic conditions associated with the influx of aeolian sand. The playa surfaces consist of fine clay, which may have a minor evaporite component. This clay surface is largely impermeable, supports no vegetation and exhibits a cracked and desiccated surface.

**STRUCTURAL GEOLOGY**

The Musgravian Block on PETERMANN RANGES has been dissected by a number of major structures during the Petermann Orogeny, most notably the Woodroffe Thrust, resulting in the juxtaposition of different crustal levels which have undergone distinctly different structural histories. The region is divided into three structural domains for the purpose of describing the structural evolution.

**SOUTH OF THE WOODROFFE THRUST**

**MUSGRAVIAN EVENT**

Data on the orientation and significance of the Musgravian fabrics is sparse, due to reworking by subsequent deformation. However, a granulite facies gneissic fabric, defined by compositional layering with parallel leucosomes is locally preserved. In the eastern Mann Ranges south of the Mt Charles Thrust, the gneissic layering dips at 45-60° northeast, whilst in outcrops near Surveyor Generals Corner it dips at 65-70° east-southeast. No mineral lines are preserved related to this fabric. Elsewhere the Musgravian gneissic fabric has been tightly folded and transposed into fabrics which developed during the subsequent Petermann Orogeny.

**PETERMANN OROGENY**

**Deep crustal mylonitic fabrics**

The Musgravian gneiss, along with post-Musgravian granites and mafic dykes have been extensively reworked by deep crustal mylonitic strain. This deformation resulted in numerous overprinting mylonitic fabrics and localised mylonite zones which nonetheless are interpreted to have developed during progressive non-coaxial strain.

The degree of non-coaxial strain associated with the mylonitic fabrics is variable, with localised intensification into discrete anastomosing mylonite zones. The most intense deep crustal mylonite is the Mt Charles Thrust, which trends west along the northern edge of the eastern Mann Ranges and continues to the southwest into South Australia. This mylonite is 50-100 m wide, dips ~30° south and has an intense south-plunging lineation with a reverse sense of movement. Locally it is reworked by subsequent lower grade mylonites. Elsewhere deep crustal mylonite zones are narrower, and have intense mylonitic folding parallel to a strong quartz stretching lineation. The fabrics are defined by grain size reduction with recrystallisation of mafic minerals to fine grained aggregates containing garnet, clinopyroxene and biotite, which are elongated in the lineation (Figure 21). The mylonitic fabrics are folded by south-plunging open folds.

Lineation directions associated with the mylonitic fabrics are variable, and are summarised in stereonets in Figure 22.

In the eastern Mann Ranges, stretching lineations are always south-plunging and are associated with mylonitic fabrics which are typically southeast to south dipping with a reverse sense of movement. In the western Mann Ranges the lineations alternate on a kilometre scale between west-southwest plunging orientations and less abundant south plunging orientations, on fabrics which vary from southwest to southeast dipping. North of the Mann Ranges, around Umujju outstation, stretching lineations related to deep crustal mylonitic fabrics plunge east-northeast along northeast dipping planar fabrics.

Few timing relationships are evident between fabrics, although on Mt Le Hunte a pervasive high strain fabric with a shallow east-plunging lineation is overprinted by a later mylonitic fabric with a south plunging lineation. More commonly however, discrete domains occur in which the lineation is either south plunging or shallowly west-southwest plunging, implying that deformation may have been partitioned between dip-slip and strike-slip movement.

**Migmatitic shear zones**

The deep crustal mylonitic fabrics are locally overprinted by shear zones containing deformed leucosomes with coarse garnet and hornblende. These shear zones truncate the regional mylonitic fabrics, and have a broadly east-west trending mineral lineation. They occur throughout the Mann Ranges, but are more abundant to the north, particularly east of Umujju outstation and in the vicinity of ‘Harrys Rockhole’ (ES205634). The migmatitic shear zones have gradational contacts into less deformed variably mylonitic granite with
no leucosomes, and represent the only zones of significant partial melting associated with the Petermann Orogeny south of the Woodroffe Thrust.

The migmatitic shear zones have a complex structural history due to inferred progressive non-coaxial strain. Migmatitic layering with hornblende-bearing leucosomes is often reworked by melt-bearing shear bands, and then isoclinally folded with a biotite-rich axial planar fabric. However, due to the mylonitic nature of this deformation, no regionally consistent structural sequence is recognisable within these zones. The migmatitic shear zones are in places reworked by later mylonitisation defined by biotite-hornblende-titanite assemblages, in which mafic rocks are boudinaged, leucosomes are strongly attenuated and coarse porphyroclasts of hornblende, garnet and feldspar are preserved.

Migmatitic shear zones are well exposed on the northern and western flanks of Mt Cockburn (the Cockburn Shear Zone) and in the valley to the south of Mt Le Hunte (the Le Hunte Shear Zone). In both zones the migmatitic fabric has been reworked by subsequent mylonitisation. The Cockburn Shear Zone is 50-100 m wide, dips shallowly west to southwest and has a west-southwest plunging biotite and quartz stretching lineation with a reverse sense of movement. The Le Hunte Shear Zone is up to 200 m wide, dips ~50° north, and has a strike-slip lineation with rare kinematic indicators suggesting a sinistral sense of movement. A similar shear zone occurs on the northern edge of the Mt Le Hunte massif, but dips south. The observed kinematics on these zones is generally related to the intense mylonitic fabric which overprints the migmatisation.

In the Harrys Rockhole region, migmatitic layering is locally well preserved, and dips shallowly east. This layering is overprinted by a near-vertical, east-trending mylonitic fabric, resulting in an east-plunging intersection lineation. Elsewhere in this region migmatitic layering is folded and transposed into the second fabric.

Retrograde shear zones and pseudotachylite zones

Retrograde lower to middle amphibolite facies shear zones locally overprint the high grade mylonitic and migmatitic fabrics throughout the region, but are particularly abundant 15 km east of Puka outstation. Here they dip east to southeast with a south-plunging lineation. Kinematic indicators on these shear zones are rare and inconsistent.

Pseudotachylite occurs sporadically through the Mann Ranges, particularly within Musgavrian granulite, but is only abundant in a hill at ES124296, where it comprises up to 10% of the rock and is related to low grade ultramylonite with a southwest plunging lineation. This pseudotachylite zone is likely to be related to the Mann Fault, which occurs immediately to the south. The degree and sense of movement on the Mann Fault is not well constrained. Lambeck et al (1988) considered it to be a steep thrust, but more recently Major and Conor (1993) and Stewart (1997) suggested a normal sense of movement, with a dextral strike-slip component.

NORTH OF THE WOODROFFE THRUST

OLIA STRUCTURAL DOMAIN

Introduction

The Olia Structural Domain encompasses the Olia Chain, and includes outliers of Dean Quartzite at Foster Cliff, Butler Dome, Stevenson Peak and Katamala Cone. This structural domain is characterised by thin-skinned deformation of the Mesoproterozoic Mantarurr Granite Suite and Neoproterozoic Dean Quartzite and Pinyinna beds of the basal Amadeus Basin sequence. Restricted areas of quartzofeldspathic amphibolite facies gneiss, with a protolith age of 1580 Ma, outcrop in the southern regions of this domain and preserve deformation fabrics from both the 1200 Ma Musgavrian Event and the 550 Ma Petermann Orogeny. The 1170 Ma Mantarurr Granite Suite and the Neoproterozoic Amadeus Basin sediments
exhibit a pervasive foliation and a series of folding events that result from progressive deformation during the Petermann Orogeny.

**Musgravian Event**

Compositional layering developed during the 1200 Ma Musgravian Event is preserved as migmatitic gneissic layering in the Mesoproterozoic amphibolite facies gneiss. SHRIMP U-Pb dating of metamorphic rims on zircons within the early gneiss produce an age of 1176 ± 40 Ma. An early diffuse compositional banding is locally present in the Mantarurr Granite Suite, preserved in zones of less intense deformation of the Petermann Orogeny (Figure 23). This diffuse layering probably represents deformation during waning stages of the Musgravian Event.

**Petermann Orogeny**

Within the granitic and gneissic basement, deformation during the Petermann Orogeny produced a pervasive, shallowly dipping planar fabric with a strongly developed, south-plunging stretching lineation. Thin-skinned, north vergent tectonics involving macro-scale, basement-cored isoclinal folding dominate the basement/cover interactions in the Olia Domain.

Biotite foliation is pervasively developed throughout the Mantarurr Granite Suite, and overprints the compositional layering of the amphibolite gneiss. This foliation trends northeast in the Foster Cliff region, but changes in orientation to trend northwest in the Stevenson Peak area. Intensity of fabric development varies throughout this structural domain with local high strain zones and bounds of low strain that may preserve an earlier, possibly Musgravian, fabric. Amphibolite dykes of the Amata Dyke Swarm are boudinaged within the foliation. South of Stevenson Peak, the biotite foliation is folded about an upright, north trending axial plane.

A stretching lineation, defined by elongated quartz and biotite, changes orientation across the structural domain, from a shallow southwest plunge in the Foster Cliff region to southeast in the Stevenson Peak area.

The first stage of deformation of the basal Amadeus Basin sequence during the Petermann Orogeny resulted in basement-cored, north-directed, recumbent isoclinal folding (F, Figure 24). As a result, an axial planar foliation defined by muscovite is developed parallel to bedding within the Dean Quartzite, and bedding is locally overturned. A strong stretching lineation, defined by elongation of quartz, is developed on the bedding/foliation surface, and has the same orientation as lineation in the basement. At the contact with basement granites, the base of the Dean Quartzite is consistently sheared into a quartz-muscovite schist that probably developed as a slippage zone during the first stage of deformation. This contact shear zone varies in width from
20 cm to 1.5 m, and contains abundant layer-parallel quartz veins. Basement-cored isoclinal folds invariably close to the north, whilst folds cored by Pinyinna beds close to the south. This geometry implies deformation was north-vergent.

The $S_1/S_2$ surface is deformed by tight asymmetric folds with moderately east-dipping axial planes ($F_3$; Figure 25). There is a weak axial planar $S_3$ fabric, which is rarely present in the Dean Quartzite, but more commonly observed in the Pinyinna beds and granitic basement. Where measured, the $S_3$ fabric is at a low angle to the $S_1$ fabric. An intersection lineation is well developed on the $S_1/S_2$ surface, and plunges shallowly to the northeast or southwest in the Butler Dome region (Figure 26). The asymmetry of the folds, and the orientation of the intersection lineation suggest tectonic transport from the east-southeast.

The $F_3$ folds are locally overprinted by north trending open upright folds ($F_4$), which are best developed around Butler Dome. These may be the same generation as upright folds in basement south of Stevenson Peak. They may represent a less intense phase of the $D_4$ deformation. Subsequent east trending warping ($F_5$) resulted in plunge reversals of earlier folds. Similar warping in Ordovician sediments to the north suggests that $F_5$ may be associated with the 400-300 Ma Alice Springs Orogeny.

POTTOYU STRUCTURAL DOMAIN

Introduction

The Pottoyu Domain comprises all regions north of the Woodroffe Thrust on PETERMANN RANGES with the exception of the Olia Chain region, and affects the Pottoyu Granite Suite and basal units of the Amadeus Basin. The domain contains the Pilkari and Wankari Detachment Zones, which formed during north-directed movement during the Petermann Orogeny. No Musgravian structures are identified in the Pottoyu Domain.
Piltardi Detachment Zone

The dominant structural feature north of the Woodroffe Thrust is the Piltardi Detachment Zone (PDZ), a 2-5 km wide north-dipping zone of interleaved basement and basal Amadeus Basin sediments involving intense mylonitisation. The PDZ is best exposed in the region north of Mt Phillips (Figure 27) and west of Chirside Creek. To the south of the PDZ, Dean Quartzite and Pinyinna beds (and locally the Bloods Range beds) conformably overlie the Pottouy Granite (for example at Mt Fagan and Mt Phillips). These basal Amadeus Basin sediments are structurally over lain by north-dipping mylonite zones which interleave granite, Dean Quartzite and Pinyinna beds. In packages between mylonite zones, there are isoclinal folds of Dean Quartzite cored by Pinyinna beds. However, on a large scale these inter-mylonite packages preserve a right way up sequence in which granite is over lain by quartzite.

At Mt Phillips and Mt McCulloch, the sequence structurally underlying the Piltardi Detachment Zone is dissected by south-dipping faults, which thrust Pottouy Granite over the basal Amadeus sediments. These thrusts postdate the PDZ. High strain zones immediately south of the PDZ (eg. ET345311) have a south-plunging lineation and a reverse sense of movement.

The kinematic indicators within the PDZ mylonite zones show a consistent north down (apparent normal) sense of movement (Figure 28) parallel to a north-plunging stretching lineation. However, the mylonites consistently juxtapose older units to the north against younger units to the south, which is not consistent with a normal sense of movement. This can be attributed to the rotation of north-directed, originally south-dipping thrusts within the PDZ into a north-dipping orientation, probably due to undercutting of the PDZ by subsequent north-directed thrusting and duplexing within the basement.

Overlying the PDZ is a basement slab, which on PETERMANN RANGES largely comprises Pottouy Granite, and which was carried north by the PDZ over basal Amadeus sediments. Immediately north of the PDZ, the slab is strongly foliated, whilst further south is an L-tectonite with a strongly developed, shallowly plunging, N-S stretching lineation. Forman (1966a) recognised the existence of a major north-verging structure and termed it the Petersmann Nappe Structure. However, unlike the recumbent fold proposed by Forman (1966a) the structure is more likely to represent a thrust nappe, in which the basement has been transported north along the detachment without forming an overturned lower limb. This interpretation is supported by the consistent right way up of
Figure 26  Detailed structural map of Butler Dome
the stratigraphy within the nappe to the north on BLOODS RANGE (Close et al in prep).

Numerous smaller detachments occur within the basement nappe. North of Puta Puta outstation on PETERMANN (ET652321), a ridge of Dean Quartzite within the nappe has undergone intense deformation, with kinematic indicators consistent with north over south sense of movement. This is likely to represent a backthrust formed during the largely north-vergent deformation.

Wankari Detachment Zone

The Wankari Detachment Zone (WDZ) is a major south-dipping structure which occurs along the southern side of the Pottoy Hills, broadly parallel with the PDZ. The best exposures of the WDZ occur in the region around Wankari outstation and in exposures extending 10 km east. In this region, Pottoy Granite structurally overlies a region of interleaved Bloods Range beds and Dean Quartzite with minor volcanics. As in the PDZ, packages between mylonite zones largely preserve a right way up stratigraphy. The mylonites within the WDZ in this region contain a shallowly southeast plunging mineral lineation, and kinematic indicators suggest dextral-reverse sense of movement. Intensity of deformation increases east, with the sediments wedging out 10 km east of Wankari.

The extension of the WDZ through eastern POTTOYU and PETERMANN is a broad zone of high strain and migmatisation accompanying strike-slip deformation. This zone is best exposed in the region of Alyapa outstation on southeastern
plunging axis, with the northern limb continuing along Dean Range. This folding of the WDZ is likely to be related to the same deformation which rotated the PDZ into north-dipping orientation. In the Curdie Range deformation is restricted to minor repetition within the Dean Quartzite. Near Mt Deering on SCOTT, well exposed sections of the WDZ show duplexing of Dean Quartzite and Bloods Range beds with multiple repetitions of the sequence.

SYNTHESIS OF STRUCTURAL EVOLUTION DURING THE PETERMANN OROGENY

A lack of precise chronological constraints on fabrics within the different structural domains makes correlation of structures difficult. However, a possible evolution of PETERMANN RANGES during the Petermann Orogeny is as follows:

1) Early thin skinned deformation

The relatively thin-skinned north-vergent deformation in the Olla Chain, with isoclinal folding of the basal Amadeus sequence, is a relatively early phase of the Petermann Orogeny. The structural trends of this event appear to be truncated by the PDZ, suggesting that this may have predated the major movement on the PDZ.

2) Nappe development

Transport of a large basement nappe northwards along the PDZ probably occurred synchronously with the development of the deep crustal mylonitic fabrics in the Mann Ranges. Shear zones in the Mann Ranges such as the Mt Charles Thrust may represent the deep crustal root zone of the PDZ. The WDZ is likely to be closely related to, and possibly an extension of, the PDZ.

3) West-vergent compression

Abundant asymmetric west-northwest verging folds in the Olla Chain indicate an apparent change in vergence direction during the Petermann Orogeny. The north-trending upright folding which overprints the regional fabrics elsewhere, particularly in the Mann Ranges, may be related to the same event. The timing of this movement is poorly constrained.

4) Late thrusts, Woodroffe Thrust

A resumption of north-directed thrusting movement late in the Petermann Orogeny led to rotation of the PDZ into a north-dipping orientation. Large scale movement on the Woodroffe Thrust led to the exhumation of the deep crustal terrain to the south, and the formation of retrograde shear zones.

METAMORPHISM

Current evidence indicates that two major metamorphic events affected the Musgrave Block on PETERMANN RANGES. The first event involved medium pressure granulite to amphibolite facies metamorphism associated with the Musgravian Event. This was overprinted by the second event associated with pervasive mylonitic fabrics which developed at deeper crustal levels. More detailed descriptions of the metamorphism can be found in Squirrell and Close (1999). A summary of the metamorphic evolution of the Mann Ranges is shown in Figure 29. The Woodroffe Thrust separates regions which were metamorphosed at significantly different grades, and therefore the regions on either side of the thrust will be described separately.
SOUTH OF THE WOODROFFE THRUST

GRANULITE FACIES METAMORPHISM (MUSGRAVIAN EVENT)

Regional granulite facies metamorphism and development of gneissic fabrics occurred at 1200-1170 Ma. However, few metamorphic assemblages or reaction textures are preserved, and the pressure-temperature evolution during this event is not well constrained. The absence of garnet within mafic granulite suggests that peak metamorphism at >700°C occurred at pressures of less than 8-10 kbars. In the nearby Tomkinson Ranges in South Australia, Clarke et al. (1995) obtained P-T estimates of ~750°C and 5 ± 1 kbar for this event whilst in the Musgrave Ranges, peak granulite facies occurred at 750-800°C and 9 ± 1 kbar (A. Camacho pers. comm. 1996).

Evidence for the evolution following the peak of metamorphism is contained within garnet-bearing felsic gneisses from the eastern Mann Ranges, in which large garnets are partially consumed by coronas and symplectites of plagioclase and orthopyroxene (Figure 30). These textures have also been described in the Tomkinson Ranges by Clarke et al. (1995a), and this reaction is generally considered to represent isothermal decompression following peak metamorphism (Harley 1989). These textures probably developed at ~5 kbars and 700-770°C, and may be interpreted in two ways:

1. Near-isothermal decompression from peak conditions of ~8 kbars at 1200-1170 Ma.

2. A second high-temperature, lower-pressure event, associated with the Giles Complex and associated granites at 1080-1060 Ma.

Due to the lack of evidence of granulite facies metamorphism affecting the Alcurra Dyke Swarm and Angatja Granite, scenario 1 is preferred. Clarke et al. (1995a) proposed that during a metamorphic event at 1080-1060 Ma, pressures in the Tomkinson Range were around 11 kbars. However, no evidence for granulite metamorphism of this age occurs on PETERMANN RANGES.

PETERMANN OROGENY

A second major metamorphic event affected the Mann Ranges and Umuntu region during the Petermann Orogeny and was associated with development of widespread pervasive mylonitic fabrics. A summary of P-T estimates for assemblages associated with this event is given in Figure 31.

The mylonitic fabrics in the Mann Ranges form part of the highest pressure metamorphic terrane documented in Australia. Partial breakdown of plagioclase to garnet and kyanite indicates that these rocks were metamorphosed at conditions approaching eclogite facies. Although some authors (Ellis and Maboko 1991, Camacho et al. 1997) consider metamorphism reached eclogite facies, the presence of plagioclase and absence of omphacite in mafic rocks precludes a true eclogite regime. The Petermann Orogeny metamorphism in Mann Ranges is considered to be high pressure granulite facies (garnet granulite facies), decreasing to high pressure garnet amphibolite facies to the north in the Umuntu region.

Many mafic dykes, particularly within the western half of the Mann Ranges, have recrystallised within the mylonitic fabric to an assemblage of garnet, clinopyroxene, hornblende, sodic plagioclase, quartz and rutile, with or without scapolite. These assemblages consistently give P-T estimates of 11-13 kbars and 700-750°C. Within the Mt Charles Thrust and other mylonites in the eastern Mann Ranges, P-T estimates are also 11-13 kbars and 700°C. A recrystallised mafic dyke in a boudin within a mylonite zone on the South Australian border south of Waluytjatjata outstation gives higher estimates of 13-15 kbars and 770°C.

Most of the mylonitic fabrics in the Mann Ranges contain clinopyroxene and have no associated partial melting. However, in the Cockburn Shear Zone, and similar mylonites near Mt Le Hunte, abundant partial melting has occurred within the Waluytjatjata Granite, associated with the development of relatively hydrous hornblende-garnet-biotite bearing assemblages. Mafic dykes within the mylonite zones have also undergone partial melting during the high pressure metamorphism. Leucosomes contain coarse hornblende, and
are confined to the high strain zones. Localisation of partial melting can be attributed to the focussing of hydrous fluids along discrete mylonite zones, as temperatures during metamorphism (700-750°C) exceeded the water saturated solidus for both granitic and basaltic bulk compositions. **Figure 32** shows the initiation of partial melting with increasing strain into one of these migmatitic shear zones.

North of the Mann Ranges, in the Mantapayika Granite, there is an increase in frequency and extent of migmatitic high strain zones, resulting in development of extensive high pressure amphibolite gneiss containing biotite, hornblende, garnet, quartz, feldspar, ilmenite and titanite. In lower strain zones, granitic texture is preserved and there is no partial melting. The transition between moderately strained granite and leucosome-bearing gneiss can occur abruptly over only 1 or 2 m. Recrystallised mafic dykes in this region contain titanite rather than rutile, and give lower pressure estimates of 9-10 kbars and poorly constrained temperature estimates of around 700°C.

High pressure assemblages are locally overprinted by later mylonite zones of progressively lower metamorphic grade, from biotite-hornblende amphibolite facies to biotite-muscovite greenschist facies. Within the Mt Charles Thrust, mylonites which equilibrated at 12 kbars and 720°C reactivated with the formation of secondary garnet-hornblende assemblages at 10 kbars and 700°C. Garnet-biotite-muscovite bearing felsic mylonite from the eastern Mann Ranges at FS041244 formed at conditions of 7 kbars and 660°C. These estimates are interpreted to reflect near-isothermal decompression from 12 kbars due to rapid exhumation of the terrain along south dipping thrusts such as the Woodroffe Thrust.

**NORTH OF THE WOODROFFE THRUST**

**MUSGRAVIAN EVENT**

The terrain north of the Woodroffe Thrust is dominated by granite which intruded during or after the Musgravian Event.
Therefore the only evidence for the metamorphic evolution during this event is in amphibolite facies gneiss south of Foster Cliff. This gneiss is strongly overprinted by Petermann Orogeny fabrics so the original mineralogy is unclear. The existence of partial melts suggests metamorphism was at least upper amphibolite facies. This is consistent with observations in the Musgrave Ranges by Muboko (1988) of temperatures of 650°C in gneiss north of the Woodroffe Thrust.

**PETERMANN OROGENY**

A pervasive Petermann Orogeny fabric occurs north of the Woodroffe Thrust where metamorphic grade decreases to the north, and isograds are subparallel to the thrust. In outcrops immediately south of the Pottorup Hills, granite has undergone partial melting and contains a gneissic fabric and coarse hornblende. Some mafic dykes contain garnet. An assemblage garnet-hornblende-plagioclase-quartz in a recrystallised mafic dyke 8 km northwest of Alyapa outstation formed at 635°C at 6.5 kbars (medium pressure amphibolite facies), almost equivalent to the water saturated granite solidosites. At Butler Dome, just to the north of the zone of partial melting, a similar assemblage gives slightly lower P-T estimates of 610°C at 6.3 kbars.

Occurrence of kyanite within Dean Quartzite in the Petermann Ranges and Olia Chain, and within Bloods Range Beds at Mt Berreaux, suggest amphibolite facies conditions. Kyanite-biotite-muscovite schist and hornblende amphibolite within the Pilakati Detachment Zone imply middle to lower amphibolite conditions. Mineral assemblages are not appropriate for precise P-T calculations but assuming temperature in excess of 500°C, the presence of kyanite suggests the Dean Quartzite in these regions was buried to pressures greater than 4 kbars (or ~15 km depth) during the Petermann Orogeny.

**GEOCHEMISTRY**

**MAFIC DYKES**

Whole-rock geochemical data are available on 14 dolerite dykes from PETERMANN RANGES. All dykes are tholeiitic. They have high MgO and moderately high Cr contents (although Mg²⁺ values [Mg/(Mg + 2Fe)] are ≤0.54) and they are magnesian tholeiites (Figure 33). They fall predominantly in the oceanic field on the TiO₂-K₂O-P₂O₅ discrimination plot of Pearce et al. (1975) and in the ocean floor basalt field on a Pearce and Cann (1973) plot. Duncan (1987) noted a similar mis-assignment of continental flood basalts from the Karoo province. Normative mineralogy, calculated using an Fe₂O₃ /
FeO ratio of 0.2 for each sample, shows the majority of samples are hypersthene and olivine normative and therefore fall in the undersaturated, olivine tholeite field of Yoder and Tilley's (1962) basalt tetrahedron. The majority of the analysed dykes can be divided into two groups (Amata and Alcura dykes) on the basis of geochemical characteristics, in particular:

- Flat versus LREE-enriched, chondrite-normalised REE patterns (Figure 34);
- HFSE ratios, e.g., Y/Nb and Zr/Nb;
- LILE/HFSE ratios (e.g., Ba/Zr and K/Zr). The Amata dykes have Ba/Zr ≤ 2.2, and the Alcura dykes ≥ 2.8; similarly the Amata dykes have K/Zr ≤ 54, and the Alcura dykes ≥ 58. Correspondingly they have distinct chondrite (and primordial mantle) normalised patterns (Figures 35a-b).

These two groups correspond closely geochemically with the Alcura and Amata dyke swarms described by Zhao and McCulloch (1993a) and Gilikson et al (1996). Not all samples fall neatly into one of these two groups, and several dykes have anomalous geochemical characteristics by comparison with these two swarms. The majority of these have more affinities with the Alcura dyke swarm, largely evident through their LILE/HFSE ratios. These dykes may represent a slightly different suite possibly analogous to the 1000 Ma Type C mafic dykes of Sheraton and Sun (1995). Sm/Nd isotopic data on two representative samples from the Amata dyke swarm and two samples (in duplicate) from the Alcura dyke swarm suggest that the two groups can also be distinguished by their εNd(T) values. The Alcura dykes have low negative εNd at 1080 Ma with values from +0.1 to −1.3 and the Amata dykes have positive εNd at 800 Ma with values of +3.1 and +4.9.

**Rare earth element geochemistry**

The Alcura dykes are characterised by LREE-enriched chondrite-normalised REE patterns with positive Eu anomalies (Eu/Eu* 1.3-2.6). These patterns show a smooth slope from heavy to light REE; (La/Yb)₉, 1.7-4.2, (La/Sm)₉, 1.2-3.6 and (Gd/Yb)₉, 0.6-1.6. The 820 Ma Amata dykes have essentially flat REE patterns although in detail they range from slightly LREE-depleted to slightly LREE-enriched; (La/Yb)₉, 0.8 to 1.7. These patterns are very comparable with MORB. These dykes have small, positive Eu anomalies.

**Sm-Nd and Rb-Sr isotopes**

εNd values indicate that the source for the Alcura dykes falls on the mantle array. The source is probably comparable with that of ocean island basalt. In contrast εNd for the Amata dykes are close to that of CHUR (chondritic uniform reservoir), or slightly enriched. The relationship between ⁸⁷Sr/⁸⁶Sr and SiO₂ suggests that heterogeneous sources are certainly possible although the paucity of data precludes distinguishing between source heterogeneity and assimilation fractional crystallisation (AFC) with any certainty.
Chondrite and primordial mantle-normalised spidergrams

Normalised against chondrite, incompatible element abundances in the Amata dykes (Figure 35a) have essentially flat, to slightly depleted mobile element patterns and K is markedly anomalous. These patterns are similar to those of oceanic plateau basalt (Saunders et al 1992). In contrast the Alcurra dykes show mobile element enrichment (Figure 35b), with K and Rb particularly enriched by comparison with Ba and Th. Sr shows a slight positive anomaly in both suites of dykes. The geochemically ambiguous (1000 Ma?) dykes again show close affinities with the Alcurra dykes.

Primordial mantle-normalised element plots for all dykes on PETERMANN RANGES show negative Nb anomalies, together with slight, negative P and Ti anomalies. These characteristics are considered a typical 'continental' signature (Tarney 1994; Martin 1994). Zr/Nb and Y/Nb ratios are lower in the Alcurra dykes than the Amata dykes, due primarily to variations in Nb content. The younger, Amata dykes, have much flatter patterns than the Alcurra dykes which tend to be slightly concave upward.

Partial melting versus fractional crystallisation

The modal mineralogy of both Alcurra and Amata dykes includes plagioclase + orthopyroxene + clinopyroxene; Amata dykes also have olivine and magnetite, and Alcurra dykes have ilmenite. Variation between Al$_2$O$_3$, TiO$_2$, MgO and CaO (Figure 36) indicate that neither fractionation nor accumulation of plagioclase, olivine or calcic-pyroxene are a major cause of variation within either Amata or Alcurra dykes. Similarly, Amata and Alcurra dykes are not apparently related to one another by fractionation or accumulation. In contrast

Figure 34  Chondrite-normalised rare earth element plot for mafic dykes from PETERMANN RANGES. Normalising values from Sun and McDonough (1989)

Figure 35a and b  Incompatible element composition of mafic dykes from PETERMANN RANGES normalised against the chondritic values of Thompson et al (1984), except Rb, K and P from Sun (1980); and the primordial mantle values of Wood et al (1979)
Sr/Ce versus Ce suggests plagioclase fractionation may be a factor in the evolution of both suites of dykes.

Conclusions

Alcurra Dyke Swarm Geochemical evidence suggests that the 1080 Ma Alcurra dyke swarm can be attributed to a subcontinental lithospheric mantle source showing contamination by either subducted sediment or by slab-derived hydrous and siliceous fluids. This is consistent with the conclusions of Zhao and McCulloch (1993a) and Glikson et al. (1996). Whole rock Sm-Nd isochrons of the Alcurra dyke swarm give ages of c.1600 Ma (Zhao and McCulloch 1993b), suggesting that the subduction which resulted in the modification of the lithospheric mantle may have occurred during a major crust-forming event at this time. This is consistent with current evidence which suggests that the major subduction and crust-forming events in the region occurred at 1600-1550 Ma (eg, Zhao and McCulloch 1993b, Camacho and Fanning 1995).

Amata Dyke Swarm The 800 Ma Amata dykes may be attributed to an asthenospheric mantle source. Their Nb/La ratios are however surprisingly low for rocks attributed to such a source. Y/Nb and Zr/Nb ratios are consistent with this model. They are very comparable geochemically with the Rooi Rand dolerites associated with the final phases of the Karoo flood basalts, described by Duncan et al. (1990) as ‘MORB-related’. These authors note they have: (1) Positive εNd and negative εSr values (but with 87Sr/86Sr > N-type MORB magmas; (2) high Zr/Nb (15-44) and Y/Nb (2.7-14.5); and (3) slight LREE depletion in primitive examples. They favour either an asthenospheric mantle plume or simply the extension and separation of the lithosphere. A plume related setting for the Amata Dyke Swarm is favoured by Zhao et al. (1994). There is evidence that the Amata Dyke Swarm is a northern continuation of the extensive Gairdner Dyke Swarm in South Australia (Zhao et al. 1994, Wingate et al. 1998).

GRANITES

Whole-rock geochemical data are available on 78 felsic rocks from PETERMANN RANGES. On a total alkali-silica plot felsic intrusive rocks range from diorite to granite, and straddle the alkaline/subalkaline field boundary. The majority of the samples are subalkaline and are predominantly shoshonitic (ie, ultrapotassic) whilst some, like the Pottoyu Granite, are high-K calc-alkaline.

Upper continental crust (UCC) normalised plots (Figure 37) indicate three distinct geochemical signatures in PETERMANN RANGES granites:

(1) Pottoyu Suite A progressive increase from less to more incompatible element contents occurs within the Pottoyu Granite which also shows a variably negative Ba anomaly. This type of pattern compares with that of average unfractated I- and S-type felsic granites from the Lachlan Fold Belt (Chappell and White 1992, Slyvester 1994), except for the Ba anomaly. The chondrite-normalised REE pattern shows LREE enrichment and a negative Eu anomaly.

(2) Umutju Suite The UCC-normalised spiderplot for the Umutju Granite Suite is characterised by a convex-up pattern. This pattern, which is best exemplified by the Walytjatjata Granite, is characterised by a marked ‘deficit’ in Th, and a slightly less marked deficit in Rb and Y. K/Rb ratios remain comparable with those of the upper continental crust. Within this geochemical category there is a range from samples with pronounced ‘depletion’ in Th and Rb, marked negative Nb-anomalies and pronounced positive P anomalies to samples with only modest Rb and Th ‘depletion’, small negative Nb anomalies, and only slight positive P-anomalies. There is a corresponding range in TiO₂/Zr and P₂O₅/Zr ratios. There is similarly, a range from negative to positive Sr-anomalies, but predominantly more or less pronounced negative Sr anomalies. The Mantapuyika Granite is distinguishable from the rest.

Figure 36 Diagrams illustrating lack of fractional crystallisation as a major process controlling the chemistry of mafic dykes from PETERMANN RANGES. Mineral vectors from Wilson (1989) and N-MORB/MAR
bears some geochemical similarities to the Mantarurr Granite.

In addition to the three dominant granite types, the following less abundant types occur.

(4) **Y-depleted gneiss** Many of the 1600-1500 Ma gneisses (including the interlayered mafic and felsic gneiss (Bgn)) have similar UCC-normalised patterns to the Mantarurr Granite, with strong Y depletion, although they differ in that they are Th-depleted, and have HREE-depleted chondrite-normalised patterns with positive Eu anomalies. Chondrite-normalised REE plots for these gneisses and the three major granite types are shown in Figure 38.

(5) **Y-undepleted gneiss** A second group of the 1600-1500 Ma gneiss has convex-up patterns with no Y depletion and marked negative Sr anomalies. Marked Sr depletion is enigmatic as these rocks tend to have small positive Eu anomalies. However, the Sr anomaly on the UCC-normalised pattern appears to relate to Y depletion, with the more markedly Y-depleted gneiss having lower P content and correspondingly little or no negative Sr anomaly.

(6) **Syn-tectonic orthopyroxene granite** Whilst charnockite on southwestern COCKBURN appears similar in their mineralogy and relative timing to charnockite in adjacent regions of South Australia identified by Glikson et al (1996), it differs geochemically by having a strong negative Y anomaly and steep REE patterns with marked LREE enrichment.

(7) **1080-1040 Ma magmatic suite** The Angatja Granite has a convex-up UCC-normalised plot, with depletion in Th, Ba and Sr. They have relatively high Zr, Nb, Y and LREE compared to other granites suggesting A-type affinities (Collins et al 1982), and have slightly negative Eu anomalies. The volcanics on northwestern POTTOYU plot on the boundary between rhyolite and trachydacite on the TAS diagram of Le Maitre (1989), and also have strong A-type granite affinities, with very high Ga/Al, LREE and Y, and a strongly negative Eu anomaly.

**PETROGENETIC IMPLICATIONS OF GRANITE GEOCHEMISTRY**

**Pottoyu and Umutju Granite Suites**

The Umutju Granite Suite shows Y enrichment and Th, Sr, Rb and Ba depletion when normalised against the average Archaean grey gneiss (Figure 39). There is also depletion in Nb relative to the UCC which is a characteristic of the deep crust relative to the UCC. The Umutju Granite Suite may be consistent with a residuum which includes biotite and minor hornblende, but not garnet. Residual plagioclase must be reconciled with the slight positive Eu anomaly which not only precludes plagioclase as a major residual phase, but also monazite, apatite and allanite which might otherwise explain the Th-depleted character of the Walutyjattaja Granite. As residual phases these latter (minor) minerals would also tend to result in REE depletion and are therefore similarly
inconsistent with the data. Pyroxene as a residual phase may partially compensate for the removal of plagioclase (reflected by the marked negative Sr anomaly) which would otherwise result in a negative Eu anomaly. These geochemical characteristics of the Umutju Granite Suite are most readily reconciled with granulite or retrogressed granulite facies source in a continental crustal setting.

The Pottoyu Granite Suite shows negative P, Ti and Zr anomalies and very marked negative Ba and Sr anomalies when normalised against the lower continental crust. Correspondingly it shows a marked positive Th anomaly contrasting with the negative Th anomaly seen in the Walytjatjara Granite. These characteristics, together with a negative Eu anomaly are consistent with residual or fractionated plagioclase, apatite, titanite, and zircon but not hornblende.

The geochemistry of the Umutju and Pottoyu Granite Suites is consistent with generation through melting of hornblende and biotite tonalite (TTG) at 6 kbars and 975°C (cf. Skjerlie and Johnson 1993), although metamorphic data for the region at this time suggests melting must have occurred at deeper levels. The Umutju Granite Suite was probably derived from a retrogressed granulite facies LILE-depleted source. Melting may result in an orthopyroxene-bearing (granulite facies) residuum. The Pottoyu Granite Suite was probably derived from an amphibolite facies tonalitic source. The Umutju Granite Suite has uniformly sloping REE patterns, a slight positive Eu anomaly and high total REE contents, with no sign of depletion in LREE to match that of the LILE. These characteristics are probably compatible with low percentage partial melting of parental TTG which were derived from a source in which HREE were retained in the residuum by garnet. Thus, it is plausible that the Umutju Granite Suite may represent deeper crustal melting than that associated with the Pottoyu Granite Suite.

**Figure 38** Chondrite-normalised rare earth element plot for major granite suites on PETERMANN RANGES. Normalising values from Sun and McDonough (1979)

**Figure 39** Normalised spidergram plot showing the Umutju Granite Suite normalised against Archaean grey gneiss of Martin (1994). LG = Lewisian granite facies gneiss, date from Weaver and Tarnay (1980)

**Mantarurr Granite Suite and Y-depleted gneisses**

The Y-deficient, non-HREE-depleted nature of the Mantarurr Granite Suite may result from residual hornblende. There is good correlation between Y and Nb throughout the PETERMANN RANGES granites in general. This suggests that amphibole rather than garnet may control the Y-depleted characteristic; a probability which is further reinforced by the absence of high Tb/Yb ratios and Cr content which tends to characterise granite associated with residual garnet (Sylvester 1994). In contrast the Y-depleted gneiss has comparatively low Yb, and high (La/Yb), characteristics.
again most consistent with garnet-bearing source rocks. Syn-
tectonic charnockite is probably consistent with a similar
source, with a granulite facies residuum.

Precursors of granites

One sample of Y-depleted gneissic granite from Walal chaypan
(FFS273244) has a calculated εNd(0) of +5.3 which suggests
involvement of material derived from depleted mantle. This
εNd(0) was calculated from Sm and Nd trace element data
using the following equation, εNd(0) = 24.7 f_sinh(45) · T, where
f_sinh(45) = [(Sm/Nd)/0.317] - 1 (see Weaver and Tarney 1980,
DePaolo 1979). Otherwise the granites may be reconciled with
crustal source rocks. However, these precursor source rocks
were in turn derived from a spectrum of sources:

(1) Precursor, crustal source rocks for the Umutju granite
suite were probably derived from a subducting oceanic
slab in either the garnet-amphibolite or hornblende
eclogite facies (cf. Tarney and Weaver 1985, Martin
1994)

(2) The precursors to the Pottoy granite suite and Y-
ref列为 depleted gneiss were probably derived from the
lithospheric mantle wedge. In the case of the Pottoy
granite suite precursor, garnet was not a stable phase
in the residuum, whilst in the case of the precursors to the
Y-depleted gneisses it was.

(3) The Manturr Granite suite is consistent with
hornblende as a stable phase at the depth of melting at the
time the granite formed, rather than reflecting
specific petrogenetic circumstances of the precursor.

Generation of these various precursors allow certain insights
into the early geological history of this part of the crust.
However, the geochemical inferences outlined above suggest
that the granites are variously derived from lower to middle
crustal processes (TTG) some of which appear to have primary
LILE depletion indicating derivation from subducting oceanic
crust. Others were probably derived from the overlying mantle
wedge. εNd(T) values for a small number of granite samples
(Table 3) suggest substantial involvement of other crust in the
formation of the Manturr Granite suite and Angatja
Granite. An εNd(CHUR) of -1.68 at 1.18 Ga for a sample from
the Walytjatjara granite suggests either involvement of a
lesser amount of other crust, or that the recycled crustal
component is somewhat younger in age than that involved in
the generation of the Manturr Granite suite and the Angatja
Granite. An εNd(CHUR) of +1.91 at 1.6 Ga for sample B741
from amphibolite facies Musgranian gneiss (Egn.) is
consistent with involvement of material from a depleted
mantle source.

GEOCHRONOLOGY

Previous geochronological data on PETERMANN RANGES
are limited to two Rb-Sr isotopic analyses of the Pottoy
Granite suite presented by Forman (1972), which yielded total
rock ages of 1190 and 1150 Ma and biotite ages of 600 and
570 Ma. As part of NTGS mapping, geochronological data
has been obtained for 18 samples on PETERMANN
RANGES. A complete list of all geochronological data for
PETERMANN RANGES is given in Table 2 and Figure 40
shows the location of samples.

SHRIMP U-Pb Geochronology

SHRIMP U-Pb zircon geochronology has been undertaken
on nine felsic lithologies from PETERMANN RANGES, in
order to constrain the ages of granite intrusion and high grade
metamorphism. This data is summarised in Table 2 and is
presented in detail in Scrimgeour et al (in prep). Dating of
migmatitic zircon cores from Musgravian gneisses suggest that
these gneisses have protolith ages of 1600-1550 Ma.
In addition to magmatic zircons, metamorphic zircon rims were
analysed in a number of samples. The timing of the high-
grade Musgravian Event is constrained by metamorphic rims
dated 1170 ± 10 Ma in felsic granulite, 1176 ± 40 in
amphibolite facies gneiss south of Foster Cliff, and 1190 ± 35
in zircons presumed to be inherited in the Walal Granite.
In addition, zircons analysed from the Manturr Granite suite
have apparent metamorphic rims which have been interpreted
to reflect a metamorphic event that occurred within error of
the magmatic age of 1168 ± 14 Ma (Fanning pers. comm.
1998). Titanite from the same rock has been dated by SHRIMP
at 1165 ± 11 Ma.

New zircon growth associated with the Petermann
Orogeny is rare on PETERMANN RANGES. However, a
garnet-hornblende migmatite from the Mantapayika Granite
contains zircons which have metamorphic rims which grew
at 561 ± 11 Ma. The preferential growth of zircon in this
sample in comparison to other lithologies can be attributed
to partial melting accompanying high fluid flux. The only other
possible Petermann Orogeny zircon age comes from a single
high-U grain in the Pottoy Granite (sample P89/433) which
gave an age of ~610 Ma for one analysis.

Zircon inheritance is rare to absent in most samples dated
by SHRIMP from PETERMANN RANGES. An exception
is the Walal Granite which contains a population assumed to
be entirely inherited, with most grains having a core at
1595 ± 22 Ma except for a single older zircon dated at
~1660 Ma. Rare inherited zircons in the Manturr Granite
suite had cores at ~1590 Ma, whilst garnet-hornblende
migmatite from the Mantapayika Granite contained an
inherited grain of possible metamorphic origin, with a
minimum age of ~1380 Ma. An intermediate age grouping
at ~1500 Ma occurs in both the 1590 Ma amphibolite facies
gneiss and 1590 inherited Walal Granite zircons, but it is
uncertain whether this age represents a geologically significant
event or similar amounts of radiogenic Pb-loss during
Musgravian metamorphism.

Single Grain Pb-Pb Evaporation Dating

Zircons from seven samples from PETERMANN RANGES
were dated using the single zircon Pb-Pb ‘evaporation’ or
‘Kober’ technique (Kober 1986; 1987). In this method, zircon
grains are analysed in a series of incremental ‘heating steps’,
which allows for the resolution of isotopic heterogeneities in
the zircon. Whilst SHRIMP U-Pb analysis is a preferable
Figure 40 Map of PETERMANN RANGES showing all geochronological data. Dates in italics are interpreted to be metamorphic or cooling ages. Note that a Pb-Pb zircon evaporation date of 1041 ± 2 Ma, additional to a SHRIMP date of 1051 ± 22 Ma, was obtained for the Wankari volcanics (see Table 2).

method for precise geochronology of complex zircons, high resolution ages can be derived from simple magmatic zircons using the single zircon Pb-Pb evaporation technique (eg, Dougherty-Page and Foden 1996). The analyses were undertaken with a Finnigan MAT 261 mass spectrometer at the University of Adelaide. Six samples from the Umutju and Angatja suites were successfully analysed, and the results are presented in Table 2. A sample from Walal Granite was also analysed but contained complex inherited zircons with cores at 1590 Ma. All other samples had no inheritance with the exception of rare older cores in one sample of Mantapayika Granite.

Sm-Nd

Dating of garnet granulite assemblages in the mafic dykes from the Mann Ranges was undertaken using a Sm-Nd mineral isochron. The sample was a recrystallised mafic dyke of the Amata Dyke Swarm from north of the Mann Ranges (sample PR96HS532A, ES 909477) containing the equilibrium assemblage garnet-clinopyroxene-hornblende-plagioclase-quartz-titanite. The garnet-hornblende-whole rock mineral isochron for this sample yielded 494 ± 59 Ma with a MSWD of 0.049 (Figure 41). This age is within error of Sm-Nd mineral isochrons of the deep crustal mylonitic assemblages in the Musgrave Ranges which gave ages of 540 ± 39, 646 ± 110 and 535 ± 52 Ma (Camacho et al 1997). 

Nd, model ages, which is a measure of the approximate length of time a rock or its protolith has been separated from the mantle, yield predominantly Palaeoproterozoic ages for intrusive rocks on PETERMANN RANGES. Sm-Nd data for six granites from PETERMANN RANGES all yield model ages in the range 1.70 to 1.85 Ga (Table 3), which is very similar to the range of values obtained elsewhere in the Musgrave Block (1.7-1.9 Ga; McCulloch 1987). A sample of a 1000 Ma dyke from the eastern Mann Ranges gave a model age of 1.93 Ga, whilst a sample of the Alcurra Dyke Swarm from the same region gave a model age of 2.56 Ga.

K-Ar, Rb-Sr

K-Ar dating of muscovite from within strained Dean Quartzite was undertaken on two samples. Sample P89/1310 was from highly strained quartzite within the Pilgari Detachment Zone, northeast of Mt McCulloch (ET963086), and gave an age of 586 ± 5 Ma. Muscovite from a strained quartzite north of Puta Pata (ET652321), in which kinematic indicators suggest a north-over-south (reverse) sense of movement (ie, a possible backthrust), gave 568 ± 5 Ma. As growth of this muscovite is likely to have occurred under amphibolite facies conditions (T > ~500°C) and the closure temperature of the K-Ar system in muscovite is believed to be ~350°C (Dodson 1979) these ages are likely to represent cooling through the closure temperature, rather than crystallisation of the muscovite. These values are consistent with Rb-Sr dating of biotite from within the Potttoy Granite by Forman (1972), which yielded ages of 570 and 600 Ma. The closure temperature of Rb-Sr in
<table>
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<th>LOCATION</th>
<th>METHOD</th>
<th>AGE (Ma)</th>
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Legend:
- **Sm-Nd mineral isochron**
- **K-Ar hornblende**
- **K-Ar muscovite**
- **SHRIMP U-Pb zircon**
- **Pb-Pb zircon evaporation**
- **Rb-Sr**
- **Biotite**
- **Core**
- **Uncertain signif.**

---

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biotite is not precisely known, but various estimates including 300 ± 50°C (Jaeger 1979) and >400°C (Del Moro et al. 1982) suggest that biotite ages from the Pottouru Granite also represent cooling rather than crystallisation. Therefore the implication of this data is the Petermann Ranges and Pottouru Hills may have cooled through 350-400°C at 560-600 Ma. This age is significantly older than K-Ar ages of 520-550 Ma for muscovite in the Mulga Park region of AYERS ROCK (Camacho and Fanning 1995).

K-Ar dating was also performed on hornblende from within a leucosome from a migmatisic garnet-hornblende gneiss within the Mantapayika Granite adjacent to the Wingellina-Docker River road (ES203655). The age of 565 ± 9 Ma for this hornblende is within error of the SHRIMP U-Pb zircon metamorphic age of 561 ± 11 Ma for a similar gneiss 13 km to the east (ES335658).

**Summary of geochronological data**

The geochronological data presented in Table 2, are in close agreement with geochronology in the western Musgrave Block and Tomkinson Ranges summarised by Glikson et al. (1996), in the Musgrave Ranges (Camacho et al. 1997) and in the eastern Musgrave Block (Camacho and Fanning 1995). These data provide further compelling evidence that the terrains north and south of the Woodroffe Thrust represent different crustal levels of the same terrain (Camacho and Fanning 1995), rather than two previously unrelated terrains which were juxtaposed during the Petermann Orogeny (Maboko et al. 1992). The geochronological data constrains igneous activity on PETERMANN RANGES to three major time periods – 1600–1550 Ma; 1200–1120 Ma and 1080–1060 Ma, and constrains the two metamorphic events at 1200–1170 Ma and 600–530 Ma. The lack of zircon inheritance older than 1660 Ma, and the model ages of 1.7–1.9 Ga, support the notion that Archaean crust is not present beneath PETERMANN RANGES.

**GEOLOGICAL HISTORY**

The earliest geological event recognised on PETERMANN RANGES is a major crust-forming and magmatic episode at 1600–1550 Ma. Evidence from Nd model ages and inherited zircons suggest that there is no crust in the region older than 2.0 Ga. The nature and significance of the 1600–1550 Ma event is poorly understood, but geochemical evidence supports the notion that it was a subduction related crust-forming event. The timing of the deposition of the supracrustal volcanic-sedimentary sequence is poorly constrained but probably also related to this event, and the sediments were intruded by felsic igneous rocks and less abundant mafic intrusions. Most of these intrusions were emplaced at 1600–1550 Ma.

Granulite to amphibolite facies metamorphism with associated intense deformation occurred during a major event at 1200–1170 Ma. The tectonic setting of this event is not well understood, but it may form part of a much larger Grenville-age mobile belt, including the Albany-Fraser Province, which resulted from continental collision. In the granulite terrain, peak metamorphic conditions were probably around 6–9 kbars and 750–800°C. Prolonged heating of the lower and middle crust led to generation of voluminous post-orogenic granite, including the Umutju, Manturrur and Pottouru Granite Suites which intruded the middle and upper crust over the period 1190–1120 Ma.

In the granulite terrain, exhumation followed the peak of metamorphism, resulting in decompression to conditions of ~5 kbar and 700–750°C. The timing of this decompression is constrained to between approximately 1170–1070 Ma, and may represent isothermal decompression following peak metamorphism or a second granulite event following exhumation.

Emplacement of voluminous mafic and ultramafic magmas of the Giles Complex occurred at 1080 Ma in the southwest of PETERMANN RANGES. Dolerite dykes of the Alcurra Dyke Swarm intruded at a similar time. Intrusion of further granite, charnockite and rapakivi granite occurred in the interval 1080–1050 Ma. This was broadly synchronous with the extrusion of felsic and minor mafic volcanic rocks onto the exhumed and eroded Pottouru Granite. The volcanic rocks were overlain by gritty and pebbly quartz sandstone of the Bloods Range beds. This depositional event has been interpreted by some authors (eg, Lindsay and Korsch 1991) as a rift sequence involving bimodal volcanism and fluvial sedimentation, related to the initial opening of the Amadeus Basin. A second phase of dolerite intrusion probably occurred at 1000–970 Ma, with the intrusion of olivine dolerite in the Mann Ranges and coarse olivine gabbrro in the Pottouru Hills.

The time break between the deposition of the Bloods Range beds and overlying Dean Quartzite is unclear, but may be up to 200 million years, including a period of erosion. Widespread subsidence over much of central Australia (including PETERMANN RANGES) led to the deposition of fluvial to shallow marine quartz sandstone (Dean Quartzite), and as the basin deepened this quartz rich sedimentation was replaced by the deposition of marine siltstone and carbonate at c. 800 Ma (Pinyinna beds). At around the same time, intrusion of dolerite dykes and gabbrros of the Amata Dyke
<table>
<thead>
<tr>
<th>Sample No</th>
<th>PR96IRS714</th>
<th>PR96IRS741</th>
<th>PR96IRS747</th>
<th>PR96DFC535</th>
<th>P688/34</th>
<th>P89/433</th>
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<td>Amphibolite facies</td>
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<td>Anguia</td>
<td>Pottinuy</td>
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<tr>
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<td>52 564 550</td>
<td>52 635 500</td>
<td>52 633 625</td>
<td>52 619 081</td>
<td>52 588 300</td>
<td>52 566 350</td>
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<tr>
<td>Noathing</td>
<td>7 132 040</td>
<td>7 151 000</td>
<td>7 153 535</td>
<td>7 126 639</td>
<td>7 219 900</td>
<td>7 207 250</td>
</tr>
</tbody>
</table>

Nd ppm       85.330  56.900  70.080  80.990  79.05  63.31
143/144 Nd   0.511928  0.511827  0.511885  0.511929  0.511824  0.511959
2 sigma   0.000056  0.000050  0.000023  0.000061  0.000042  0.000063
SMDNd   0.1914  0.1824  0.1809  0.1833  0.1675  0.1872
147Sm/144Nd  0.1158  0.1103  0.1094  0.1139  0.1013  0.1132
143/144Nd ch  0.512638  0.512638  0.512638  0.512638  0.512638  0.512638
143/244Nd dep  0.531308  0.531308  0.531308  0.531308  0.531308  0.531308
T mofechur   1.34  1.43  1.37  1.30  1.3  1.24
T mod:dep   1.79  1.85  1.79  1.76  1.7  1.71
age (T)    1.175  1.6  1.181  1.071  1.19  1.14
143/144 (T)  0.511035  0.510666  0.511006  0.51128  0.51031  0.511161
143/144ch T  0.511121  0.510569  0.511113  0.51125  0.511161
eps Nd chT   -6.18  1.91  -2.08  -2.48  -1.32  -1.02
Sr87/86   0.750050  0.818641  0.755340  0.793026  0.793932  0.869833
2 sigma   0.000038  0.000065  0.000030  0.000066  0.000039  0.000044
Sr ppm    209.9  127.2  243.97  121.96  167.57  91.69
Rb ppm    178.37  218.57  222.66  226.45  228.39  250.26
Rb/87Sr  0.8498  1.7183  0.9127  1.8568  0.7357  0.3664
frac 87  1.216  1.224  1.216  1.221  1.221  1.220
at wtSr  87.614  87.609  87.614  87.611  87.611  87.606
87Rb/86Sr  2.469  5.025  2.653  5.417  3.9766  8.0221
87/86 (T)  0.708612  0.703155  0.710566  0.710015  0.726049  0.738451

Swarm occurred, probably associated with mantle plume activity.

Sedimentation occurred intermittently in the region during the Neoproterozoic, with the deposition of sandstones in a variable fluvial to marine environment (Inindia beds, not preserved on PETERMAN RANGES), followed by a later influx of clastic sands and silts in a fluvial to shallow marine environment (Winnall beds). Elsewhere disconformities separate the Pinyinna beds (Bitter Springs Formation equivalents), Inindia beds and Winnall beds, suggesting that intermittent tectonism or salt movement occurred during this period.

A major intracratonic orogenic event, the Petermann Orogeny, affected the region during the interval 580-520 Ma. This orogeny was associated with north-verging dextral oblique compression, and resulted in significant crustal shortening and thickening. No magmatism is associated with this event, and temperatures within the lower crust were not significantly perturbed from a stable continental geotherm, suggesting that high mantle heat flow could not have initiated deformation. However, elevated temperatures in the middle and upper crust during this event suggest that a heat source within the crust may have contributed to thermal weakening of the lithosphere. Deep crustal rocks at around 40 km depth underwent intense mylonitic deformation at high-pressure granulite facies conditions (12-13 kbars, 700-750°C), and discrete zones of fluid flow led to localised partial melting. At middle and upper crustal levels, the basal units of the Amadeus Basin sequence underwent intense isoclinal folding, thrusting and duplexing under kyanite-grade amphibolite facies conditions (6-7 kbars, 600-650°C), with some partitioning of strain occurring between the cover and basement. A large basement-cored nappe complex accommodated much of the north-directed transport along the Pilbara Detachment Zone. Further partitioning of the strain occurred between the Pinyinna beds and the overlying Inindia and Winnall beds, with the Pinyinna beds presumably acting as a décollement surface. The lower crustal rocks were rapidly exhumed along the north-verging Woodroffe Thrust late in the Petermann Orogeny. The occurrence of rocks at the present surface which were once at >40 km depth during the Petermann Orogeny implies that this event must have resulted in the development of significant topography. A thick sequence of conglomerate which fills the Mount Currie sub-basin probably represents proximal foreland deposits associated with this orogeny.

Erosion of mountains formed by the Petermann Orogeny was largely complete by the Ordovician, when quartz sands and minor silts were deposited in a shallow sea which extended across the northeastern part of PETERMAN RANGES.
Further tectonism occurred to the north in the Amadeus Basin during the Devonian-Carboniferous Alice Springs Orogeny, which led to tilting and gentle folding and possible minor reactivation of some Petermann Orogeny structures.

The occurrence of fluvo-glacial sediments, now largely preserved in Western Australia, suggests glaciation of the region during the Permian. The Cainozoic history of Petermann Ranges is dominated by erosion, and particularly since the end of the Pliocene, by steadily drying climatic conditions. The overall drying of the climate has occurred through cycles of drier (glacial) and wetter (interglacial) climatic periods linked to the expansion and contraction of the polar ice-caps. In central Australia in general, two periods of extensive deep weathering are known, the first at the end of the Cretaceous to early Palaeocene, and a later during the late Eocene. The earlier of the two periods resulted in widespread chemical weathering, the development of laterite profiles, with deep leaching in underlying paludal zones. Laterite preserved in the area probably relates to this cycle of weathering. The later Eocene phase largely affected sediments in Cainozoic basins, such as the Ayers Rock Basin (Ayers Rock). Associated with the earlier deep weathering cycle was the culmination of the widespread peenplanation of the region. By the early Cainozoic the landscape was generally subdued with extensive flat, laterised plains cut by shallow drainage, and broad, smooth profile uplands at the site of the present day higher ranges. At around 20 Ma, subsidence in the Lake Eyre region initiated a renewed cycle of erosion, steepening and sharpening the slopes of the uplands, incising drainage and stripping much of the lateritic plains. The bevelled crests on many of the modern upland areas, particularly in the Petermann Ranges, are a remnant of the older upland surface. Peak dry conditions occurred about 18,000 ybp, and coincided with the maximum expansion of the sand plains and dune fields. The slightly wetter climate of the present has resulted in the stabilisation of sand plains and dunes by vegetation, and caused some breaching of these aeolian features by reactivated drainage (eg, Armstrong Creek).

Geological interpretation

Magnetic data

The TMI image shows a distinct difference in the magnetic signature of the rocks on either side of the Woodroffe Thrust. The location of the Woodroffe Thrust itself is well defined apart from on Butler Dome, where its location is less clear.

South of the Woodroffe Thrust there is a complex magnetic response corresponding to deformed intrusions of the Umtutju Granite Complex and the Walal Granite. These granites have high amplitude responses (up to 500 nT). Magnetic trends can be traced and often form folded patterns.

North of the Woodroffe Thrust the magnetic character of the rocks is less complicated. A northwest trending package of magnetic rocks is a prominent feature in the magnetic data. This package corresponds to highly deformed Pottouy Granite associated with the Wankari Detachment Zone. In northern POTTUOY and regions north of the Pilardi Detachment Zone, where the Pottouy Granite is less deformed, it has a more discrete magnetic character.

The southern margin of the Mulyati Granite is bounded by the Woodroffe Thrust. The extent of the granite can easily be mapped from the magnetic data as it is not as deformed as the surrounding rocks. The Kulu Granite in eastern Petermann Ranges is a magnetic body with high frequency responses. The Foster Cliff Granite is a magnetic intrusion comprising curvilinear north-south trends.

An interpretation of the geophysical data of Petermann Ranges 1:250 000 and southern BLOODS RANGE 1:250 000 areas is presented by Slater (1999).

Gravity data

There is a major drop in gravity from south to north across the Woodroffe Thrust. This can be attributed to the relative proximity of lower crustal rocks to the surface south of the thrust, and also a potential offset of the Moho preserved from the Petermann Orogeny, as inferred for the Redbank Shear Zone of the Arunta Block by Beekman et al (1997).

In southwest Petermann Ranges a gravity high corresponds with the interpreted location of the Mann Fault. The gravity response is therefore largely due to the presence of the Giles Complex ultramafic bodies close to the surface which only occur to the south of the Mann Fault. It also may be partly attributable to an offset of the Moho along the Mann Fault, which was proposed elsewhere in the Musgrave Block by Lambeck and Burgess (1992).
Table 4 Specifications of the Petermann and Petermann East airborne surveys

<table>
<thead>
<tr>
<th></th>
<th>Petermann Survey</th>
<th>Petermann East Survey</th>
</tr>
</thead>
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<tr>
<td>Client</td>
<td>NT DME</td>
<td>NT DME</td>
</tr>
<tr>
<td>Contractor</td>
<td>Austrex International Ltd</td>
<td>Austrex International Ltd</td>
</tr>
<tr>
<td>Survey area</td>
<td>Cockburne, Duffield, Pottoyu, Petermann, Hull, Bloods Range 1:100 000 maps</td>
<td>Butler Dome, Olia Chain, Imbumbunna 1:100 000 maps</td>
</tr>
<tr>
<td>Date of survey</td>
<td>September-October 1985</td>
<td>September-October 1987</td>
</tr>
<tr>
<td>Kilometres flown</td>
<td>38 018 km</td>
<td>20 937 km</td>
</tr>
<tr>
<td>Flight line direction</td>
<td>North–south</td>
<td>North–south</td>
</tr>
<tr>
<td>Flight line spacing</td>
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<tr>
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<td>VH-FGS Rockwell Strike Commander 500S</td>
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<tr>
<td>Gamma spectrometer</td>
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<td>33.56 litre 256 channel Exploranium GR800D</td>
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<td>Sample interval</td>
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<tr>
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<td>Scintrex ViW 2321-H6 Cesium vapour with Sonotek AADC 2CIAB compensator</td>
</tr>
<tr>
<td>Time sample interval</td>
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</tr>
<tr>
<td>Sample interval</td>
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<td>8 m</td>
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</table>

A gravity trough approximately corresponds with the location of the Piltardi Detachment Zone. This can be attributed to some degree to the presence of basal Amadeus basin sediments close to the surface, within and immediately underlying the detachment zone.

**ECONOMIC GEOLOGY**

No economic mineral deposits have yet been identified on PETERMANN RANGES. Previous investigations in the region have largely concentrated on the base metal potential, particularly in the Olia Chain. There is significant prospectivity for base metals within the Pinyinna beds, and associated with the shear zones along the Piltardi Detachment Zone. There is potential for nickel and chromium mineralisation associated with the Giles Complex south of the Mann Fault.

**Base Metals, Gold**

Exploration for base metals was conducted in the Butler Dome and Petermann Ranges area by Planet Mining in 1965 (Wilson 1966, Jergenson 1966, Woyzbun 1968, McMahon and Partners 1968). The target zone was Cuinozoic felsic igneous and volcanic, with many anomalies in lead, zinc and cobalt, developed over the Pinyinna beds. Numerous drill holes at Butler Dome failed to intersect any notable concentrations of base metals, suggesting that the mineralisation only reflects supergene enrichment. Highly strained and ferruginised Pinyinna beds from within the Piltardi Detachment Zone at ET865128 contain anomalous Co (87 ppm), Cu (0.15%), Pb (0.44%), V (0.33%) and Zn (0.22%). Scattered gossanous or lateritic outcrops within the granitic basement have been assayed throughout PETERMANN RANGES but typically they contain only minor enrichment in Cu (10-90 ppm), Zn (50-110 ppm) and less commonly Pb. Small historic copper workings occur immediately north of Piltardi waterhole on PETERMANN (ET914135), and contain malachite bearing quartz veins within strongly mylonitised Pottoyu Granite. Assay results on these veins yielded 1.95% Cu with no other significant anomalous.

Traces of gold were described by George (1907) from quartz veins in granite near Foster Cliff, but no other gold occurrences have been historically recorded on PETERMANN RANGES. The only significant gold occurrence detected during this study was 0.19 ppm in a quartz vein from ET660280 within the Piltardi Detachment Zone. This vein also contains 1.5% Bi and 1.45% Cu.

**Nickel, Chromium, Platinum, Chrysoprase**

Several sub-economic accumulations of nickel (with minor chromium and cobalt) are associated with supergene enrichment in lateritised Giles Complex ultramafic rocks in regions of South Australia and Western Australia immediately
adjacent to PETERMANN RANGES (eg, Daniels 1975). One of these deposits is associated with palaeodepressions in the Claude Hills peridotite/gabbro intrusion (Miller 1969) between 1-3 km south of the Northern Territory border, with an estimated resource of 4.5 million tonnes at 1.5% Ni. The Claude Hills intrusion extends into the Northern Territory at ES210266, and assays undertaken on lateritised pyroxenite from this locality yielded 1.0% Ni, 0.55% Cr and 77 ppm Co. Trace amounts of platinum group elements (2 ppb Pt, 1 ppb Pd) were encountered. Drilling in the Northern Territory was undertaken by the South Australian Department of Mines in 1965 to test the extension of concealed Ni mineralisation associated with a gravity low (Miller 1966). The results of this drilling suggested that the Quaternary cover deepens significantly to the east-northeast into the Northern Territory, with more than 55 m of cover overlying the basement. However, an intersection of 75 m at 0.51% Ni was obtained below 13 m of Quaternary cover at ES211261, 300 m south of the border. The nickeliferous laterite and jasper contains veins of chrysoprase, which have been mined intermittently in the Claude Hills in South Australia, less than one kilometre from the Northern Territory border.

GROUNDWATER

The information provided in this section was kindly supplied by Col Garner of the Water Resources division of the Department of Lands, Planning and Environment, Alice Springs. Detailed information on bore localities, aquifers and water quality is available from this organisation.

Groundwater resources of PETERMANN RANGES are poorly known. Ninety-six bores have been sunk from the early 1970s until the end of 1996, but many of these were repeat bores at the same locality after early bores failed to intersect an aquifer or did not produce water of sufficient quality. The availability of good-quality water has been essential for the opening up of the area for homeland settlements, which number approximately twenty across the map sheet. Most of the bores were drilled for this purpose, with the remaining number largely to provide water during road construction.

Water quality varies enormously throughout the area, from very good to very poor. Maximum recorded levels of total dissolved solids (TDS) were 54,000 mg/l (typical seawater is 35,000 mg/l TDS). The major aquifers are fractures in granitic and gneissic rocks of the Musgrave Block, which underlie ~90% of the map sheet. The groundwater is probably accessed in fractures in these largely impermeable rocks.

ACKNOWLEDGEMENTS

The authors thank the people of the Docker River, Mutitjulu, Angatja, Amata, Pipalyatjara, Kalka and Wingellina communities for allowing access to their land, and to Max Heggen (DME), Gordon Williams and other Central Lands Council representatives for facilitating land access. We also wish to acknowledge Martin Hand, Thomas Flöttmann and Alfredo Camacho for their significant geological contributions to this work, both in the field and in subsequent collaboration. Technical assistance in the field beyond the call of duty was provided by Peter Crispe and Chris Field. Nigel Duncan, Barry Pietsch, Angelique Cutovinos and Phil Ferenczi are also thanked for their contributions in the field.

Geochronology at the University of Adelaide was undertaken by Jon Dougherty-Page (Zircon Pb-Pb evaporation) and Karin Hatch and John Foden (Sm-Nd). K-Ar hornblende dating was undertaken by Alfredo Camacho at the Australian National University. SHRIMP analysis was done by Richard Armstrong and Mark Fanning from the Research School of Earth Sciences. Russell Shaw (AGSO) provided thin sections from the Mann Ranges.

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APPENDIX

ANGATJA GRANITE. NEW NAME


Reserved in Register of Proposed Names: 13/11/96

Derivation of Name: Angatja Outstation, in the immediately adjacent region of South Australia; 26° 4' 5.4"S, 130° 18' 27.6"E, MANN.

Synonymy: Comprises part of the Musgrave-Mann Metamorphics of Thomson (1969) and undivided metamorphosed granites of Forman (1972).

Constituent Formations: Nil.

Distribution: On the lower slopes of the eastern Mann Ranges north and east of Mt. Charles (26° 0' 10.7"S, 130° 7' 1.6"E) (MANN) and in low outcrops immediately to the east. Extent in South Australia is unknown.

Type Locality: Porphyritic hornblende granite 25° 58' 27.9"S, 130° 11' 8.8"E.

Reference Localities: Rakapiki granite 25° 58' 35.2"S, 130° 11' 8.8"E; Charnockite 25° 58' 12.8"S, 130° 8' 55.6"E.

Thickness: n/a.

Lithology: Foliated porphyritic orthopyroxene-clinopyroxene charnockite, porphyritic hornblende granite, and clinopyroxene-orthopyroxene rapakivi granite. Locally strongly mylonitised, and recrystallised to biotite-clinopyroxene-garnet-hornblende bearing assemblages.

Depositional Environment: n/a.
Geomorphic Expression: Low rocky hills and outcrops with boulders and tors.

Relationships: Intrudes and contains xenoliths of c.1550 Ma granulite facies felsic gneisses. Intrudes 1078 Ma Alcurra Dyke Swarm, but is intruded by c.1000 Ma mafic dykes and the 800 Ma Amata Dyke Swarm. Rapakivi granite forms dykes 1-5 m wide which intrude granulites.

Age: Mesoproterozoic. Pb-Pb zircon evaporation age of 1071 ± 5 Ma for porphyritic hornblende granite at 25° 58' 27.9"S, 130° 11' 8.8"E.

Correlatives: Believed to be related to 1080-1050 Ma granites documented in the western Musgrave Block by Sun et al (1996).

Comments: Variably mylonitised and metamorphosed at ~12 kbars and 700-750°C during the c.560 Ma Petermann Orogeny.

WALAL GRANITE New name


Reserved in Register of Proposed Names: 13/11/96.

Derivation of Name: Walal clayan, 25° 59' 34.1"S, 130° 15' 13.9"E, PETERMANN RANGES.

Synonymy: Comprises part of the Musgrave-Mann Metamorphics of Thomson (1969) and Forman (1972).

Constituent Formations: Nil.

Distribution: In low outcrops in the vicinity of Walal clayan and low hills extending 6 km to the east. Extent in South Australia is unknown.

Type Locality: Northern edge of Walal clayan (25° 59' 27.6"S, 130° 15' 13.9"E).

Thickness: n/a.

Lithology: Foliated porphyritic clinopyroxene granite and granodiorite with coarse euhedral to subhedral purple-brown phenocrysts of K-feldspar. Primary clinopyroxene and hornblende is largely replaced by metamorphic garnet, biotite and hornblende. The porphyritic granite and granodiorite is intruded by a medium grained equigranular granite, also containing purple K-feldspar, with <5% mafic minerals comprising garnet, biotite, hornblende and clinopyroxene.

Depositional Environment: n/a.

Geomorphic Expression: High steep rocky hills in the Mann Ranges with bouldery outcrop and smooth rock faces. Lower scattered rocky hills and pavements north of the Mann Ranges.

Relationships: Intrudes c.1600-1550 Ma granulite facies felsic and mafic gneisses, and c.1200 syn-tectonic chaemicackles. Intruded by 1078 Ma Alcurra Dyke Swarm and 800 Ma Amata Dyke Swarm. Truncated to the north by the Woodroffe Thrust and to the south by the Mann Fault.

Age: Mesoproterozoic. Pb-Pb zircon evaporation ages of 1175 ± 7 Ma for the Walalajeta Granite (25° 56' 49.6"S, 129° 24' 34.2"E), 1172 ± 6 Ma for the unnamed clinopyroxene granite (25° 59' 33.9"S, 130° 1' 55.5"E), 1145 ± 6 Ma for the Puka Granite (25° 1' 29.4"S, 129° 53' 13.5"E).

Correlatives: Similar age, but geochemically distinct from the Pottou and Mantarurr Suites and Walal Granite on PETERMANN RANGES.

Comments: Variably mylonitised and metamorphosed at ~10-13 kbars and 700-750°C during the c.560 Ma Petermann Orogeny.

UMUTUJU GRANITE SUITE New name


Reserved in Register of Proposed Names: 13/11/96.

Derivation of Name: Umutuju outstoution, 25° 35' 31.4"S, 129° 27' 50.6"E, PETERMANN RANGES.


Constituent Formations: Walajajeta Granite, Puka Granite, Mantpayika Granite, unnamed charnockite and unnamed clinopyroxene granite.

Distribution: Throughout the Mann Ranges and scattered low outcrops and rocky hills extending up to 30 km north of the Mann Ranges on PETERMANN RANGES, and an unknown extent into Western Australia and South Australia.

Type Localities: Type localities for the constituent formations are given in their respective formal definitions.

Thickness: n/a.

Lithology: Variably deformed and mylonitised porphyritic clinopyroxene- and hornblende-bearing granites. Primary mineralogy largely consisted of quartz, K-feldspar, plagioclase, clinopyroxene and Fe-Ti oxides, with or without biotite, and are overprinted by mylonitic fabrics defined by quartz, feldspar, hornblende, garnet, Fe-Ti oxides and biotite with or without clinopyroxene and titanite. Rounded K-feldspar and less abundant plagioclase phenocrysts are typically blue-grey in colour and 1-3 cm in diameter. Localised high strain zones are migmatic with coarse garnet and hornblende.

Depositional Environment: n/a.

Geomorphic Expression: High steep rocky hills in the Mann Ranges with bouldery outcrop and smooth rock faces. Lower scattered rocky hills and pavements north of the Mann Ranges.

Relationships: Intrudes c.1600-1550 Ma granulite facies felsic and mafic gneisses, and c.1200 syn-tectonic chaemicackles. Intruded by 1078 Ma Alcurra Dyke Swarm and 800 Ma Amata Dyke Swarm. Truncated to the north by the Woodroffe Thrust and to the south by the Mann Fault.

Age: Mesoproterozoic. Pb-Pb zircon evaporation ages of 1175 ± 7 Ma for the Walalajeta Granite (25° 56' 49.6"S, 129° 24' 34.2"E), 1172 ± 6 Ma for the unnamed clinopyroxene granite (25° 59' 33.9"S, 130° 1' 55.5"E), 1145 ± 6 Ma for the Puka Granite (25° 1' 29.4"S, 129° 53' 13.5"E).

Correlatives: Similar age, but geochemically distinct from the Pottou and Mantarurr Suites and Walal Granite on PETERMANN RANGES.

Comments: Variably mylonitised and metamorphosed at ~10-13 kbars and 700-750°C during the c.560 Ma Petermann Orogeny.

MANTAPAYIKA GRANITE New name


Reserved in Register of Proposed Names: Date: 27/07/99.

Derivation of Name: Mantapayika outstoution; 25° 35' 10.5"S, 129° 27' 51.4"E, PETERMANN RANGES.


Constituent Formations: Nil. Forms part of the Umutuju Granite Suite.

Distribution: Throughout a region of 2,500 - 3,000 km² north of the Mann Ranges encompassing the northern half of the COCKBURN
and DUFFIELD 1:100 000 sheet areas, PETERMANN RANGES.

**Type Locality:** Porphyritic granite: Isolated outcrop of granite at 25° 43' 33.7"S, 129° 57' 14.5"E.

**Reference Locality:** Migmatic hornblende-gneiss: Pavement near Wilsons-Docker River road at 25° 38' 25.9"S, 129° 11' 57.3"E

**Thickness:** n/a.

**Lithology:** Varially mylonitised porphyritic clinopyroxene granite, with rounded blue-grey K-feldspar phenocrysts, typically 1-3cm but up to 6cm in diameter. Less common weakly porphyritic to equigranular phases occur, locally containing primary hornblende. The primary granite mineralogy is overprinted by a mylonitic fabric defined by quartz, feldspar, garnet, clinopyroxene and biotite, with or without hornblende. Migmatic gneisses occur in zones of high strain, and contain partial melts and biotite-hornblende-garnet-titanite bearing assemblages.

**Depositional Environment:** n/a.

**Geomorphic Expression:** Low rocky hills and pavements, widely scattered with extensive Caimozoic cover.

**Relationships:** No contacts exposed with other granites. Intruded by mafic dykes of the Alcurna and Amata Dyke Swarms. Truncated by the north by the Woodruffe Thrust.

**Age:** Mesoproterozoic. Part of the Umtutu Granite Suite, dated elsewhere at 1180-1140 Ma.

**Correlatives:** Very similar to Walijatjata and Puka Granites, with only minor textural and geochemical differences. Similar age to Pottoyu and Mantarurr Suites, PETERMANN RANGES.

**WALYJTJATA GRANITE** New name

**Proposer:** D.F. Close, C.J. Edgoose, I.R. Scrimgeour.

**Reserved in Register of Proposed Names:** 13/11/96.

**Derivation of Name:** Walyjtjata outstation; 25° 58' 42.7"S, 129° 27' 55.9"E, PETERMANN RANGES.

**Synonymy:** Comprises part of the Musgrave-Mann Metamorphics of Thomson (1969) and undivided metamorphosed granites of Forman (1972).

**Constituent Formations:** Nil. Forms part of the Umtutu Granite Suite.

**Distribution:** Throughout the western part of the Mann Ranges within the northern Territory, and low outcrops immediately to the north of the Mann Ranges. Extent within South Australia and Western Australia is unknown.

**Type Locality:** In creek 3 km north of Walyjtjata outstation at 25° 56' 48.9"S, 129° 28' 24.3"E.

**Thickness:** n/a.

**Lithology:** Varially mylonitised porphyritic clinopyroxene granite, with rounded blue-grey K-feldspar phenocrysts, typically 1-3cm but up to 6cm in diameter. Less common weakly porphyritic to equigranular phases. The primary clinopyroxene granite mineralogy is overprinted by a mylonitic fabric defined by quartz, feldspar, garnet, clinopyroxene and biotite, with or without hornblende. Localised hydrous shear zones contain partial melts and biotite-hornblende-garnet-titanite bearing assemblages.

**Depositional Environment:** n/a.

**Geomorphic Expression:** Rocky hills, locally high and steep, with bouldery outcrop and smooth rock faces.

**Relationships:** Intrudes 1600-1550 granulite facies felsic and mafic gneisses. Is intruded by 1078 Ma Alcurna Dyke Swarm and 800 Ma Amata Dyke Swarm.

**Age:** Mesoproterozoic. Pb-Pb zircon evaporation age of 1175 ± 7 Ma for porphyritic clinopyroxene granite at 25° 56' 49.6"S, 129° 24' 34.2"E.

**Correlatives:** Very similar to Mantapayika and Puka Granites, with only minor textural and geochemical differences. Similar age to Pottoyu and Mantarurr Granite Suites, PETERMANN RANGES.

**Comments:** Varially mylonitised and metamorphosed at ~12-13 kbars and 700-750°C during the c.560 Ma Petermann Orogeny.

**PUKA GRANITE** New name

**Proposer:** I.R. Scrimgeour, D.F. Close, C.J. Edgoose.

**Reserved in Register of Proposed Names:** 13/11/96.

**Derivation of Name:** Puka outstation; 25° 59' 28.42"S, 129° 53' 28.42"E, PETERMANN RANGES.

**Synonymy:** Comprises part of the Musgrave-Mann Metamorphics of Thomson (1969) and undivided metamorphosed granites of Forman (1972).

**Constituent Formations:** Nil. Forms part of the Umtutu Granite Suite, along with the Mantapayika and Walyjtjata Granites.

**Distribution:** In low outcrops immediately to the north of the Mann Ranges, Northern Territory. The extent of the unit within South Australia is unknown.

**Type Locality:** On northern side of low outcrop 5 km northwest of Puka outstation at 25° 55' 50.70"S, 129° 53' 33.46"E

**Thickness:** n/a.

**Lithology:** Varially mylonitised, weakly porphyritic to coarsely megacrystic clinopyroxene- and hornblende-bearing granite containing plagioclase phenocrysts which mainly range in diameter from 3 mm to 3 cm but in places form megacrysts up to 9 cm. The primary hornblende granite mineralogy is overprinted by a mylonitic fabric defined by quartz, feldspar, garnet and biotite. Localised hydrous shear zones contain partial melts and hornblende-garnet bearing assemblages.

A weakly porphyritic, charnockitic granite (containing orthopyroxene and clinopyroxene) also forms part of this unit.

**Depositional Environment:** n/a.

**Geomorphic Expression:** Low rocky hills with bouldery outcrop.

**Relationships:** Interpreted to intrude 1600-1550 granulite facies felsic and mafic gneisses. The Puka Granite is intruded by 1078 Ma Alcurna Dyke Swarm and 800 Ma Amata Dyke Swarm.

**Age:** Mesoproterozoic. Pb-Pb zircon evaporation age of 1145 ± 6 Ma for weakly porphyritic hornblende granite at 25° 55' 50.70"S, 129° 53' 33.46"E.

**Correlatives:** Very similar to Mantapayika and Walijatjata Granites (also part of the Umtutu Granite Suite), with only minor textural and geochemical differences. Similar age to Pottoyu and Mantarurr Suites, PETERMANN RANGES.

**Comments:** Varially mylonitised during the c.560 Ma Petermann Orogeny.

**POTTOYU GRANITE SUITE** Redefinition of unit

**Proposer:** C.J. Edgoose, D.F. Close, I.R. Scrimgeour.

**Derivation of Name:** Pottoyu Hills, south of Petermann Ranges,
PETERMANN RANGES.

Syntonomy: Comprises the Pottuyu Granite Complex of Forman (1966a, 1972) and outcrops previously mapped as Olia Gneiss and undifferentiated to the north of the Petermann Ranges and south of the Pottuyu Hills by Forman (1966a, 1966b, 1972).

Constituent Formations: Undivided Pottuyu Granite Complex and Mulyati Granite.

Distribution: Throughout the Pottuyu Hills, in scattered low outcrops to the south of the Pottuyu Hills, and north of the Petermann Ranges extending onto BLOODS RANGE. Extent to west into Western Australia is not known.

Type Localities: (1) Coarsely porphyritic granite 25° 7’ 16.6”S, 129° 10’ 49.9”E; (2) Hornblende-bearing granite gneiss 25° 34’ 48.7”S, 130° 1’ 24.8”E; Equigranular granite 25° 21’ 38.3”S, 129° 9’ 36.6”E.

Thickness: n/a.

Lithology: Coarsely porphyritic K-feldspar-rich foliated biotite granite, with spherical K-feldspar phenocrysts 1-6 cm in diameter typically with rapakivi textures. The mineral assemblage is quartz, K-feldspar, plagioclase, biotite, titanite and Fe-Ti oxides, with or without allanite, epidote and hornblende. Less abundant K-feldspar-rich medium to fine grained equigranular biotite granite and aplite occurs. A gneissic texture with partial melting and coarse hornblende is developed in high strain regions in the southern Pottuyu Hills.

Depositional Environment: n/a.

Geomorphic Expression: Rounded rocky hills covered by tors and boulders.

Relationships: Overlain by c.1060 Ma felsic volcanics and Bloods Range bedded, and Neoproterozoic Dean Quartzite. Intruded by Alcurra Dyke Swarm (c. 1078 Ma) and Amata Dyke Swarm (c. 800 Ma).

Age: Mesoproterozoic. U-Pb zircon ages of 1144 ± 12 Ma (25° 15’ 3.2”S, 129° 39’ 22.9”E) and 1192 ± 13 Ma (25° 8’ 12.8”S, 129° 52’ 22.8”E), and Rb-Sr whole rock ages of 1150 Ma (25° 20’ 49.6”S, 129° 54’ 15.6”E; Forman, 1972) and 1190 Ma (25° 24’ 4”S, 130° 3’ 49.6”E; Forman, 1972).

Correlatives: Similar age, but geochemically distinct from the Mantarrurr and Umutju Granite Suites and Walal Granite on PETERMANN RANGES.

Comments: Varibly deformed and metamorphosed to amphibolite facies during the c.560 Ma Petermann Orogeny. Metamorphic grade is mid to upper amphibolite facies.

MANTARURR GRANITE SUITE

Name


Reserved in Register of Names: 13/11/96.

Derivation of Name: Mantarrurr outstation, 25° 35’ 7.9”S, 130° 27’ 34.8”E, PETERMANN RANGES.


Constituent Formations: Utanta Granite, Foster Cliff Granite, Wala Wura Granite, Kulu Granite.

Distribution: Throughout the Olia Chain and in low outcrops extending 20 km south and southwest of Foster Cliff on PETERMANN RANGES.

TypeLocality: Type localities for the constituent formations are given in their respective formal definitions.

Thickness: n/a.

Lithology: Texturally variable biotite-rich foliated granites. The mineralogy typically comprises quartz, K-feldspar, plagioclase, biotite, titanite, ilmenite and muscovite, with or without allanite and garnet. The granites are typically variably porphyritic, with rectangular to sub-rounded K-feldspar phenocrysts up to 5cm in diameter. Large areas are finely porphyritic to equigranular.

Depositional Environment: n/a.

Geomorphic Expression: Low outcrops and rounded hills. Rubbly slopes underlying quartzite scarps in Olia Chain.

Relationships: Intrudes c.1550-1600 Ma amphibolite facies felsic gneiss. Intruded by 1078 Ma Alcurra Dyke Swarm and 800 Ma Amata Dyke Swarm.

Age: Mesoproterozoic. SHRIMP U-Pb zircon age of c.1168 ± 14 Ma (M. Fanning pers. comm. 1998) for the Kulu Granite (25° 43’ 52.3”S, 130° 19’ 51.1”E).

Correlatives: Similar age, but geochemically distinct from the Pottuyu and Umutju Suites and Walal Granite on PETERMANN RANGES.

Comments: Deformed and metamorphosed at 5-6 kbars and 600-650°C during the c.560 Ma Petermann Orogeny.

MULYATI GRANITE New name


Reserved in Register of Proposed Names: 13/11/96.

Derivation of Name: Mulyati, locality (rockhole) at 25° 22’ 46.5”S, 129° 10’ 26.3”E, PETERMANN RANGES.


Constituent Formations: Nil. Forms part of the Pottuyu Granite Suite.

Distribution: Comprises scattered low hills and outcrops south of the Pottuyu Hills encompassing most of the southern half of the Pottuyu 1:100 000 sheet. Extent into Western Australia is not known.

Type Localities: Low hill 1 km west of Docker River-Winjellina road at 25° 21’ 38.3”S, 129° 9’ 36.1”E.

Thickness: n/a.

Lithology: K-feldspar-rich medium to fine grained equigranular biotite granite and aplite. Contains <5% mafic minerals comprising biotite and Fe-Ti oxides.

Depositional Environment: n/a.

Geomorphic Expression: Low rocky hills and granite pavements.

Relationships: Sharp intrusive relationships locally observed with porphyritic granite of Pottuyu Granite Complex. No consistent timing relationships.

Age: Mesoproterozoic. Correlated with granites elsewhere in the Pottuyu Granite Complex with U-Pb zircon ages of 1144 ± 12 Ma (25° 8’ 12.8”S, 129° 52’ 22.8”E) and 1192 ± 13 Ma (25° 20’ 49.6”S, 129° 54’ 15.6”E), and Rb-Sr whole rock ages of 1150 Ma (25° 24’ 4.0”S, 130° 3’ 49.6”E; Forman, 1972) and 1190 Ma (25° 24’ 4”S, 130° 3’ 49.6”E; Forman, 1972).

Correlatives: Similar age, but geochemically distinct from the Mantarrurr and Umutju Granite Suites and Walal Granite on PETERMANN RANGES.

Comments: Varibly deformed and metamorphosed during the c.560 Ma Petermann Orogeny. Metamorphic grade is mid to upper amphibolite facies.
WALA WURU GRANITE  New name
Reserved in Register of Proposed Names: 29/04/99.
Derivation of Name: Wala Wuru, Aboriginal name for Stevenson Peak, 25° 29’ 55.1”S, 130° 10’ 48.2”E, PETERMANN RANGES.
Constituent Formations: Nil. Forms part of the Mantarurr Granit Suite.
Distribution: Outcrops in the vicinity of Stevenson Peak and up to 6 km to the south and 5 km to the east, and on the eastern side of Butler Dome on PETERMANN RANGES.
Type Locality: 1 km south-southeast of Stevenson Peak at 25° 30’ 21”S, 130° 11’ 2.8”E.
Thickness: n/a.

Lithology: Foliated biotite granite with large rectangular white to pale orange K-feldspar phenocrysts in a fine to medium grained biotite-rich matrix. Phenocrysts are typically 1-3 cm in diameter. The mineralogy typically comprises quartz, K-feldspar, plagioclase, biotite, titanite, ilmenite and epidote.

Depositional Environment: n/a.

Geomorphic Expression: Low outcrops and rounded rocky hills. Rubbly slopes underlying quartzite scarps of Stevenson Peak region and Butler Dome.

Relationships: Has sharp intrusive contacts with the Utanta and Foster Cliff Granites.

Age: Mesoproterozoic. Correlated with Kulu Granite which has a SHRIMP U-Pb zircon age of c.1168 ± 14 Ma (M. Fanning pers. comm. 1998).

Corelatives: Geochemically and mineralogically similar to Wala Wuru Granite, Foster Cliff granite and Kulu Granite. Similar age, but geochemically distinct from the Pottoyu and Umutju Granite Suiites and Walal Granite in PETERMANN RANGES.

Comments: The Butler Dome Granite is strongly enriched in Th and therefore defines a strong radiometric anomaly. Deformed and metamorphosed during the c.560 Ma Petermann Orogeny at ~6 kbars and 600-650°C.

KULU GRANITE
Reserved in Register of Proposed Names: 13/11/96.
Derivation of Name: Kulu, Aboriginal name for rocky hill 10 km south of Foster Cliff at 25° 40’ 33.9”S, 130° 25’ 54.8”E, PETERMANN RANGES.
Constituent Formations: Nil. Forms part of the Mantarurr Granite Suite.
Distribution: Main area of outcrop is a 10 x 12 km region 6-15 km south of Foster Cliff, as well as smaller bodies in the vicinity of Foster Cliff and 18 km south-southwest of Foster Cliff.
Type Locality: 15 km south of Foster Cliff at 25° 43’ 43.3”S, 130° 24’ 16.6”E
Thickness: n/a.

Lithology: Coarsely porphyritic foliated biotite granite with coarse phenocrysts of both K-feldspar and plagioclase which are typically 1-3 cm in diameter. Plagioclase phenocrysts are often a pale green colour and are smaller than the K-feldspar phenocrysts. The matrix is medium grained and consists of quartz, feldspar, biotite, epidote, titanite and muscovite, with less abundant ilmenite and garnet.

Depositional Environment: n/a.

Geomorphic Expression: Low outcrops and rounded rocky and bouldery hills.

Relationships: Intrudes 1600-1550 Ma amphibolite gneiss and locally contains large xenoliths of the gneiss. Has sharp intrusive contacts with the Foster Cliff Granite with no clear timing relationships. Intruded by mafic dykes of the Alcurra and/or Amata Dyke Swarms.

Age: Mesoproterozoic. SHRIMP U-Pb zircon age of c.1168 ± 14 Ma (M. Fanning pers. comm. 1998).

Corelatives: Geochemically and mineralogically similar to the Utanta Granite, Wala Wuru Granite and Foster Cliff Granite. Similar age, but geochemically distinct from the Pottoyu and Umutju Granite Suites and Walal Granite on PETERMANN RANGES.

UTANTA GRANITE  New name
Reserved in Register of Proposed Names: 29/04/99.
Derivation of Name: Utanta - Aboriginal name for Butler Dome, 25° 38’ 10.8”S, 130° 14’ 13.9”E, PETERMANN RANGES.
Constituent Formations: Nil. Forms part of the Mantarurr Granite Suite.
Distribution: Occurs over approximately 4 x 10 km of continuous outcrop on the western side of Butler Dome.
Type Locality: In creek 5 km NNW of Butler Dome 25° 36’ 1.2”S, 130° 13’ 25.9”E.
Thickness: n/a.

Lithology: Coarsely porphyritic biotite granite, conspicuously more felsic than other granites in Mantarurr Suite. Contains K-feldspar phenocrysts up to 3 cm in diameter in a coarse grained matrix in which mafic minerals occur as coarse clusters of biotite and Fe-Ti oxides with minor muscovite, garnet and allanite. Fluorite is locally present.

Depositional Environment: n/a.

Geomorphic Expression: Rubbly slopes underlying the western quartzite scarps of Butler Dome, leading down into low bouldery rounded hills.

Relationships: Few clear relationships. Has a sharp intrusive contact with the WalaWuru Granite but with no clear timing relationship.

Age: Mesoproterozoic. Correlated (on basis of geochemical similarity) with Kulu Granite which has a SHRIMP U-Pb zircon age of c.1168 ± 14 Ma (M. Fanning pers. comm. 1998).

Corelatives: Geochemically and mineralogically similar to Wala Wuru Granite, Foster Cliff granite and Kulu Granite. Similar age, but geochemically distinct from the Pottoyu and Umutju Granite Suites and Walal Granite in PETERMANN RANGES.

Comments: The Butler Dome Granite is strongly enriched in Th and therefore defines a strong radiometric anomaly. Deformed and metamorphosed during the c.560 Ma Petermann Orogeny at ~6 kbars and 600-650°C.
FOSTER CLIFF GRANITE New name


Reserved in Register of Proposed Names: 13/11/96.

Derivation of Name: Foster Cliff, 25° 35' 8.9"S, 130° 25' 40.0"E, PETERMANN RANGES.


Constituent Formations: Nil. Forms part of the Mantarurr Granite Suite.

Distribution: Occurs extensively throughout Olia Chain, particularly in regions up to 10 km west and south of Stevenson Peak, in the vicinity of Foster Cliff and extending 10-15 km southwest of Foster Cliff and a 4x4 km region cented 6 km northeast of Butler Dome, PETERMANN RANGES.

Type Locality: 1.5 km west of Foster Cliff at 25° 35' 9.6"S, 130° 24' 39.2"E

Thickness: n/a.

Lithology: Foliated biotite granite which is typically finely porphyritic with abundant small phenocrysts of K-feldspar 2-5 mm in diameter. Locally the granite is equigranular and fine to medium grained. The mineralogy typically comprises quartz, K-feldspar, plagioclase, biotite, titanite, ilmenite and epidote, with secondary muscovite and accessory allanite. This granite is locally intruded by fine to medium grained leucogranites, and leucocratic veins and pegmatites.

Depositional Environment: n/a.

Geomorphic Expression: Low outcrops and rounded rocky hills. Rabbly slopes underlying quartzite scarps of Foster Cliff region and Butler Dome.

Relationships: Has contacts with the Kulu granite which range from being sharp and intrusive to being apparently gradational. Has sharp intrusive contacts with the Utanta and Wala Wuru Granites. No consistent timing relationships are evident, although the presence of a diffuse early fabric suggests that this may be the oldest granite in the Mantarurr Granite Suite. Is intruded by mafic dykes of the 800 Ma Amata Dyke Swarm and possibly also the 1078 Ma Alcurra Dyke Swarm.

Age: Mesoproterozoic. Correlated (on the basis of geochemical similarities) with Kulu Granite which has a SHRIMP U-Pb zircon age of c.1168 ± 14 Ma (M. Fanning pers. comm. 1998).

Correlatives: Geochemically and mineralogically similar to the Utanta Granite, Wala Wuru Granite and Kulu Granite. Similar age, but geochemically distinct from the Pottuoyu and Umutju Granite Suites and Walal Granite on PETERMANN RANGES.

Comments: Deformed and metamorphosed at 5-6 kbars and ~600-650°C during the c.560 Ma Petermann Orogeny.