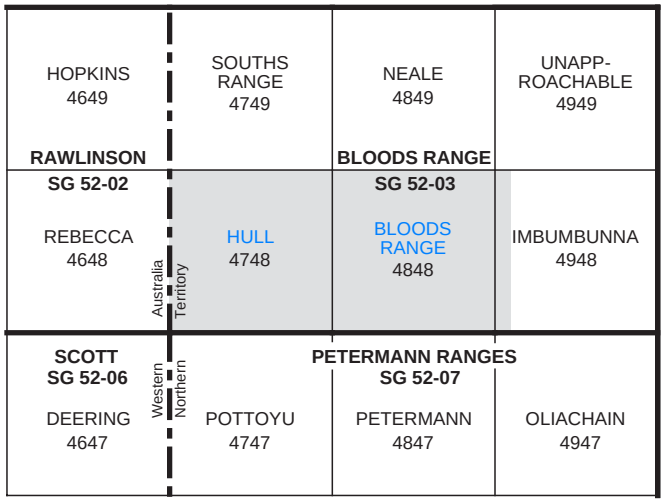
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NORTHERN TERRITORY GEOLOGICAL SURVEY



HULL AND BLOODS RANGE, Northern Territory

Sheets 4748, 4848

1:100 000 GEOLOGICAL MAP SERIES EXPLANATORY NOTES

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ABSTRACT

HULL and BLOODS RANGE[1] encompass the northern margin of the Meso- to Neoproterozoic Musgrave Block and the southern margin of the Neoproterozoic to Palaeozoic Amadeus Basin. Musgrave Block basement in this region comprises the voluminous 1190-1140 Ma Pottoyu Suite granite that extends into PETERMANN RANGES, the 1153 Ma shallow level Amputjuta Dacite and the 1164 Ma Ilyaralona Granite. Unconformably overlying the granite basement is a locally deposited rift succession, the Tjauwata Group. This succession extends into Western Australia and comprises voluminous mafic volcanics, minor felsic volcanics, polymictic conglomerate, red beds and quartzite. Zircons from a rhyolite within the Tjauwata Group have yielded an age of 1075 ± 2 Ma, which correlates with the 1078 ± 5 Ma Smoke Hill Felsic Volcanics of the Bentley Supergroup in Western Australia. Shallow-level coeval granite bodies of the Hull Granite Suite intrude the lower levels of the rift succession and have yielded a SHRIMP U-Pb zircon age of 1084 ± 9 Ma and a Pb-Pb Kober age of 1075 ± 2 Ma. Dolerite dykes, interpreted to belong to the 1080-1070 Ma Alcurra dolerite, crosscut the lower stratigraphy of the Tjauwata Group and the Hull Suite granites.

The onset of deposition in the Amadeus Basin is marked by the influx of deltaic sediments of the Kulail Sandstone. These unconformably overlie the Tjauwata Group rift succession and locally grade into, or interfinger with, shallow marine deposits of the Dean Quartzite. A conformable succession of siltstone and carbonates, the Pinyinna beds, is deposited over the basal quartz sandstone units, and is thought to be synchronous with the intrusion of the 820 Ma Amata Dyke Swarm. Deposition of marine to fluvial sediments (Winnall beds and Inindia beds) continued in the Amadeus Basin throughout the Neoproterozoic, although there is only minor outcrop of Winnall beds preserved in the Bloods Range region.

Oblique convergence during the 570-530 Ma intraplate Petermann Orogeny resulted in dominantly north-vergent deformation that structurally dissected the Musgrave basement and overlying sediments. In HULL and BLOODS RANGE, metamorphism during this event ranged from mid-amphibolite to greenschist facies and decreased in grade towards the north. A regional-scale thrust duplex system developed during orogenesis, resulting in interleaving of basement and lower Neoproterozoic cover, and the northward transport of the Pottoyu Granite and Tjauwata Group. Structural fabrics range from pervasive micaceous foliations and intense isoclinal folding in higher-grade regions to discrete thrust planes at upper crustal levels. A strong structural discontinuity occurs between the Pinyinna beds and overlying quartz clastic successions of the Inindia and Winnall beds, with the Pinyinna beds acting as a decollement horizon during compression.

Downward flexure of the crust in front of the north-vergent basement nappe complex created a narrow foreland basin, infilled by proximal deposits of the Mount Currie Conglomerate. Undeformed Ordovician transgressive marine sediments onlap onto relict topography formed during the Petermann Orogeny. Partially lithified Cenozoic talus slopes occur adjacent to the main quartzite ranges while the majority of HULL and BLOODS RANGE are covered by Quaternary sediments, including colluvium, alluvium, sand, clay and minor calcrete.

Although there are no known economic mineral deposits in the Bloods Range region, assay results from grab samples indicate anomalous Cu, Pb and Ag levels in sediments associated with basaltic magmatism and in undeformed quartz veins. Groundwater in the Docker River (Kaltukatjara) region is of variable quality and likely to be stored in aquifers of unconsolidated deposits, sourced by local recharge from nearby ranges and underground flow from the Docker River.

[1] Names of 1:250 000 and 1:100 000 mapsheets are shown in large and small capital letters, respectively, eg BLOODS RANGE, HULL.

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INTRODUCTION

This report describes the geology of the Hull and Bloods Range 1:100 000 special geological maps (**Figure 1**), which comprise HULL, BLOODS RANGE and a small portion of the western IMBUMBUNNA (Sheet 4948). These form most of the southern half of BLOODS RANGE in the southwestern part of the Northern Territory, bordering on Western Australia.

The area covered by these two special mapsheets is bounded by latitudes 24°30'S and 25°00'S, and longitudes 129°00'E and 130°03'E. The HULL special mapsheet incorporates the westernmost part (5 minutes longitude) of BLOODS RANGE in order to include all of Mount Harris and the BLOODS RANGE special sheet includes 3 minutes longitude of western IMBUMBUNNA to incorporate the eastern McNichols Range. This entire area is Aboriginal Freehold and forms part of the Petermann Aboriginal Land Trust. The map and report are the results of work conducted by the Northern Territory Geological Survey (NTGS) from 1997 to 1999 and this is the final phase of an NTGS program to map the Northern Territory portion of the Musgrave Block, which began in 1987 in KULGERA. Mapping in BLOODS RANGE was limited to the Musgrave Block and basal Amadeus Basin units, which only occur in the southern half of the mapsheet. The northern half of BLOODS RANGE includes considerable areas of outcropping Palaeozoic Amadeus Basin rocks, which were not included in this project.

First Edition mapping of BLOODS RANGE was conducted in 1962 by Geoscience Australia (GA), then known as the Bureau of Mineral Resources (BMR; Forman 1963, 1966a, 1966b). The NTGS program was conducted using 1:25 000-scale colour aerial photographs flown in 1988. Airborne geophysics was acquired over the area in 1985 and 1987 by NTGS. Some regions were not visited due to their cultural significance to Traditional Owners. The largest of the exclusion zones includes the Ruined Rampart (Mannanana Range), and an area of approximately 75 km² north of the Ilyaralona Range in HULL (refer to map face). Analysis and interpretation of petrological, geochemical, assay, geochronological and geophysical data acquired during the project aided the interpretation of field observations. Igneous rock names follow the IUGS approved nomenclature scheme (Le Maitre 1989). The 1996 AGSO Timescale is used in this report. Cited locations in this publication are based on Map Grid of Australia zone 53J coordinates and the GDA94 map datum, and are deemed accurate to ± 50 m. Within text and figure captions, the Universal Grid Reference style is used as

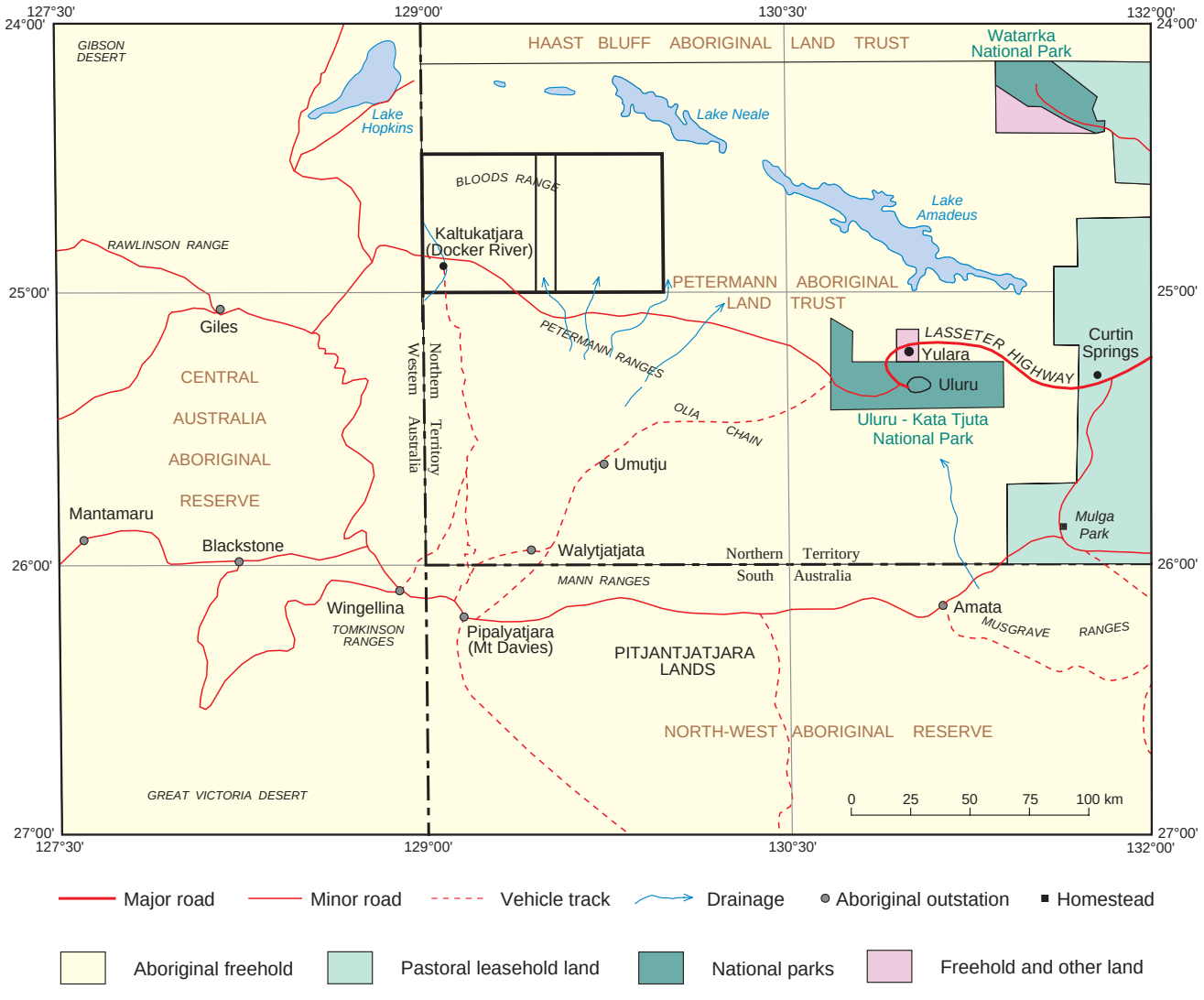


Figure 1. Location of HULL (left) and BLOODS RANGE 1:100 000 special geological maps, showing area of overlap of the two maps.

explained on the mapface (eg Mount Harris at 551900mE, 7275000mN is represented as ET519750). Full MGA grid references are provided in tables.

Previous geological studies in the area include scattered observations made by early explorers and prospecting parties. Some geoscientific work, related to the petroleum potential of the Amadeus Basin, was conducted in the 1960s. Forman (Forman 1963, Forman 1966b) detailed the activities of early explorers and these other studies. Work by BMR in 1962 was the first geologically targeted study in the region. Mineral exploration in BLOODS RANGE by private companies is limited to some work by Planet Mining in the 1960s (Brown 1966, Tassell 1969). Most of the area is taken up in tenement applications, and exploration activity is likely to recommence in 2003, due to recent successful negotiations for exploration access with Traditional Owners, under the requirements of the *Aboriginal Land Rights Act* (1976).

Access, land use and population

The Bloods Range region is reached by road south from Alice Springs via the Stuart Highway to Erldunda, west via the Lasseter Highway to Yulara, and west via Docker River Road to Docker River (*Kaltukatjara*). The latter is a wide, formed dirt road that continues westwards into Western Australia on to Warburton and Giles Meteorological Station. In Western Australia, it is known as the Great Central Road. An airstrip about 7 km east of Docker River provides access into the area by air. There are numerous graded tracks that lead to outstations scattered across the region: Kulail, Puntitjata, Tjuninanta, Walu, Amputjuta and Karukali. A new outstation was established in 1999 about 4 km northeast of Amputjuta. Vehicular tracks are also numerous, and cross-country driving is generally possible in most areas (**Figure 2**). The dominant land uses of the region are traditional hunting and ceremonial activities.

The main population centre is Docker River Community (Kaltukatjara), where there is a permanent population of approximately 330. Docker River Community was established in 1967-8 as a living area for local people of the Pitjantjatjara and Ngaatjatjara language groups.

Climate and Vegetation

The area belongs to the arid zone of Hooper *et al* (1987) and the climate is characterised by long hot summers and mild winters. In summer, there are extensive periods where the temperature exceeds 40°C every day. Winter daily averages are 20-30°C mean daily maximum in July, with a mean daily minimum of 3.4°C. Rainfall occurs predominantly in summer, with an average of 253.7 mm per annum averaged over 40 years (data from Giles Meteorological Station). The mean annual potential evaporation is in the order of 2700 mm per annum. The effectiveness of rainfall on plant growth is determined by the conditions under which the rain occurs. Heavy storms in summer do less to ensure long-term plant growth than more evenly distributed moderate falls. However, the natural cycle for the region is for rainfall to be erratic and extended dry spells are common.

A vegetation survey of the Northern Territory (Wilson *et al* 1990) described six different vegetation communities in the region. These generally reflect variations in landform and soil, but at the map scale of 1:1 00 000 are fairly generalised. The dominant community is spinifex (*Plectrachne melvillei*) with desert oak (*Allocasuarina*

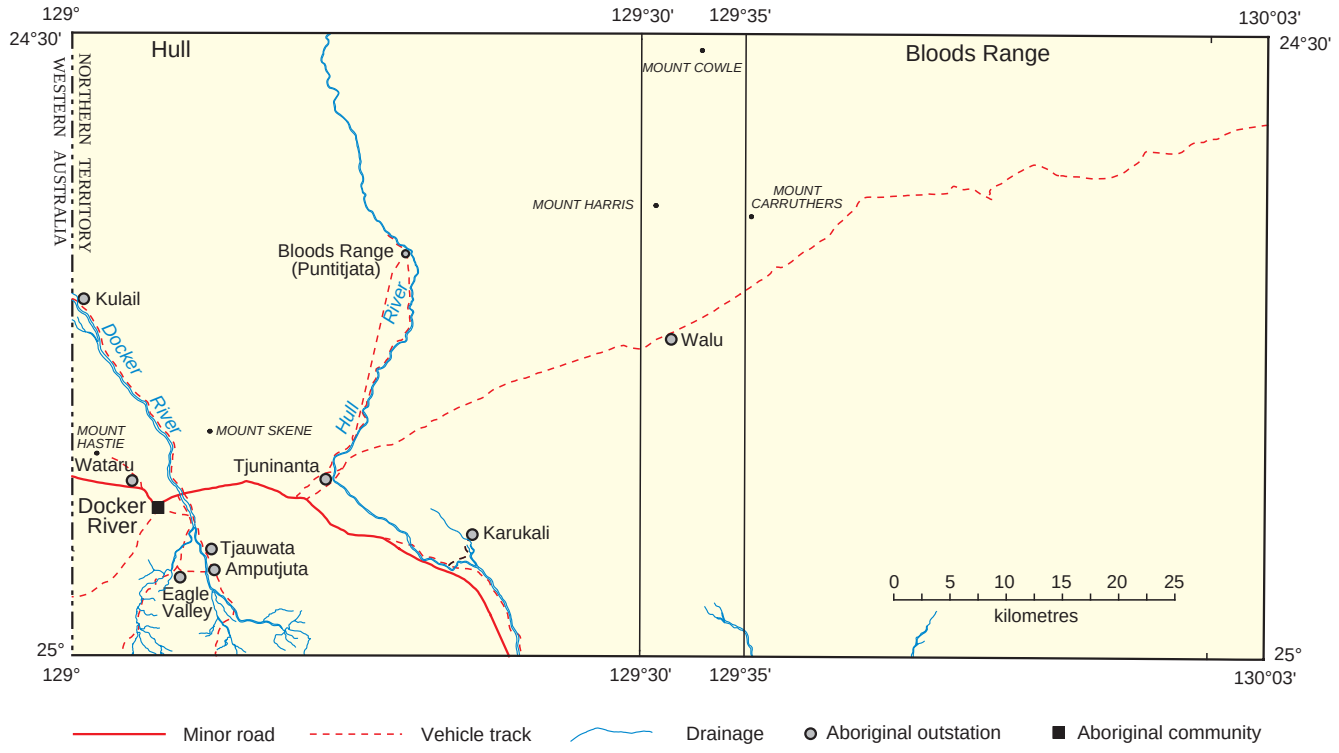


Figure 2. Main access tracks and outstations in HULL and BLOODS RANGE. Western boundary of BLOODS RANGE special at 129°30'E; eastern boundary of HULL special at 129°35'E.

decasneana) overstorey in extensive dune fields in the north and west that comprise about 35% of Hull and Bloods Range. Tall open shrubland of mulga (*Acacia aneura*) over woollybutt (*Eragrostis eriopoda*) grassland forms about 25% of the central and southeastern parts of the region. Tall shrubland and hummock grassland of hard spinifex (*Triodia basedowii*) and blue mallee (*Eucalyptus gamophylla*) also comprises about 25% of the area in the south central and southeast. The ranges (eg Mannanana and Bloods Ranges) support a community of spike-flowered spinifex (*Triodia spicata*) and Holly grevillea (*Grevillea wickhamii*). In Learmouth Park and along Chirnside Creek is a sparse shrubland of dead finish (*Acacia tetragonophylla*) and witchetty bush (*Acacia kempeana*) over grasses. Scattered areas near the ranges in the central and southwest of the mapsheets support hummock grassland of spinifex with mulga and witchetty bush.

Geomorphology

Six distinct geomorphic units have been distinguished in Hull and Bloods Range (**Figure 3**): 1) Quartzite ranges; 2) Hills; 3) Dissected hills; 4) Low rises; 5) Alluvial and colluvial plains; and 6) Sand plains and dune fields.

Quartzite ranges – These are the major named topographic features of the region. They include Dean Range, Mannanana Range, Ilyaralona Range, Piultarana Range, Mount Skene area, Mount Hastie area, ranges west of Docker River, Bloods Range, Rowley Range, McNichols Range and Pinyinna Range. They are dominantly composed of silicified quartzite that is resistant to weathering. The morphology of the ranges shows some variation, but mostly consists of a scarp with an associated steep talus slope on the southern side, and a more moderate dip slope on the northern side. Most of the ranges are elongated east–west. The highest elevation is 1029 m above sea level (asl) at the southern end of the Dean Range. Mount Carruthers in the Rowley Range is 1009 m asl, which is about 500 m above the level of the surrounding plains. The more extensive ranges often show a bevelled summit over considerable distances and this probably represents a remnant of the Palaeogene-Neogene upland surface. More recent relative uplift in the region is a result of subsidence in the Lake Eyre region, and this has resulted in renewed erosion, producing the steep morphology evident today.

Low hills – There are two broad groups within this geomorphic category. Smooth rounded hills have developed on outcrop of Mount Harris Basalt in the region around Mount Harris. North and northeast of Ilyaralona Range, and east of Kulail, more angular hills and low ranges have developed on quartz sandstones. The rounded hills reach a maximum elevation of 624 m asl, about 80 m above the level of the plains, with the angular hills reaching a similar elevation. Many of the angular hills display a scarp and dip slope morphology and are generally much more vegetated. Distinctive vegetation of *Triodia longiceps* (spinifex) is common on the basalt hills.

Dissected low hills – In the Learmonth Park area, south of Docker River, a strongly developed dendritic drainage system has formed in low hills of weathered granitic

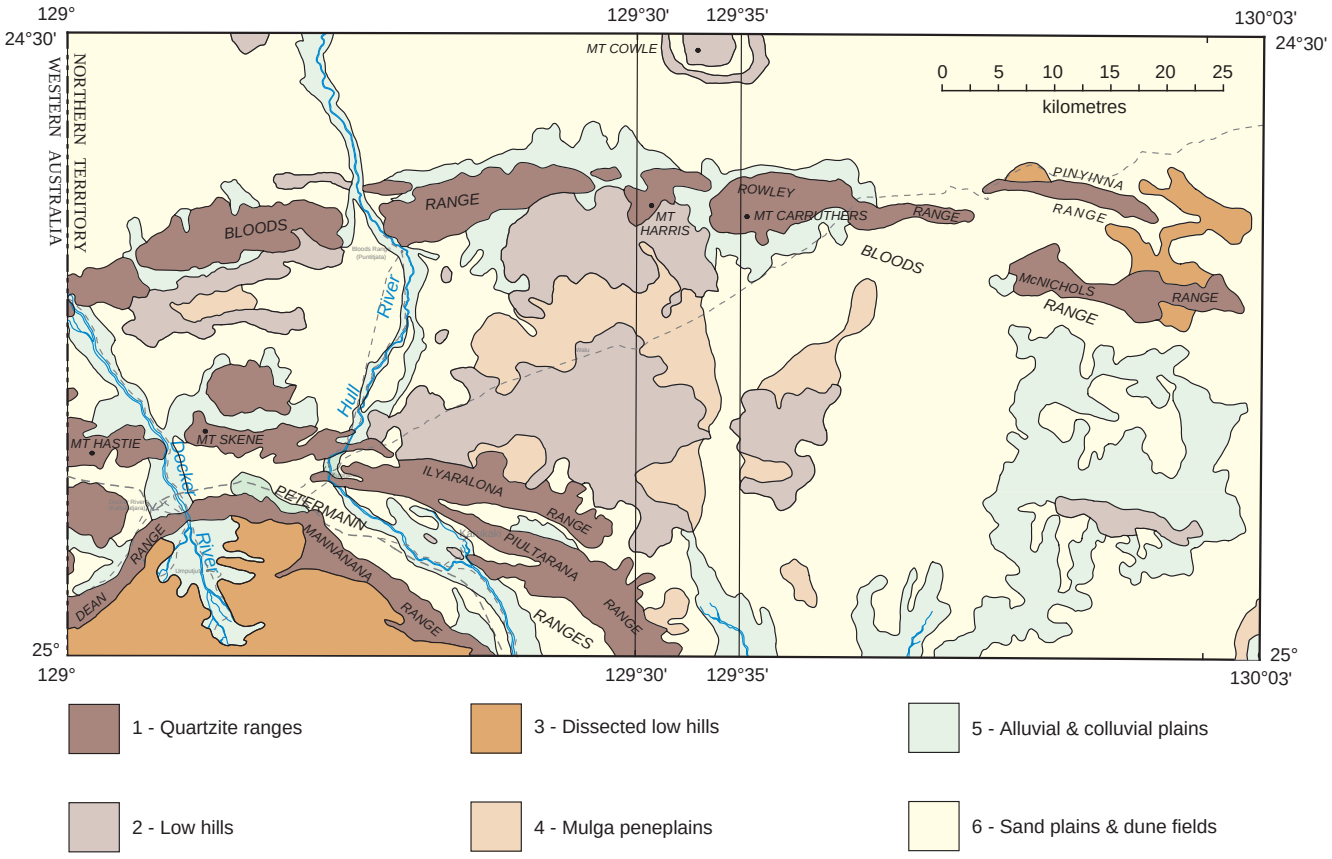


Figure 3. Generalised geomorphic units of Hull and Bloods Range. Western boundary of Bloods Range special at 129°30'E; eastern boundary of Hull special at 129°35'E.

rocks. The very southern part forms the northwestern extension of the Pottoyu Hills in PETERMANN RANGES. The hills themselves have a typical granitic form of boulders, small tors and pavements on hill slopes and summits.

Mulga peneplains – These areas are commonly developed over subcrop of the Mount Harris Basalt. The undulating rises are characterised by very gentle slopes separated by weakly developed broad drainage systems. They also include and are fringed by colluvial plains. The surface of the rises is covered by abundant vein quartz scree, and they support an open vegetation of mulga and grasses. Some areas have calcrete outcrop and subcrop that usually support low chenopod shrublands (*Maireana spp.*). The larger intervening colluvial plains support groved mulga.

Alluvial and colluvial plains – Alluvial plains flank the major drainage systems of the area, which include the Docker and Hull Rivers in the west, and the floodouts of Chirnside and Shaw Creeks in the east. The rivers flow from the south, and terminate in dunefields in the north. Channels are wide and shallow in section, and have broad sandy to loamy floodplains. In their northern extent, they appear to have breached the aeolian sand plains to some extent. Colluvial plains form around the margins of slightly more elevated areas (eg low rises) and also fringe the alluvial plains. The dominant geomorphic activity is sheetwash flow. Soils are generally sandy clay loams and sandy clay, and support abundant groved mulga.

Sand plains and dune fields – These occur in the northern, central and eastern parts of the region. Sand plains are more extensive in the southeast and central parts, whereas dune fields are best developed in the east, and to the north of Bloods and Rowley Ranges. Dunes are largely stabilised by vegetation with some minor activity on crests. Several different orientations occur across the sheet areas, reflecting the interference of wind patterns around the larger topographic features. A more consistent northwest–southeast orientation occurs in the far north, away from the ranges. The average height of dune crests varies from 8 m to 12 m above the swales.

REGIONAL GEOLOGICAL SETTING

HULL and BLOODS RANGE encompass the northern margin of the Mesoproterozoic Musgrave Block and the southern margin of the Neoproterozoic to Palaeozoic intracratonic Amadeus Basin. The region also includes a late Mesoproterozoic package of rift sediments and volcanics that underlies the southwestern Amadeus Basin (**Figure 4**).

The Musgrave Block is an east–west-oriented basement inlier that straddles the South Australian, Northern Territory and Western Australian borders. It is dominated by high- to medium-grade gneisses and intrusive rocks. The oldest known rocks in the inlier are felsic, mafic and peraluminous gneisses with protolith ages of 1600-1300 Ma (Gray 1978, Camacho and Fanning 1995, Scrimgeour *et al* 1999, White *et al* 1999). The precursors of these gneisses are largely granitic, with minor volcanic and sedimentary components (Moore and Goode 1978). During the 1200-1160 Ma Musgravian Event, these gneisses were metamorphosed under granulite and amphibolite facies conditions. Further metamorphic overprints at about 1300 Ma and 1080 Ma have been identified in the western Musgrave Block (Clarke *et al* 1995a, White *et al* 1999). The northern section of the Musgrave Block that lies within the Northern Territory is dominated by extensive magmatic bodies that intruded during and immediately after the Musgravian Event over the period 1190-1140 Ma (Edgoose *et al* 1993, Camacho and Fanning 1995, Scrimgeour *et al* 1999). Multiple phases of mafic dyke intrusions are recognised across the Musgrave Block spanning a period from 1078 Ma to 800 Ma (Goode 1970, Camacho *et al* 1991, Zhao and McCulloch 1993, Glikson *et al* 1996, Scrimgeour *et al* 1999). Two of these dyke swarms are regionally extensive and include the 1080-1070 Ma Alcurra dolerite[2] (Zhao and McCulloch 1993), and the 824 Ma Amata Dyke Swarm (Tomkinson Ranges; Shensu Sun, unpublished data cited in Glikson *et al* 1996). The Amata Dyke Swarm is correlated with the Gairdner Dyke Swarm in the Gawler Craton and Stuart Shelf (Zhao *et al* 1994) which forms an arcuate trend extending through eastern and northern South Australia and southern Northern Territory.

A rift succession that unconformably overlies Musgrave basement and disconformably underlies the Amadeus Basin is exposed in HULL and BLOODS RANGE (Lindsay and Korsch 1991). This succession comprises quartzite, quartzose sediments, mafic and felsic volcanics, polymictic conglomerate, epiclastics and red beds, and continues westward approximately 60 km into Western Australia. The package is correlated with the Neoproterozoic Bentley Supergroup which outcrops west of Bell Rock Range and north of Barrow Range in BENTLEY and TALBOT in Western Australia (Daniels 1974). The bimodal volcanics are coeval with the 1078 Ma layered mafic to ultramafic Giles Complex (western Musgrave Block), with localised small granite and charnockitic bodies and with the widespread Alcurra dolerite.

The intracratonic Amadeus Basin is a large east–west-trending structural remnant of the Centralian Superbasin that extends 800 km across the southern part of the Northern Territory and into Western Australia. It is approximately 300 km wide and locally contains more than 14 km of Neoproterozoic to Palaeozoic shallow marine to fluvial sediments (Lindsay and Korsch 1991) that represent at least nine deposition cycles separated by regional unconformities (Shaw 1991). The Amadeus Basin was connected to the Officer, Ngalia, Georgina, Wiso and Canning Basins at various times during its evolution (Shaw 1991, Walter *et al* 1995), but its present configuration was determined by two major intraplate orogenic events: the 570-530 Ma Petermann Orogeny on the southern margin and the 400-300 Ma Alice Springs Orogeny on the northern margin. A basal Neoproterozoic shallow marine/tidal succession of Dean Quartzite (correlative of the Heavitree Quartzite) and Pinyinna beds (dolostones and shales, correlative of the Bitter Springs Formation; Forman 1966b, Lindsay and Korsch 1991) outcrop in HULL and BLOODS RANGE. Stratigraphically

[2] Previously referred to as Alcurra Dyke Swarm.

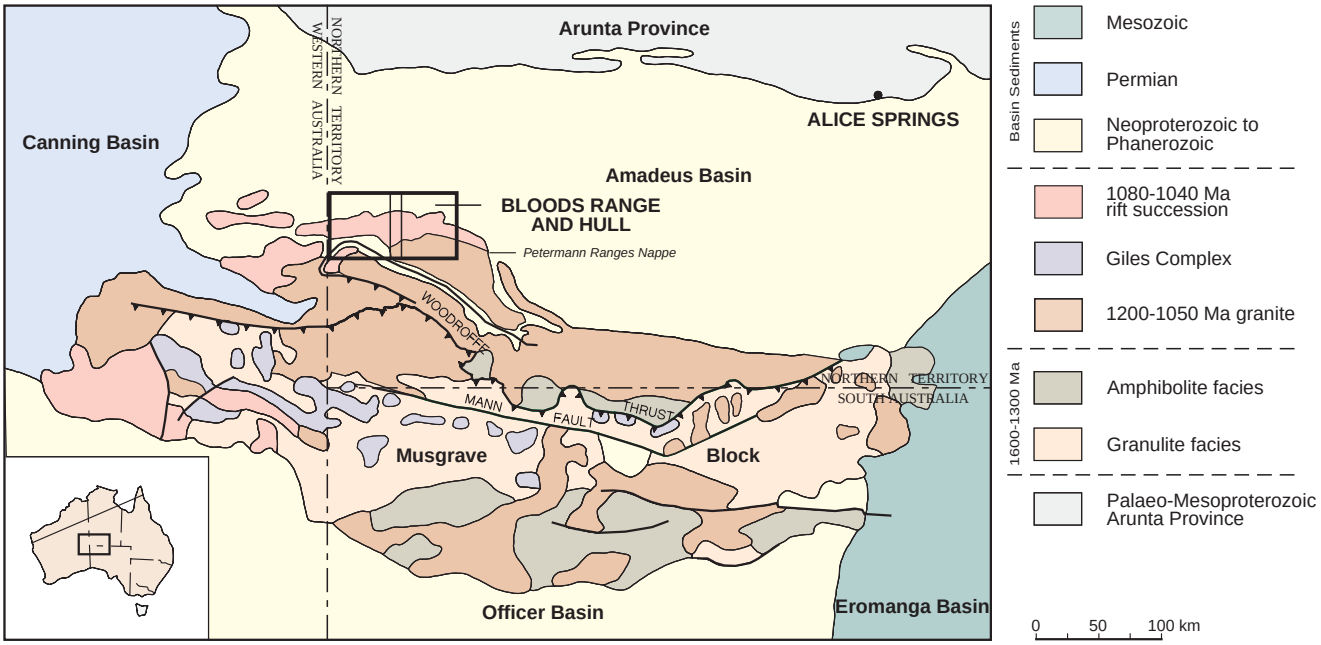


Figure 4. Regional geological setting.

above the Pinyinna beds are late Neoproterozoic sandstone-dominated sediments of the Inindia and Winnall beds (Forman 1966b, Shaw 1991). The Inindia beds are not exposed in HULL and BLOODS RANGE, whereas the Winnall beds outcrop in stratigraphic isolation as remnants preserved in doubly plunging synclinal structures on the northern margin of the mapsheets.

Intraplate deformation during the 570-530 Ma Petermann Orogeny (Maboko *et al* 1992, Clarke *et al* 1995b, Camacho 1997, Scrimgeour *et al* 1999) resulted in the exhumation and dissection of the Musgrave Block along crustal-scale structures such as the Woodroffe Thrust and Mann Fault, which are interpreted to displace the Moho (Lambeck and Burgess 1992). Dextral strike-slip movement during this orogenic event is centred on the steeply dipping Mann Fault that extends east–west across the length of the Musgrave Block. This transpressive system produced a bivergent flower structure (Myers *et al* 1996, Camacho 1997) with pervasive north-vergent deformation extending into AYERS ROCK, PETERMANN RANGES, HULL and BLOODS RANGE. The expression of the Petermann Orogeny varies across the Musgrave Block. In the Mann Ranges region, pervasive mylonitic deformation occurred at high-pressure granulite facies conditions of 12-13 kbar and 700-750°C with structurally focused fluid flow leading to localised partial melting (Scrimgeour and Close 1999). In the Musgrave Ranges (WOODROFFE, South Australia), mylonitic deformation occurred within discrete shear zones under high-pressure granulite to eclogite facies conditions (Camacho *et al* 1997, Camacho and McDougall 2000). Areas to the north of the Woodroffe Thrust were metamorphosed at greenschist to amphibolite facies conditions. The intensity of Petermann Orogeny decreased eastward, where the effects were limited to greenschist facies shear zones south of the Woodroffe Thrust (Edgoose *et al* 1993, 2002).

Structural interleaving of basal Amadeus Basin units with Musgrave basement occurred on the northwestern margin of the Musgrave Block during the Petermann Orogeny. The Petermann and Bloods Range regions are dominated by a large-scale basement-cored nappe complex that was transported northwards along a zone of intensely deformed and duplexed basement and cover successions, the Piltardi Detachment Zone (Scrimgeour *et al* 1999). The locally developed Cambrian Mount Currie Sub-basin, along the southwestern margin of the Amadeus Basin, is interpreted to be a proximal foreland basin into which conglomerate and coarse arkose were shed from the topography produced by the Petermann Orogeny (Forman 1966b, Young *et al* 2002). Palaeozoic sediments of the southern part of the Basin were deposited on a platform that developed following the Petermann Orogeny. This Palaeozoic succession includes numerous periods of non-deposition and is thinner than the succession deposited in the deeper trough to the north (Lindsay and Korsch 1991).

A second phase of less intense deformation was experienced in the southwestern Amadeus Basin during the 400-300 Ma Alice Springs Orogeny. This event produced gentle, open upright folding of the Palaeozoic successions and some tightening of Petermann-age structures in the Neoproterozoic sediments. Permian basins containing sediment of a probable glacial or fluvio-glacial origin locally overly the northern Musgrave Block and western Amadeus Basin, particularly in Western Australia.

STRATIGRAPHY

A summary of the lithological units of the Musgrave Block and Amadeus Basin exposed in HULL and BLOODS RANGE is outlined in **Table 1**.

MUSGRAVE BLOCK

Pottoyu Granite Suite

Voluminous magmatic activity during and immediately after the 1200-1160 Ma Musgravian Event is extensive throughout

UNIT, WITH MAP SYMBOL, LITHOLOGY	DISTRIBUTION	COMMENTS, AGE
PALAEOZOIC (545-251 Ma)		
Larapinta Group (Ol)		
White to red sandstone, locally bioturbated, minor siltstone conglomeratic sandstone and limestone interbeds.	Scattered mesas in eastern BLOODS RANGE.	Almost flat-lying, unconformably overlies deformed granite and onlaps deformed Dean Quartzite at McNichols Range. Thickness uncertain but >10 m. Trace fossils (eg *Diplocraterion*) on PETERMANN RANGES suggest Ordovician age.
Mount Currie Conglomerate (Ecm)		
Well rounded clasts of quartzite.	Northeast corner of BLOODS RANGE.	No lithified outcrop on BLOODS RANGE. Loose clasts on low rises overlying Pinyinna beds. Maximum thickness in AYERS ROCK probably 6-7 km. Fluvial sedimentation, in possible rift or half-graben setting. Probable Cambrian age.
UNCONFORMITY (PETERMANN OROGENY, 570-530 Ma)		
NEOPROTEROZOIC (1000-540 Ma)		
Winnall beds (Pwi)		
White quartz sandstone, minor siltstone.	Northern edge of HULL and BLOODS RANGE and east of Pinyinna Range.	Shallowly dipping strata at Mount Cowle. Isolated outcrop east of Pinyinna Range appears to underlie Mount Currie Conglonmerate.
Pinyinna beds (Ppi)		
Red and grey shale, grey phyllite, crystalline brown and grey dolomite.	Within Mannanana, Piultarana, Ilyaralona and Bloods Ranges and within Mount Skene area.	Correlated with Bitter Springs Formation. Age probably 820 Ma. Top of succession not exposed. Thickness >100 m, possibly significantly greater.
Dean Quartzite (Pde)		
Crystalline quartz sandstone, rare quartz conglomerate.	Prominent strike ridges comprising Mannanana, Piultarana, Ilyaralona and Bloods Ranges and Mount Skene, Mount Hastie areas.	Correlated with Heavitree Quartzite in northern Amadeus Basin. Age poorly constrained, but probably about 850 Ma. Thickness probably >50 m, but is typically structurally thickened.
Kulail Sandstone (Pku)		
Crystalline quartz sandstone with quartz conglomerate and quartz-muscovite layers.	Lower scarp of quartzite strike ridges including Mannanana, Bloods and Rowley Ranges. Lower slopes in Mount Hastie, Mount Skene areas.	Conformably underlies Dean Quartzite with gradational to interfingering contact. Possible deltaic depositional environment. Age similar to that of Dean Quartzite (850 Ma). Thickness laterally variable ranging from 150-300 m, where upper and lower contacts are exposed.
EROSIONAL DISCONFORMITY		
MESOPROTEROZOIC (1600-1000 Ma)		
TJAUWATA GROUP - RIFT SUCCESSION		
Bloods Range Formation (Pbl)		
Polymictic pebble conglomerate (possible debris flows), quartzite-cobble conglomerate, immature sandstone, red and dark fine sandstone and siltstone, epiclastic and volcaniclastic rocks, rare tuff.	Locally outcropping on lower slopes of Bloods and McNicholls Ranges.	Disconformable relationship with overlying Kulail Sandstone suggests period of non-deposition. Lithologically, appears to be locally derived from Puntitjata Rhyolite and Mount Harris Basalt. May represent alluvial deposition of locally derived material from underlying Puntitjata Rhyolite. Possible rift sediments.
Puntitjata Rhyolite (Pvp)		
Finely porphyritic rhyolite.	Lower slopes of Rowley Range and low hills in central to central-western sections of HULL.	Dated at 1075 ± 2 Ma (Zircon Pb-Pb evaporation). Overlies Mount Harris Basalt.
Mount Harris Basalt (Pvh)		
Amygdaloidal basalt with layered altered (silica and epidote) and unaltered zones. Rare quartzite interbeds.	Rounded hills south of Bloods and Rowley Ranges.	Intruded by Walu Granite dated at 1084 ± 9 Ma (Zircon Pb-Pb evaporation). Crosscut by dolerite dykes interpreted to belong to 1080 Ma Alcurra dolerite. Alteration banding clearly visible in outcrop.
Tjuntinanta Formation ($P tj_{a,b,c}$)		
Interlensed succession of silicified epidotised amygaloidal basalt (Ptj_a), quartzite, quartz muscovite schist, dark grey phyllitic schist (Ptj_b), volcaniclastics (Ptj_c).	Low hills north of Ilyaralona Range in central-eastern HULL and central-western BLOODS RANGE.	Thickness of unit difficult to determine due to intense structural overprint. Overlies Karukali Quartzite, upper stratigraphic contact not exposed. Possible relict pillow structures within basalt successions suggest subaqueous deposition.
Karukali Quartzite (Pka)		
Crystalline quartz sandstone containing quartz pebble conglomerate beds, trough cross-beds and heavy mineral horizons.	Localised outcrops south-southeast of Mount Harris and in central western BLOODS RANGE.	Unconformably overlies undivided Pottoyu Granite Suite and is intruded by mafic dykes interpreted to belong to the 1080 Ma Alcurra dolerite. Thickness of unit is 5-10 m. Winnowed heavy mineral horizons suggest possible shoreline setting.

Table 1. Lithological units of the Musgrave Block and Amadeus Basin on HULL and BLOODS RANGE.

UNIT, WITH MAP SYMBOL, LITHOLOGY	DISTRIBUTION	COMMENTS, AGE
ALCURRA DOLERITE (Ꝑdl)		
Dolerite dykes	Localised occurrences in central eastern HULL.	Correlated with dykes in SA dated at 1080 Ma. Recrystallised to biotite schist in some areas.
HULL GRANITE SUITE (1090-1075 Ma)		
Imbumbunna Granite (Ꝑgm)		
Coarsely porphyritic biotite-muscovite-epidote-garnet granite.	Low hills at single location 18.5 km northeast of Shaw Creek.	Geochemically related to Rowley Granophyre and Walu Granite. Weak development of foliation.
Rowley Granophyre (Ꝑgr)		
Finely porphyritic biotite-epidote granite.	Low hills 4.5 km west-southwest and south of Walu Outstation.	Geochemically related to Imbumbunna Granite and Walu Granite. Dated at 1075 ± 2 Ma (Zircon Pb-Pb evaporation). Intruded by mafic dykes interpreted to belong to the 1080 Ma Alcurra dolerite.
Walu Granite (Ꝑgwa)		
Medium-grained biotite-muscovite granite.	Single location 8.5 km southwest of Mount Harris.	SHRIMP U-Pb dating of zircons has yielded age of 1084 ± 9 Ma. Geochemically related to Rowley Granophyre and Imbumbunna Granite. Variable development of foliation.
POTTOYU GRANITE SUITE (~1190-1140 Ma)		
Undivided Pottoyu Granite Suite (Ꝑgp)	Low hills south of Dean and Mannanana Ranges. Valleys within Ilyaralona and Piultarana Ranges. Isolated low hills to subcropping in southern section of BLOODS RANGE.	Typically has very distinctive rounded phenocrysts, locally up to 6 cm in diameter. Continuation of unit in PETERMANN RANGES that yielded SHRIMP U-Pb ages of 1192 ± 13 Ma and 1144 ± 12 Ma.
Coarsely porphyritic biotite granite, typically with rapakivi texture. Less abundant equigranular granite and aplite.		
Amputjuta Dacite (Ꝑga)		
Fine to medium K-feldspar-rich equigranular biotite granite.	Low hills forming arcuate belt immediately south of Dean and Mannanana Ranges.	Ambiguous field relationships with undivided Pottoyu Granite Suite. Dated at 1153 ± 3 Ma (Zircon Pb-Pb evaporation). Geochemically similar to undivided Pottoyu Granite Suite.
Ilyaralona Granite (Ꝑgi)		
Coarsely porphyritic muscovite-biotite granite.	Limited outcrop 3.5 km north of Ilyaralona Range.	Dated at 1163 ± 4 Ma (Zircon Pb-Pb evaporation). Geochemically similar to undivided Pottoyu Granite Suite.

Table 1. (continued).

the Musgrave Block (Maboko *et al* 1991, Edgoose *et al* 1993, Camacho and Fanning 1995, Glikson *et al* 1996) and dominates the adjoining PETERMANN RANGES area (Scrimgeour *et al* 1999). The resultant granites have been termed the Kulgera Supersuite (Major and Conor 1993, Edgoose *et al* 2003). Although granites of this age are less extensive in outcrop in HULL and BLOODS RANGE, geophysical interpretation suggests that they dominate the basement. All 1190-1140 Ma granites in HULL and BLOODS RANGE are assigned to the Pottoyu Granite Suite (Scrimgeour *et al* 1999).

Undivided Pottoyu Granite Suite (Ꝑgp)

The undivided Pottoyu Granite Suite is a regionally extensive unit that mainly outcrops in the Pottoyu Hills, which extend across northern PETERMANN RANGES and southwestern BLOODS RANGE. Small, localised outcrops of the granite are scattered to the northeast of Walu Outstation and in the southern section of BLOODS RANGE. Unconformably overlying the granite is either Karukali Quartzite (basal Tjauwata Group) or Dean Quartzite/Kulail Sandstone (basal sediments of the Amadeus Basin). In HULL, mafic dykes probably associated with the 1080-1070 Ma Alcurra dolerite intrude the undivided Pottoyu Granite Suite.

The suite comprises several phases with complex intrusive relationships. The dominant phase is coarsely porphyritic with large spherical phenocrysts of K-feldspar typically up to four centimetres in diameter, commonly showing rapakivi textures. The assemblage also contains biotite, and minor titanite and opaques, with or without epidote, allanite, muscovite and chlorite. Muscovite and chlorite are likely to be metamorphic in origin. Hornblende occurs as a secondary mineral associated with increased strain and amphibolite-grade metamorphism in the Pottoyu Hills. Other phases within the suite include coarse- to medium-grained weakly porphyritic to equigranular and aplitic units. A large sill-like body of coarse equigranular granite lies at the northern contact with the Amputjuta Dacite, west of the Ruined Rampart.

Geochronology on samples of undivided Pottoyu Granite Suite from PETERMANN RANGES has yielded SHRIMP U-Pb magmatic zircon ages of 1144 ± 12 Ma and 1192 ± 13 Ma and Rb-Sr whole rock ages of 1150 Ma and 1190 Ma (Scrimgeour *et al* 1999). This suggests a prolonged period of intrusion, spanning approximately 45 million years for the Pottoyu Granite Suite.

Amputjuta Dacite (Ꝑga)

The Amputjuta Dacite (new name, **see Appendix 1**) is a hypabyssal intrusive that underlies the Dean Quartzite along the Mannanana Range. It has a sharp contact with the undivided Pottoyu Granite Suite, but outcrop relationships are ambiguous, showing mutually intrusive associations. Geochemical analysis indicates that the Amputjuta Dacite

forms part of the Pottoyu Granite Suite and the porphyritic texture of the unit suggests that the dacite is a shallow-level intrusive equivalent of the main megacrystic pluton. Mafic dykes that are probably associated with the 1080-1070 Ma Alcurra dolerite intrude the Amputjuta Dacite.

Mineralogically the dacite comprises phenocrysts of plagioclase (labradorite) and rounded quartz in a matrix that contains quartz, K-feldspar, plagioclase, chlorite and biotite. In zones of high strain, developed during the Petermann Orogeny, a fine-grained biotite foliation is accompanied by the near complete breakdown of plagioclase phenocrysts to fine-grained sericite and muscovite.

Pb-Pb dating of zircons using the Kober evaporation technique has yielded a magmatic age of 1153 ± 3 Ma for the Amputjuta Dacite.

Ilyaralona Granite (Pgi)

A small area of outcrop of coarsely porphyritic biotite-muscovite granite occurs immediately north of the Ilyaralona Range at location ET350534. The Ilyaralona Granite (new name, see **Appendix 1**) characteristically contains abundant phenocrysts of euhedral pink K-feldspar and plagioclase in a quartz, biotite, muscovite and epidote matrix (**Figure 5**). Occasional mafic xenoliths are present throughout the granite. In thin section, some plagioclase crystals show antiperthitic textures and partial recrystallisation is indicated by granoblastic textures in the finer-grained quartz crystals. Geochemical analysis indicates that the Ilyaralona Granite forms part of the Pottoyu Granite Suite. The granite has yielded a Kober Pb-Pb zircon evaporation age of 1163 ± 4 Ma (Close *et al* 2003).

Tjauwata Group

The newly named Tjauwata Group (see **Appendix 1**) is a rift succession, exposed beneath basal sediments of the southwestern Amadeus Basin. This Group incorporates three units from the First Edition map (Forman 1966a), the Bloods Range beds, Mount Harris Basalt and an unnamed intrusive porphyry, and is correlated with similar lithologies in adjoining parts of Western Australia (**Figure 4**). NTGS mapping has subdivided and redefined the stratigraphy of this rift succession in the Northern Territory, under the name Tjauwata Group.

The thickness of the group is difficult to estimate due to widespread structural repetition. However, it is possible to determine an overall, generally north-dipping stratigraphy. The Karukali Quartzite forms a thin, sporadically preserved basal unit, which is overlain by interlayered quartzitic sediments, volcaniclastics, and mafic and minor felsic volcanics of the Tjuninanta Formation. This is overlain by the Mount Harris Basalt, an apparently thick succession of well layered basalt flows. In places, the Mount Harris Basalt is overlain by felsic volcanics of the Puntitjata Rhyolite. The top of the group comprises a succession of interbedded volcaniclastics and sediments of the Bloods Range Formation. A disconformity, representing a depositional hiatus and probable erosion, separates the Tjauwata Group rift succession from overlying transgressive sediments (Kulail Sandstone transitional into Dean Quartzite) of the southwestern Amadeus Basin.

The relationship of the Tjauwata Group to the overlying Amadeus Basin has been the subject of some debate. Some authors (eg Korsch and Lindsay 1989, Lindsay and Korsch 1991) interpreted the rift succession to be the result of a thermal peak related to an extensional phase that initiated the opening of the Amadeus Basin. Overlying basal units of the basin would therefore represent the sag phase following rifting. Other workers (eg Shaw 1991) believed the rift succession to be too old to be directly related to the development of the basin. The age of the basal Amadeus Basin succession [Deposition Interval 1 of Shaw (1991), which includes the Heavitree/Dean Quartzite and Bitter Springs Formation/Pinyinna beds] is constrained to a 200-300 million year time interval by Sm-Nd dating of Zhao and McCulloch (1993). The Stuart Pass Dolerite, which intrudes Arunta basement but does not crosscut Amadeus Basin sediments, yields an age of 1083 ± 23 Ma, whereas correlatives of spilites in the Bitter Springs Formation are dated at 790 ± 40 Ma and 797 ± 49 Ma. Shaw (1991)



Figure 5. Typical Ilyaralona Granite (Pgi) at ET352537.



Figure 6. Karukali Quartzite (Ɛka) showing conglomerate lenses with quartz cobble clasts, and heavy mineral horizons (ET626532).

recognised that the volcanics of the rift were likely to be related to the Smoke Hill Felsic Volcanics of the Tollu Group in the western Musgrave Block, which has yielded a SHRIMP U-Pb zircon age of 1078 Ma (Glikson *et al* 1996). Using this correlation as an age constraint for the rift succession would result in a 150-200 Ma time span between the rift and subsequent sag phases, which is longer than would be expected in a typical rift-sag basin (Shaw 1991). More recently, Camacho (in press) argued for a considerable time break within the Bitter Springs Formation between the lower Gillen Member and the upper Loves Creek Member, which contains the spilites. This interpretation would suggest that deposition was more or less continuous from the 1090-1075 Ma Tjauwata/Tollu Group into the transgressive phase of the Heavitree/Dean Quartzite and Gillen Member; this was then followed by a period of quiescence before the onset of the 820 Ma Loves Creek Member.

The extent of the Tjauwata Group under the present day Amadeus Basin is unknown. Wellman (1991) noted about 1 km disparity between the estimated (from outcrop) thickness of the sedimentary succession and the interpreted depth to magnetic basement across much of the basin area. Potentially, this extra thickness could be accounted for by the Tjauwata Group, including the Mount Harris Basalt, which is largely non-magnetic, extending under a large area in the southern and possibly central parts of the Basin. In addition, the previously reported thickness of basal Neoproterozoic sediments in the southern part of the Basin has been overestimated. The Dean Quartzite is substantially thickened by structural repetition in outcrops on the southern margin, and away from the basin margin probably forms a thin sheet. Scattered information from drilling in the southern part of the Basin indicates that in many places, Neoproterozoic units are often absent from the section [eg Murphy 1 (KULGERA) which contained no Winnall beds]. It is therefore possible that a considerable thickness of Tjauwata Group sediments may underlie parts of the basin.

Recent drilling by the Geological Survey of Western Australia, approximately 350 km southwest of Giles Meteorological Station (Empress 1A), intersected >50 m of basalt underlying basal Officer Basin sediments (Stevens and Apak 1999). K-Ar dating of the basalt resulted in an age of 1058 ± 13 Ma suggesting that the unit might be coeval with the Tjauwata Group and 1080-1070 Ma Tollu Group. This provides further evidence that extensive volcanics may underlie much of the western Centralian Superbasin.

Karukali Quartzite (Ɛka)

A thin unit of quartzite, quartz muscovite schist and quartz conglomerate unconformably overlying granite basement forms the basal Karukali Quartzite (new name, see **Appendix 1**). This unit is overlain by basalt and sediments of the Tjuninanta Formation. Outcrop is restricted to two regions, around ET562675 and ET610534. Poorly preserved dolerite dykes, interpreted to be part of the Alcurra dolerite, intrude the quartzite at location ET563674. The succession is 5-10 m thick and contains lenses of rounded quartz cobble clasts, quartz gravel layers and horizons of heavy mineral assemblages dominated by hematite (**Figure 6**). Trough cross-beds are rarely preserved. Occasional lenses of rounded, pink K-feldspar clasts within the quartzite suggest that sediment was locally derived from the underlying undivided Pottoyu Granite Suite.

Moderate to intense deformation has produced a pervasive well developed muscovite foliation associated with isoclinal folding and non-coaxial shear fabrics. Rodding of quartz gravel and pebble clasts defines a locally developed stretching lineation. The contact with granite basement is often reactivated to form a shear zone.

Tjuninanta Formation (Ɛtj$_{a, b, c}$)

The Tjuninanta Formation (new name, see **Appendix 1**) is a succession of interbedded sediments, volcaniclastic rocks, and mafic and felsic volcanics that are both stratigraphically and structurally repeated. It has been subdivided into three mappable lithofacies: sedimentary rocks, mafic volcanics, and epiclastics with minor felsic volcanics.

The rocks of the Tjuninanta Formation were previously included within the Bloods Range beds, unnamed porphyry,

and Mount Harris Basalt on the First Edition map (Forman 1966a). NTGS mapping has redefined the stratigraphic position and lithologies of the Bloods Range Formation to sit at the top of the Tjauwata Group. The Tjuninanta Formation, a dominantly quartzose metasedimentary package, forms the lower stratigraphy of the group, whereas the Mount Harris Basalt is redefined as a thick succession of layered basalt flows that overlies the Tjuninanta Formation.

Basalt is intercalated with sediments and volcaniclastic and epiclastic rocks, and has been included in the Tjuninanta Formation rather than the Mount Harris Basalt in recognition of the difference in depositional environment. Many outcrops of 'unnamed porphyry' are epiclastic to varying degrees and are clearly interbedded with sediments and basalt. These rocks have also been incorporated into the Tjuninanta Formation, and the intrusive portions of the former unit are now named Rowley Granophyre.

Mafic volcanic rocks (Ptj$_a$)

Basalts are intercalated with both sediments and felsic volcanics/epiclastic rocks throughout most of the Tjuninanta Formation. Narrow bands of metasandstone within the basalt layers of the formation are less mature, being poorly sorted with angular lithic fragments, and are commonly epidotised along with the enclosing basalt. As in the Mount Harris Basalt, epidotisation and silicification is patchy but widespread. However, in contrast to the well developed layering in the Mount Harris Basalt, highly silicified, epidotised, and amygdaloidal basalt in these rocks forms boulder piles about 2-4 m in diameter, surrounded by foliated, weakly epidotised, non-amygdaloidal fine-grained basalt. The surrounding basalt is often brecciated and sometimes includes visible quartz grains. These features lead to an interpretation that these rocks are altered pillow basalts (PW Haines, University of Tasmania, pers comm 1999). The silicified boulder piles are poorly preserved pillows, and the inter-pillow basalt is hyaloclastite (comparable to Hyaloclastite A of Yamagishi 1987). The presence of quartz grains in the hyaloclastite is interpreted to indicate incorporation of a small component of sedimentary material during emplacement. Pillows constitute about 10-20% of the outcrop. They contain large abundant amygdales (vesicles infilled with quartz and epidote) and this may indicate that the basalts were emplaced into relatively shallow water (McPhie *et al* 1993). The dominance of pillow lavas in comparison to lava flows in subaqueous basaltic flows has been noted in distal emplacement settings (Waters and Wallace 1992). Subsequent deformation and the high degree of alteration of this basalt succession have destroyed the finer textures of these rocks, preventing the identification of clasts or fragmentation in the hyaloclastite.

The hyaloclastite carries a moderate to strong foliation that anastomoses around the silicified pillows. This suggests that alteration of the basalts occurred prior to deformation during the Petermann Orogeny, although it is possible that post-deformation silicification could have produced the same effect. It is most likely that silicification of the basalts occurred soon after extrusion and/or emplacement (*see Mount Harris Basalt*).

Metasedimentary rocks (Ptj$_b$)

Metasedimentary rocks of the Tjuninanta Formation are dominated by quartz-muscovite schist and muscovite-bearing quartzite. Quartzite, lithic metasandstone, minor outcrops of dark grey slate and rare dark diagenetic chert are also present. The chert appears to have formed as nodules within the slate. The metasediments are invariably highly strained, with a strong S_1 fabric of muscovite/sericite that often obliterates S_0. Generally, bedding is only evident where S_0 and S_1 are at an angle, eg in the hinges of folds. The succession is tightly folded with S_1 axial planar to the folds.

Most metasedimentary rocks of the Tjuninanta Formation contain very little locally derived volcanic detritus. The exception is in narrow zones immediately adjacent to basalt (Ptj$_a$) where mafic volcanic material is locally visible in quartz-rich sediments. The relatively clean quartz-muscovite schists and muscovite quartzites appear to have a mature basement source, with muscovite developed during subsequent deformation and low-grade metamorphism. This suggests that intermittent volcanism during early phases of the rifting did not result in major changes to the sediment source area.

Volcaniclastic and epiclastic rocks (Ptj$_c$)

Most of the exposures of this lithofacies were formerly mapped as unnamed intrusive porphyry (Forman 1966a, b). In outcrop, the rocks consist of sparsely to abundantly porphyritic K-feldspar and quartz phenocrysts/clasts in a pale fine-grained quartz and muscovite/sericite groundmass. Phenocrysts/clasts can be up to 3 cm but are more commonly 2-3 mm, and the finely and coarsely porphyritic material is commonly interlayered on outcrop scale, giving a bedded appearance. Exposures consist of several types: discrete outcrops in contact with sedimentary rocks; narrow (0.5 m or less) zones within basalt; and one extensive area in contact with basalt.

In thin section, the largely volcanic nature of these rocks is apparent. Both phenocrystic/clastic quartz and feldspar show common embayment and corrosion on grain boundaries, and have subrounded shapes. Some angular grains also occur. Most large grains are clear, although some quartz shows weak undulose extinction. Others are finely recrystallised and commonly consist of intergrown quartz and feldspar, indicating that they may be lithic in origin. These grains are generally angular and irregular in outline, or may be stretched in the fabric where shearing has been more intense. Alteration is ubiquitous, with many feldspars being partially replaced by epidote. The matrix comprises fine-grained quartz, feldspar and white mica. New growth of coarser fresh muscovite is locally apparent. Widespread recrystallisation has precluded the preservation of any obviously volcanic textures in the matrix.

Mount Harris Basalt (Pvh)

Mafic volcanics outcrop extensively north of Ilyaralona Range and south of Bloods Range with isolated outcrops beneath Mannanana Range, south of Piultarana Range and at the base of the Wailarra Hills in IMBUMBUNNA. The basalt



Figure 7. Veins of Walu Granite intruding Mount Harris Basalt (**Ꝑ**vh) near ET452697.



Figure 8. Prominent layering in Mount Harris Basalt (**Ꝑ**vh) near ET553733.

flows of the Mount Harris Basalt (see **Appendix 1**) overlie the Karukali Quartzite and probably predate the Puntitjata Rhyolite although the stratigraphic relationships are not clear. Field relationships indicate that the Walu Granite intrudes the Mount Harris Basalt (**Figure 7**), placing an minimum age constraint of 1084 ± 9 Ma on the emplacement of the basalt. Dolerite dykes that are interpreted to be of the Alcurra dolerite, crosscut the Mount Harris Basalt with a coarse-grained gabbro outcropping at ET516738. The exact thickness of the basalt succession is not known due to structural complexity, although the minimum thickness is estimated at 1-2 km.

The Mount Harris Basalt has a distinctive banded appearance in outcrop due to alternating resistant, fine-grained, unaltered, foliated layers and unfoliated pervasively silicified, epidotised, and amygdaloidal layers (**Figure 8**). The amygdules vary in size from 3 mm to 6 cm, with an average diameter of 0.5-0.75 cm. Milky quartz, pink K-feldspar and epidote infill the amygdules and the inward growth pattern of the quartz is locally visible. Narrow veins of epidote, milky quartz and quartz + hematite crosscut the basalt.

The alternation of unaltered and altered layers within the Mount Harris Basalt is interpreted to be the result of siliceous fluids focused along amygdaloidal flows. Banding is clearly visible on basalt hills immediately east of Mount Harris, with altered 3-4 m thick layers forming prominent ridges that dip shallowly southwest to northwest. Less altered basaltic layers are 5-8 m thick and carry the regional S_2 fabric that generally dips east.

Puntitjata Rhyolite (Ꝑvp)

The Puntitjata Rhyolite (new name, see **Appendix 1**) lies in the upper part of the Tjauwata Group and is interpreted to immediately overlie, or be laterally equivalent to the Mount Harris Basalt and to underlie the Bloods Range Formation in the overall northward-younging succession. Outcropping

stratigraphic relationships are not always preserved, as in places, the basalt is absent and the rhyolite is structurally repeated with the overlying Bloods Range Formation and the Kulail Sandstone/Dean Quartzite transgressive succession. Where the rhyolite is absent, the Mount Harris Basalt is immediately overlain by these units. Pb-Pb zircon dating of a sample of Puntitjata Rhyolite gave an age of 1075 ± 2.5 Ma, interpreted to be the timing of crystallisation of the rhyolite (Close *at al* 2003).

The Puntitjata Rhyolite is sporadically exposed along the southern footslopes of the Bloods and Rowley Ranges, in a few localities west of the Hull River, around the Mount Skene Ranges and in a few isolated outcrops within the Mount Harris Basalt. It is generally strongly foliated with a dominant southeast dip, particularly along the Bloods and Rowley Ranges. It is also strongly weathered, with the majority of exposures dominated by pale, kaolinised material with rounded quartz in relief on weathered surfaces. Much of this extensive weathering is probably Palaeogene-Neogene in age, when much of the succession was buried below extensive colluvial fans flanking the ranges. Fresh rock is generally highly silicified and forms closely jointed outcrop with very weak to no foliation apparent.

Along the Bloods and Rowley Ranges, the upper part of the Puntitjata Rhyolite is dominated by tuffs, probable epiclastic rocks and minor silty sediments, in contrast to the middle and lower parts, which are interpreted to consist largely of flows. Even in highly weathered material, tuffs and epiclastics can be recognised due to the abundance of rounded quartz on weathered surfaces, whereas flows generally contain very little quartz as phenocrysts. Quartz in tuffs and epiclastics consists of both phenocrysts and composite fragments. Very weak layering in a few places could be relict flow banding, but is more likely to be depositional layering in tuffs.

Flows consist of a very fine-grained groundmass, which is cherty where the rock is silicified, with abundant tabular pink K-feldspar, 2-3 mm in length, and less common quartz phenocrysts. The rocks vary from purple-brown to dark grey, and locally have a weakly vesicular appearance.

Tuff from the southern flank of Rowley Range shows unwelded glass shards and a fine ash-like groundmass. It contains phenocrysts that consist of quartz, quartz-feldspar and sometimes quartz-muscovite, some of which are interpreted to be lithic fragments. The groundmass is invariably a cryptocrystalline brown material. In the flows, some samples show phenocrysts with a narrow rim of dark matrix. These may be inherited fragments, indicating that the flows are epiclastic to some extent. The dirty and varied nature of zircon in the rock suggests these crystals are also largely inherited, ie incorporated prior to eruption.

The contact with the overlying Bloods Range Formation appears to be gradational to transitional, with tuffs and epiclastic rocks in the upper part of the rhyolite grading into volcaniclastics and sediments of the Bloods Range Formation.

Bloods Range Formation (Ꝑbl)

The definition of the Bloods Range Formation (formerly Bloods Range beds, see **Appendix 1**) in the First Edition mapping of BLOODS RANGE included all the sedimentary rocks between the Musgrave basement and Dean Quartzite of the Amadeus Basin. The term Bloods Range Formation is now confined to a succession of siltstone, fine sandstone, conglomerate and volcaniclastic rocks that overlies the Puntitjata Rhyolite and Mount Harris Basalt, and underlies the basal transgressive Kulail Sandstone and Dean Quartzite of the Amadeus Basin. The definition describes a stratigraphic interval rather than a distinctive and uniform sedimentary succession, as the Bloods Range Formation shows considerable variation in lithology across its extent. These lithological variations are interpreted to reflect localised sediment sources.

The Bloods Range Formation overlies Puntitjata Rhyolite on the footslopes of the Bloods and Rowley Ranges. Most outcrops are weathered and carry a moderate to strong, generally southeast-dipping foliation. The formation comprises red-bed sediments, volcaniclastic rocks, interlayered fine sandstone, siltstone and clast-supported

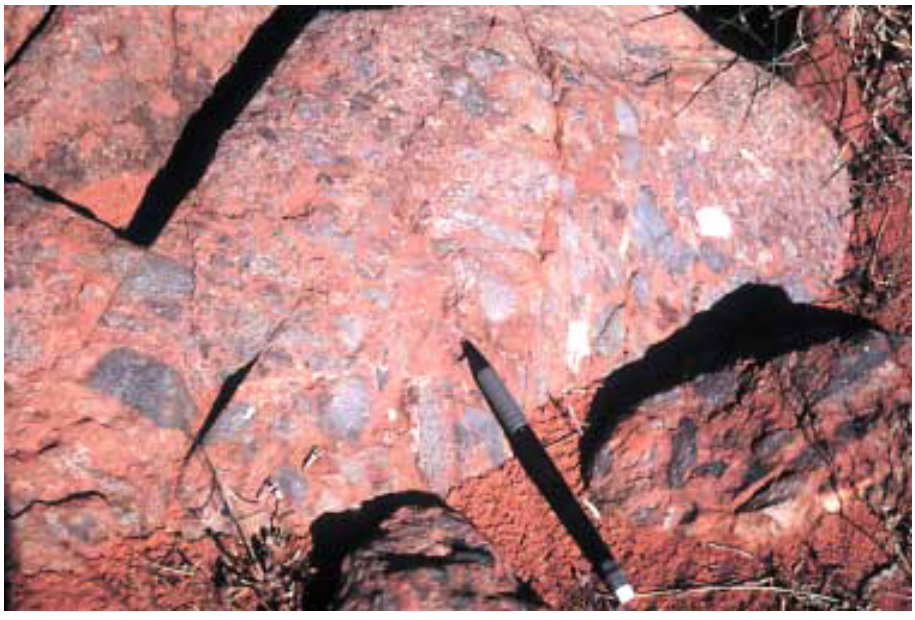


Figure 9. Polymictic clasts in conglomeratic unit of Bloods Range Formation (Ꝑbl) near ET408752.

pebble conglomerate, and is characterised by lateral variations in thickness and internal stratigraphy. Clasts within the conglomerate range from cobbles to pebbles, within a matrix ranging from grit to fine silt-sized particles. The clasts are polymictic, dominated by purple-red altered felsic volcanic material, with a minor component of rip-up material from interlayered sandstone and siltstone (**Figure 9**). The composition of the matrix varies from very fine volcanic detritus with rare subrounded to subangular undulose quartz grains to quartz-dominated, with subangular to subrounded quartz grains. The increased quartz component suggests local reworking or a more distant sediment source.

Exposures of Bloods Range Formation elsewhere in the mapsheet (eg Mount Skene and Mount Hastie, and including the region near Mount Berteaux in PETERMANN RANGES) comprise lithologies that are interpreted to reflect an increasingly mixed sediment source. Local provenance is still clearly indicated by the feldspathic and immature nature of most of the sediments, suggesting that they are largely derived from underlying Musgrave basement, but in general, the sediments contain a higher quartz content. In addition, coarser units contain well rounded vein quartz and quartzite pebble- and cobble-sized clasts interpreted to have been derived from a distal source. Limited interlayered mafic and felsic extrusives occur within the Bloods Range Formation in the Mount Berteaux region. The Wankari volcanics in PETERMANN RANGES yielded a Kober Pb-Pb zircon age of 1041 ± 2 Ma (Scrimgeour *et al* 1999) and are interpreted to underlie quartz-rich sediments of the Bloods Range Formation, although intense structural overprinting makes this stratigraphic interpretation equivocal.

Depositional Environment of the Tjauwata Group

Initial extension after some degree of uplift of the Musgrave basement saw a weak marine incursion and deposition of the thin and sporadically preserved Karukali Quartzite in a shoreline setting, interpreted from heavy mineral concentrations along bedding surfaces. Continued extension saw incipient rifting with resultant bimodal volcanism and dominantly quartz-rich sedimentation (Tjuninanta Formation). Most of the sedimentary units were derived from a mature basement source with only local incorporation of contemporaneous volcanic detritus. The preservation of a basement sediment source and the uniformity of the sediments suggests that intermittent volcanism during these early phases of rifting did not result in major changes to the sediment source area and these sediments can be classified as an inter-eruptive succession (Orton 1995, 1996); that is they were deposited by sedimentary processes without significant volcanic influence. The presence of pillow basalts indicates an aqueous environment, and the large size and abundance of the amygdales (vesicles infilled with quartz and epidote) in the pillows may indicate the basalts were emplaced into relatively shallow water (McPhie *et al* 1993). The dominance of pillow lavas in comparison to lava flows in subaqueous basaltic flows has been noted in distal emplacement settings (Waters and Wallace 1992). The Tjuninanta Formation is interpreted to have been deposited in a shallow water setting, possibly marine, as suggested by the intercalated pillow basalts.

Extension and rifting continued, with a probably thick (1-2 km?) accumulation of basalt in numerous thin flows (Mount Harris Basalt). This was followed by a succession of felsic volcanic flows, tuffs and minor epiclastics (Puntitjata Rhyolite), which is also probably thick. The absence of water interaction features such as pillow structures and hyaloclastites in the Mount Harris Basalt and the Puntitjata Rhyolite suggests deposition in a subaerial environment. The presence of bimodal volcanics with little to no sedimentary input indicates a shift to a more proximal location within the rift in comparison to the interpreted more distal succession of the underlying Tjuninanta Formation.

The environment of deposition of the Bloods Range Formation is interpreted to have been rapidly changing and laterally variable on both the local and broader scale, reflecting sedimentation in a range of alluvial settings that vary in space and time. Coarse- to medium-grained clastics (polymictic pebble conglomerate and volcanogenic-rich sediments) accumulated in proximal alluvial fans and associated fast-flowing, braided streams, that often involved the cannibalising of partly lithified sediments deposited during earlier cycles. Finer-grained portions of the succession probably accumulated as overbank deposits, in abandoned channels and as a result of the disruption of established drainage by local eruptive events. It is possible that the polymictic pebble conglomerate in part represents debris flows, although the recognition of debris flows is difficult in ancient volcanic environments. Most of the rocks are moderately strained, but it is probable that some of the elongation and parallelism of larger clasts is due to imbrication, which would be expected in channel deposits of braided stream systems, but which have also been described in channel debris flows (Orton 1996). Although the presence of indisputable flows is ambiguous in the Bloods Range Formation, the lateral and vertical variation of facies, the clearly local provenance of sediments, and the abundance of volcanogenic detritus, indicate this to be a syn-eruptive succession as described in Orton (1995).

Correlations with the Bentley Supergroup

Important correlations can be made between the newly defined Tjauwata Group and parts of the Bentley Supergroup of the Blackstone region in Western Australia. The Bentley Supergroup comprises a succession of sediments and volcanics that unconformably overlies granulite, gneiss and schist of the Musgrave Block (Daniels 1974). The Supergroup has been divided into four groups, two of which, the Tollu and Pussy Cat Groups, are thought to be lateral equivalents (Daniels 1974). The Tjauwata Group shows close affinities with the Tollu Group in terms of stratigraphic position, lithological similarities and age. Proposed correlations between the two groups are illustrated in **Figure 10** and described below.

The basal Karukali Quartzite, which consists of quartzite, quartz muscovite schist and quartz conglomerate, is correlated with the MacDougall Formation, the basal unit of the Tollu Group (Daniels 1974, Glikson *et al* 1996). This formation comprises a similar succession of quartzite, sandstone and rounded pebble conglomerate that unconformably overlies granite of the Musgrave Block.

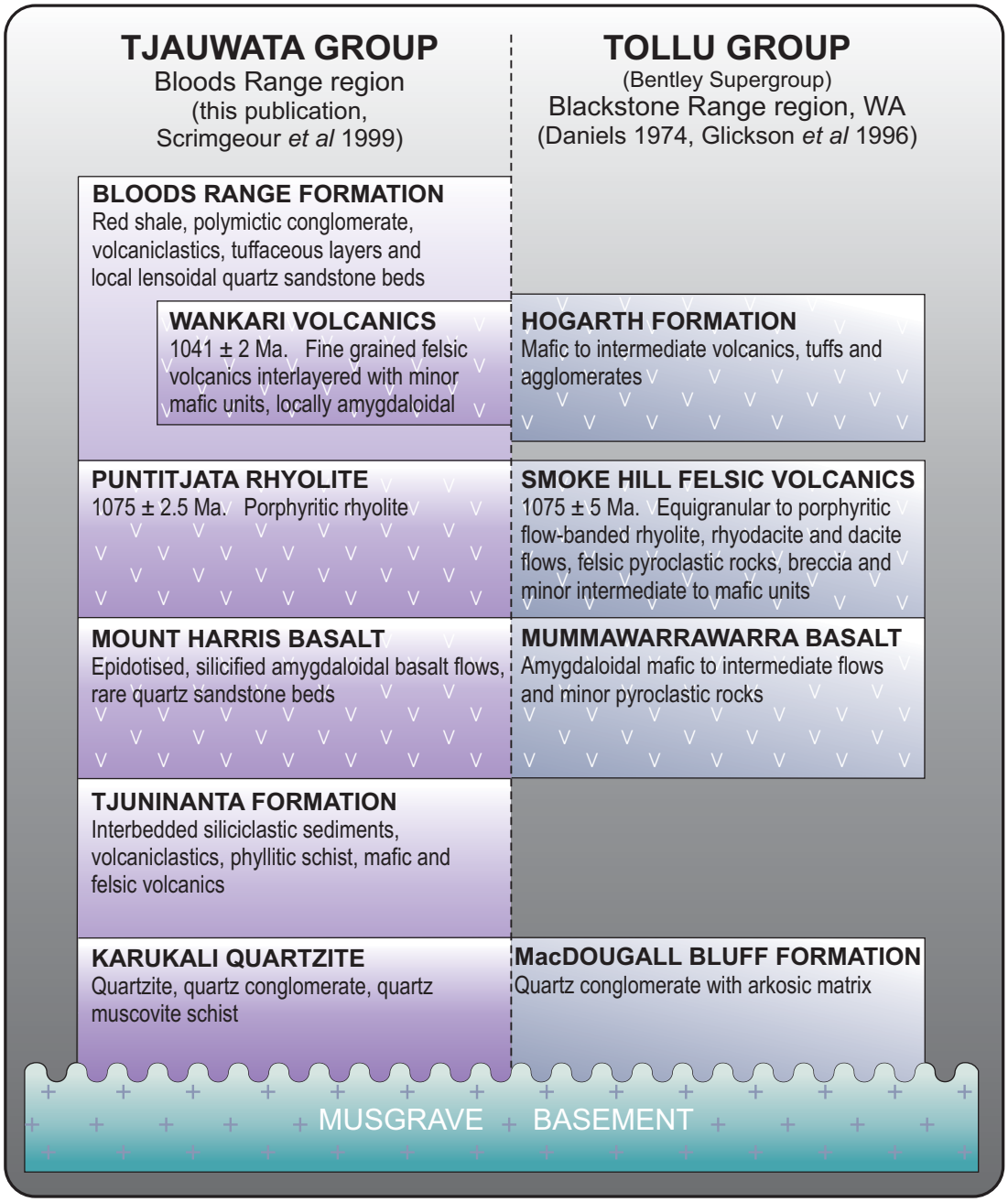


Figure 10. Correlations between Tjauwata Group and Tollu Group (western Musgrave Block, WA).

Conformably overlying the MacDougall Formation is the Mummawarrawarra Basalt of the Tollu Group, comprising a succession of thin, vesicular and amygdaloidal basalt flows and rare tuffs that are variable epidotised. The Mummawarrawarra Basalt is locally intruded by basaltic dykes and gabbroic stocks (Daniels 1974, Glikson *et al* 1996). Correlation is made between the Mummawarrawarra Basalt and the Mount Harris Basalt of the Tjauwata Group based on lithological similarities, general stratigraphic position and geochemical similarities (*see Geochemistry*). No equivalent of the Tjuninanta Formation occurs within the Tollu Group. However, a succession of interlayered siltstone, shale, dolomite and epidotised amygdaloidal basalt constitutes the Glyde Formation of the Pussy Cat Group, which is the lateral equivalent of the Tollu Group (Daniels 1974), and this formation may be equivalent to the Tjuninanta Formation. The absence of an equivalent unit within the Tollu Group is not surprising given the dynamics of deposition within the pre-Amadeus rift basin, which is likely to have resulted in a degree of lateral stratigraphic variation within the regional succession.

Within the Tollu Group, the Mummawarrawarra Basalt is overlain by the Smoke Hill Felsic Volcanics that comprise rhyolite, rhyodacite and dacite flows with pyroclastic rocks and minor intermediate to mafic components (Glikson *et al* 1996). In some areas, flow banding and contorted layering are features of this volcanic succession (Daniels 1974). A U-Pb SHRIMP zircon age of 1078 ± 5 Ma for the felsic volcanic was obtained by Sun *et al* (1996) and Pb-Pb dating of zircon in a sample of Puntitjata Rhyolite has resulted in a similar age of 1075 ± 2.5 Ma, confirming that the two suites are coeval.

The Hogarth Formation overlies the Smoke Hill Felsic Volcanics and forms the upper part of the Tollu Group. This

formation comprises fine-grained mafic to intermediate vesicular volcanic lavas, tuffs and agglomerates (Daniels 1974). Lithological similarity and stratigraphic position has lead to a broad correlation of the Hogarth Formation with the Wankari volcanics, which occur within the Bloods Range Formation of the Tjauwata Group in PETERMANN RANGES. U-Pb SHRIMP dating of zircons from the Wankari volcanics yielded an age of 1051 ± 22 Ma, whereas Pb-Pb Kober dating of the sample resulted in an age of 1041 ± 2 Ma (Scrimgeour *et al* 1999).

1090 - 1060 Ma intrusive rocks

Hull Granite Suite

The Hull Granite Suite (new name, see **Appendix 1**) comprises a group of granites with a strong geochemical affinity, and ages of about 1080 Ma. This suite is correlated with the 1071 ± 5 Ma Angatja Granite in PETERMANN RANGES (Scrimgeour *et al* 1999) and similar 1080-1060 Ma granites in the western Musgrave Block (Glikson *et al* 1996). This granite suite forms the felsic intrusive phase of a major magmatic event from 1080-1040 Ma that produced the voluminous mafic to ultramafic magmas of the Giles Complex in the western Musgrave Block and bimodal extrusive units of the Tollu Group (Sun *et al* 1996). Igneous activity during this period is thought to have been a combination of melting of granulite facies country rock due to the emplacement of large volumes of mafic magmas, and derivation from mafic magmas as a result of coupled crustal assimilation and fractional crystallisation (Sun *et al* 1996)

Walu Granite (Pgwa)

The Walu Granite (new name, see **Appendix 1**) is exposed in several small outcrops around 10 km southwest of Mount Harris. On the northwest slope of the westernmost hill, rare narrow veins of granite intrude the Mount Harris Basalt near the contact, although no xenoliths of basalt were observed in the granite. The granite is medium to medium-fine-grained, leucocratic and contains greenish biotite and rare hornblende as small clots. Patches and veins of epidote and quartz are common throughout. A weak foliation is locally developed in narrow zones of strain, in contrast to unsilicified parts of the nearby basalt, which show a prominent fabric. At one locality, the Walu Granite is intruded by a narrow, strongly sheared mafic dyke, now largely retrogressed to biotite and chlorite. The dyke is interpreted to be part of the 1080-1070 Ma Alcurra dolerite.

In thin section, the rock shows ubiquitous alteration of feldspar and growth of secondary epidote. Biotite and hornblende are commonly intergrown and less altered. Muscovite is rare, but fresh, and is interpreted to be secondary in origin. Quartz is strongly undulose, with some embayment on grain boundaries, and is generally finer grained than feldspars. Perthitic and antiperthitic textures are common.

Magmatic zircon from the granite has been dated by the U-Pb method on SHRIMP II at 1084 ± 9 Ma (Armstrong 1998). The granite intrudes the Mount Harris Basalt, which has an age constraint of 1075 ± 2.5 Ma (the age of the overlying/comagmatic Puntitjata Rhyolite), and which is also correlated with the Smoke Hill Felsic Volcanics of the Tollu Group dated at 1078 ± 5 Ma (Glikson *et al* 1996). There is sufficient overlap in the age ranges of the basalt and the granite to account for the clearly intrusive field relationship. The closeness of the ages indicates that the Walu Granite must have intruded at very shallow crustal levels into the base of the newly consolidated volcanic pile.

Rowley Granophyre (Pgr)

This shallow level intrusive unit outcrops in both HULL and BLOODS RANGE near ET495625 where it intrudes the Tjuninanta Formation. Texturally, the Rowley Granophyre (new name, see **Appendix 1**) is porphyritic with plagioclase, K-feldspar and quartz phenocrysts in a groundmass of medium- to coarse-grained quartz and feldspar. Mafic minerals comprises less than 5% of the rock and include



Figure 11. Typical Imbumbunna Granite (Pgm) near ET940458.

biotite, chlorite and opaques. Abundant granophyric intergrowths between quartz and alkali feldspar are evident in thin section. Strain locally intensifies across the intrusion, resulting in the development of a very fine-grained quartz-sericite foliation.

The granophyre is crosscut by strongly deformed, poorly preserved mafic dykes, possibly of the 1080-1070 Ma Alcurra dolerite. Magmatic zircons from the Rowley Granophyre have yielded a Pb-Pb Kober age of 1075 ± 2 Ma (Close *et al* 2003).

Imbumbunna Granite (Ꝑgm)

The Imbumbunna Granite (new name, see **Appendix 1**) occurs as an isolated outcrop that is unconformably overlain by Dean Quartzite east-northeast of Shaw Creek in Bloods Range in the region of ET935463. This granite is characterised by randomly oriented K-feldspar laths 2-3 cm in length (**Figure 11**) and contains primary biotite, muscovite and garnet, with secondary epidote. The random orientation of phenocrysts and lack of mineral alignment in the matrix indicates that the granite has seen little or no strain. A geochemical affinity with the Rowley and Walu Granites places the Imbumbunna Granite within 1080 Ma Hull Suite, although separation of zircons for Pb-Pb Kober dating yielded only metamict crystals.

Alcurra dolerite (Ꝑdl)

South of the Manananna and Dean Ranges, mafic dykes with various orientations intrude the undivided Pottoyu Granite Suite and the Amputjuta Dacite. Recrystallisation of these dykes during the 570-530 Ma Petermann Orogeny has resulted in the partial to total recrystallisation of primary pyroxenes to hornblende and epidote, with increasing actinolite and chlorite to the north.

North of the Ilyaralona Range, poorly outcropping dolerite dykes intrude the Rowley Granophyre and Walu Granite, and crosscut the Karukali Quartzite. The margins of these dykes are sometimes recrystallised to biotite, whereas elsewhere, they have locally recrystallised to a greenschist facies assemblage of chlorite, epidote, actinolite, quartz and albite. A small, coarse-grained gabbroic body that lies south of Mount Harris at ET515737 is characterised by an intergranular to subophitic texture between plagioclase and clinopyroxene, and has abundant apatite and magnetite. Secondary chlorite is rarely present.

The age of the mafic dyke suite is constrained by field relationships and geochemical affinities. A poorly outcropping dolerite dyke crosscuts the 1084 ± 9 Ma Walu Granite, which intrudes the Mount Harris Basalt. Geochemical analysis suggests the dykes outcropping on BLOODS RANGE have broad similarities to the 1080 Ma Alcurra dolerite across the Musgrave Block. Geochemical signatures of these dykes and the Mount Harris Basalt are strongly similar and suggest a common source. With the exception of the coarse-grained gabbro south of Mount Harris, all analysed geochemical samples have been taken from dykes south of the Mannanana Range. No geochemistry is available from the dykes outcropping to the north of the Ilyaralona Range due to the weathered nature of outcrop.

Amadeus Basin

Neoproterozoic to Ordovician sediments of the Amadeus Basin are exposed in Hull and Bloods Range, but complete stratigraphic successions are poorly preserved, due to the intensity of the Petermann Orogeny overprint on the southwestern margin of the basin. However, correlations have been made with successions on the northern margin of the Amadeus Basin where stratigraphic relationships are well exposed (Forman 1966b, Lindsay and Korsch 1991). In Hull and Bloods Range, basal sediments either disconformably overlie the Tjauwata Group or unconformably overlie Musgrave basement. They comprise the shallow marine/tidal Dean Quartzite/Kulail Sandstone and the Pinyinna beds. To the east, in AYERS ROCK and KULGERA, the Pinyinna beds are disconformably overlain by late Neoproterozoic siliciclastic sediments of the Inindia beds, followed by the Winnall beds (Forman 1966b, Shaw 1991). However, in Hull and Bloods Range, the Inindia beds are not exposed, and the Winnall beds outcrop in stratigraphic isolation on the northern margin of the mapsheets. Remnants of Cambrian molasse-style sediments (Mount Currie Conglomerate), which were deposited as a result of Petermann Orogeny-age uplift, are locally present in Bloods Range, and shallowly dipping fossiliferous Ordovician sandstones of the Larapinta Group onlap Musgrave basement and Neoproterozoic Amadeus Basin sediments.

Kulail Sandstone (Ꝑku)

Disconformably overlying the Bloods Range Formation is the Kulail Sandstone (new name, see **Appendix 1**), a purple-red to orange, medium-grained, generally equigranular quartz to quartzofeldspathic sandstone unit, containing abundant sedimentary structures. The upper contact with the Dean Quartzite varies from being largely gradational, with clean white Dean Quartzite beds intercalated with more feldspathic beds of the Kulail Sandstone, to locally sharp. On the south side of the Manananna Range near Livingstone Pass, the succession directly overlies the Pottoyu Granite Suite, and includes narrow lenses of well bedded clean quartz arenite/quartzite, and feldspathic beds with well rounded quartzite cobbles. The thickness of the unit is laterally variable and ranges from locally absent up to 100 m, although this is an estimate only, due to discontinuous outcrop and possible structural thickening.

The base of the Kulail Sandstone comprises lenses and beds (≤50 cm thick) with moderately sorted quartz gravel to quartz pebble clasts. This is generally overlain by finely laminated quartz sandstone layers with a corresponding increase in feldspathic content. Higher in the unit, abundant trough cross-beds are present with cosets up to 2 m in height (**Figure 12**). At location ET069645, clean well sorted quartz sandstone and quartzite channel deposits are preserved within a succession of thinly bedded, fine to medium, red lithic sandstone. Winnowed heavy mineral horizons sometimes occur towards the base of the unit and may indicate a shoreline depositional setting. The Kulail Sandstone is interpreted to be deposited in a transitional, possibly deltaic environment, representing a change from the alluvial/fluvial setting of the Bloods Range Formation



Figure 12. Trough cross-beds in Kulail Sandstone (Ꝑku) near ET075634.

to the onset of shallow marine sedimentation (Dean Quartzite).

Dean Quartzite (Ꝑde)

The Dean Quartzite forms prominent ridges of the Mannanana, Piultarana, Ilyaralona and Bloods Ranges. This unit is defined as the stratigraphic equivalent of the Heavitree Quartzite of the northern margin of the Amadeus Basin (Forman 1966b). In general, the Dean Quartzite conformably overlies the Kulail Sandstone, although in Hull and Bloods Range, the quartzite is rarely unconformable on granite basement of the Musgrave Block, with the entire Tjauwata Group succession missing from the stratigraphy. The upper contact with the Pinyinna beds is conformable and generally gradational. The true thickness of the Dean Quartzite is difficult to estimate, due to structural repetition and the rarity of exposures of both upper and lower stratigraphic contacts. At the Pinyinna Range and Bloods Range west of the Hull River, best estimates of thickness are approximately 250 m.

The Dean Quartzite comprises a succession of recrystallised, well sorted, equigranular, massive to thickly bedded quartz sandstone. Occasional lenticular layers of rounded quartzite gravel up to 5 cm thick also occur. The presence of dark grey laminations at the base of the succession in some locations is probably due to hematite concentrations. In outcrops near Kulail outstation, the basal Dean Quartzite contains quartz and quartzite pebble conglomerate with a hematite-rich matrix. Sedimentary structures are generally absent. The regionally extensive sheet-like nature of the Dean and Heavitree Quartzites suggests a shallow marine depositional environment (Lindsay 1999, Wells *et al* 1970).

Intense deformation during the 570-530 Ma Petermann Orogeny has led to the development of tight to isoclinal folding of the Dean Quartzite and has produced an axial planar muscovite fabric. Within the Piltardi Detachment Zone, in the Manananna Range and in outcrops northeast of Shaw Creek, this fabric locally intensifies to form thrust-related shear zones that develop a strong quartz stretching lineation on the foliation surface.

Pinyinna beds (Ꝑpi)

The Pinyinna beds are defined as a succession of shale and grey crystalline, laminated, foetid and stromatolitic dolostone, conformably overlying the Dean Quartzite (Forman 1966b). They form the equivalent of the Bitter Springs Formation that outcrops in the northern section of BLOODS RANGE and on the northern margin of the Amadeus Basin (Forman 1966a). The Pinyinna beds are structurally interleaved with the Dean Quartzite and granitic basement in the Piltardi Detachment Zone and form part of repeated thrust packages at Bloods Range and McNichols Range.

In Hull and Bloods Range, the upper stratigraphic contact of the Pinyinna beds is not exposed, so that the complete stratigraphy and true thickness are not known. The type locality as described by Forman (1966a), is an overturned, steeply south-dipping succession under the Dean Quartzite at the Pinyinna Range. At the type locality, the Pinyinna beds comprise a 250 m thick succession of laminated micaceous siltstone overlain by pink and grey dolostone. The thickest exposed section in the mapped area is north of the Piultarana Range, where the unit forms a thrust slice within the Piltardi Detachment Zone. It comprises 750 m of dominantly grey to brown crystalline dolostone overlying north-dipping Dean Quartzite, with shale beds rarely exposed under the quartzite scree slope (**Figure 13**). A conformable section overlying the Dean Quartzite at location ET337751 comprises approximately 20 m of quartz-rich sandstone and siltstone containing a muscovite-rich, bedding-parallel fabric. This is then overlain by 10-20 m of purple and green shale, which is in turn overlain by 20 m of pale brown siltstone and finally by 15 m of white, fine-grained siliceous sediment.

The age of the Pinyinna beds is based on correlation with the Bitter Springs Formation. Spilites within the Loves Creek Member of the Bitter Springs Formation have been geochemically correlated with dolerites of the Amata Suite that have yielded an Sm-Nd age of 800 Ma (Zhao and McCulloch 1993), thereby providing a minimum age constraint. A detrital zircon analysis was undertaken on one



Figure 13. Shale units within Pinyinna beds (Ppi) near ET528765.



Figure 14. Symmetrical ripples in Winnall beds (Pwi) at Mount Cowle near ET587902.

sample of Pinyinna beds to determine provenance. Sixteen SHRIMP U-Pb analyses of zircons from the white, fine-grained siliceous sediment at ET337751 yielded a number of age populations. Two dominant groupings gave weighted mean $^{207}Pb/^{206}Pb$ ages of 1058 ± 31 Ma and 1198 ± 23 Ma whereas the remaining data yielded scattered ages from the oldest grain with an apparent $^{207}Pb/^{206}Pb$ age of 1786 ± 6 Ma to approximately 1540 Ma (Armstrong 1998, *see Geochronology*). These ages suggest that sediments within the Pinyinna beds were locally derived from 1080-1040 Ma granites and volcanics exposed throughout much of the Musgrave Block (Camacho 1997, Glikson *et al* 1996), with additional zircons sourced from 1200-1140 Ma granites and 1600-1500 Ma gneisses.

Winnall beds (Pwi)

Sediments defined by Forman (1966a) as Winnall beds are exposed in stratigraphic isolation in HULL and BLOODS RANGE as a series of mesas and strike ridges that include Mount Cowle. West of the Pinyinna Range, poorly outcropping, unlithified quartz sandstone, containing occasional quartzite clasts, appears to underlie the Mount Currie Conglomerate and is assigned to the Winnall beds. At Mount Cowle, the shallowly dipping succession comprises approximately 500 m of well bedded to flaggy, medium-grained, moderately sorted, clean quartz sandstone containing abundant symmetrical ripples (**Figure 14**) and trough cross-beds up to 30 cm in height. Interbeds of dirtier sandstone with a vuggy appearance are present, suggesting a greater degree of clay input. Bedding surfaces often contain clay galls.

The lower stratigraphic contact for the Winnall beds is generally obscured on the southwestern margin of the Amadeus Basin. An unconformable relationship with the underlying Inindia beds is exposed at Liddle Hills in HENBURY (Ranford *et al* 1965) and has been suggested at South Range in BLOODS RANGE (Forman 1966b). However, the implied angular unconformity at South Range could be the result of diapiric movements that caused bedding disruption within the Winnall beds (PW Haines, University of Tasmania, pers. comm, 1999). In KULGERA, an intervening decollement surface between the Inindia and

Winnall beds has been described from the Erldunda Range (Edgoose *et al* 1993).

The Winnall beds are interpreted as stratigraphic correlatives of the Pertatataka Formation to the east and north within the Amadeus Basin (Wells *et al* 1970) and of the Sir Frederick Conglomerate and Ellis Sandstone to the west (Shaw 1991, Warren and Shaw 1995). No complete section of the Winnall beds outcrops in the southern margin of the Amadeus Basin and preserved remnants vary greatly in thickness. In AYERS ROCK and KULGERA, up to 1 km of Winnall beds outcrops adjacent to areas of Inindia beds that are directly overlain by the Ordovician Larapinta Group. Edgoose *et al* (1993) suggested that topographic relief prior to deposition of the Winnall beds could account for thickness variations within the unit, and that subsequent erosion preserved only the deeper depocentres.

The Winnall beds are interpreted to have been deposited in fluvial and shallow marine to continental shelf environment (Forman 1966a, Edgoose *et al* 1993).

Mount Currie Conglomerate (Ɛca)

The Mount Currie Conglomerate is poorly exposed in BLOODS RANGE, northeast of the Pinyinna Range, where its presence is indicated by residual, rounded pebble to cobble clasts of light grey to brown quartzite. Limited outcrop suggests that the conglomerate unconformably overlies the Pinyinna beds on the northern side of the exposure. In AYERS ROCK, the Mount Currie Conglomerate unconformably overlies the Winnall beds and is well exposed at Mount Currie and Kata Tjuta where up-section changes in clast composition have been recognised by Forman (1963) and Young *et al* (2002). The basal unit of the conglomerate is oligomictic, comprising sandstone clasts probably sourced from the underlying Winnall beds. Up-section, the conglomerate becomes more polymictic, and is dominated by porphyritic rhyolite clasts with a lesser basalt and sandstone component. A Pb-Pb Kober zircon date from a rhyolite clast within this succession yielded an age of 1062 ± 6 Ma (Young *et al* 2002) suggesting the likely source to be felsic volcanics of the Tjauwata Group. The upper part of the Mount Currie Conglomerate grades into clasts that are dominantly granitic in composition, with minor rhyolite, basalt, and rare sandstone and granitic gneiss. The source for this part of the conglomerate is probably the granite-dominated northern section of the Musgrave Block.

The Mount Currie Conglomerate is interpreted to represent at least 6 km of molasse-style deposition into the Mount Currie Sub-basin, adjacent to highlands exposed during the Petermann Orogeny (Forman 1966b, Lindsay and Korsch 1991). This is supported by the inverse stratigraphy of the clasts, which reflects the gradual unroofing of the Musgrave Block during this orogenic event (Young *et al* 2002). The Mount Currie Conglomerate is correlated with the Arumbera Sandstone on the northern margin of the Amadeus Basin (Wells *et al* 1970).

Larapinta Group (Ola)

Shallowly dipping, poorly lithified sandstone units that outcrop in the eastern section of BLOODS RANGE are interpreted to belong to the Ordovician Larapinta Group. Bioturbated and fossiliferous layers containing gastropods and ostracodes are present at location ET968491 within flat-lying sediments that unconformably overlie steeply foliated and lineated, undivided Pottoyu Granite Suite. At location ET008512, a 5-10 m thick, basal, pale green-grey to pink siltstone with abundant halite pseudomorphs is overlain by to 2-3 m of dolomite with calcrete capping. The uppermost layer is a medium quartz sandstone with some indication of bioturbation and poorly preserved ripples. Some layers within this sandstone contain possible rillenkarren textures, suggesting a calcareous component. At McNichols Range, Ordovician sediments comprise <10 m of alternating beds of clast supported, poorly sorted conglomerate, with angular clasts of Dean Quartzite (**Figure 15**), and equigranular quartz sandstone containing abundant trough cross-beds. The presence of bioturbation, gastropod body fossils and dolomitic layers within this Ordovician succession is consistent with the Stokes Siltstone of the Larapinta Group, as described in AYERS ROCK and KULGERA (Edgoose *et al* 1993, Young *et al* 2003).

In Bloods Range, these Ordovician sediments directly overlie basement or onlap the Dean Quartzite at the McNichols Range. Metamorphic muscovite in the Dean Quartzite in this area suggests that the basal Neoproterozoic Amadeus sediments were buried to 8-10 km. Therefore, significant uplift and



Figure 15. Shallowly dipping Larapinta Group sediments (Ola), comprising quartz sandstone with angular clasts of quartzite near ET872712.

exhumation must have occurred during the Petermann Orogeny, prior to the onset of Ordovician deposition.

Cenozoic deposits

Cenozoic deposits in HULL and BLOODS RANGE are products of both defunct and currently active environments. Highly silicified to silcretised sediments are present on the crests and dip slopes of many of the quartzite ranges, and ferruginised weathering profiles also occur in some areas, indicating that duricrust-forming processes were functioning in the region during this period. The two mapped units are- Shallow soils over subcrop (Cz/s), and Talus and scree (Czt).

Shallow soils over subcrop (Cz/s)

Small areas of soil that mask near-surface rock occur in the central part of the HULL-BLOODS RANGE region, where they are associated with the Mount Harris Basalt, and in the eastern part, where they are associated with granite. Structural trends in the shallowly buried rocks are often clearly visible on aerial photographs. The surficial deposits consist largely of weathered rock fragments from grit to clay size, and where associated with basalt, often contain abundant vein quartz fragments. A weakly zoned soil profile often develops and vadose calcrete is locally present. The soil-forming processes are currently active, but as their primary age is unknown, they are designated Cenozoic.

Talus and scree (Czt)

This unit includes both active and defunct colluvial fans that flank all of the main ranges in HULL and BLOODS RANGE. The two types can be readily distinguished in the field and on aerial photographs, but have not been separated at map scale for ease of reference. Older fan deposits are predominantly preserved on northern (dip) slopes where they can extend several hundred metres from the nearest outcrop of the range. However, along the Bloods, Rowley and McNichols Ranges, they are also preserved in places on southern (scarp) slopes. At their proximal end, these fans can be up to 30-40 m above the level of the surrounding plains, and dip at about 10° towards their distal ends. They are distinct from active fans in that they are usually separated from the main part of the range by incised drainage and currently active scree slopes, and they contain consolidated or semi-consolidated scree material. The deposits consist of pebble- to cobble-sized, slightly rounded local lithologies (most commonly Dean Quartzite), with finer sand and clay forming a loose to consolidated matrix.

At the eastern end of the Mount Skene Range, and noted on the southern fan slopes of the McNichols Range, a palaeosol of probable Palaeogene-Neogene age is preserved. It sits on an older fan deposit, and is composed of ferruginised grit to sand-sized particles, weakly cemented by finer sand and clay. The palaeosol contains abundant vertical worm tubes or root tubules and was described by Forman (1963, 1966a, b) as *Skolithos*-bearing Ordovician sandstone.

Active fans have loose angular pebbles, cobbles and larger clasts, ranging up to very large boulders, of local rock types. Loose grit and sand forms the finer fractions. At their distal ends, they are encroached by aeolian sand of the surrounding plains. These fans are sourced both from continuing erosion of the ranges and from the dissection of older, defunct fans.

Quaternary

Quaternary deposits comprise approximately 55% of HULL and BLOODS RANGE. Units that make up these largely unconsolidated deposits include aeolian sand (Qs), colluvial and eluvial soils (Qr), alluvium (Qa), and calcrete (Qc).

Qs, Qr, Qa, Qc

Aeolian sand (Qs) is the most widespread of the unconsolidated surficial deposits, covering about 40-45% of the mapsheet area. It forms both plains and dune fields that are extensive in the north, east and southeast, but more scattered in the west. Qs consists of fine to medium sand that is imparted with a characteristic red colour by fine particles of red clay. In dune fields, the interdune area (swale) may have a clay surface over clay or loam soil at depth. This soil probably represents the underlying palaeoplain, exposed via winnowing of the thin aeolian cover.

Colluvial and eluvial soils (Qr) are particularly prominent in the central part of HULL and BLOODS RANGE, largely coinciding with subcrop of the Mount Harris Basalt that has presumably provided a source for the clay fraction. Sheetwash processes currently active in these areas provide a surface colluvial component to the deposits, but at depth, they are probably largely eluvial in nature. They are dominantly sandy clay loams to clay loams, and have a characteristic deep red colour. They represent a modified palaeoplain that probably originated in Palaeogene-Neogene times.

Alluvial deposits (Qa) occur as streambed and overbank deposits along rivers and creeks, and include some proximal outwash from the ranges. River and creek beds contain coarse to medium pale sand with abundant rock fragments in some places. Overbank deposits are characterised by sand to sandy loam material. Where drainage breaches sand plains, the floodplain is confined to a narrow strip. In Learmonth Park, dendritic drainage of low hills produces a network of interconnecting floodplains along creeks and a broad plain flanking the Docker River.

Calcrete (Qc) forms low mounds largely flanking broad drainage features north of Walu Outstation in areas of low outcrop and subcrop of the Mount Harris Basalt. The calcrete probably formed through upward movement of the water table in the soil profile, with the basalt contributing calcareous material. Jacobsen *et al* (1988) identified this type of calcrete as the younger of two calcrete phases, with Electron Spin Resonance-dated samples from AYERS ROCK giving ages in the range 22 000-27 000 ybp. The calcrete consists of fine-grained to amorphous calcite, sometimes strongly consolidated but often friable to powdery. It may contain veins and patches of cloudy or clear chalcedony.

STRUCTURE AND METAMORPHISM

Deformation fabrics and metamorphic assemblages within the HULL-BLOODS RANGE region formed during the

570-530 Ma intraplate Petermann Orogeny. 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 mid to upper crust during this event suggest that an ambient heat source within the crust may have contributed to thermal weakening of the lithosphere and resulted in the localisation of intraplate deformation (Sandiford and Hand 1998, Scrimgeour and Close 1999).

The flat to shallowly dipping nature of the Ordovician Larapinta Group indicates that little deformation occurred in this region during the 400-300 Ma Alice Springs Orogeny.

Structure

Deformation during the Petermann Orogeny is pervasive over HULL and BLOODS RANGE, resulting in the interleaving of Musgrave basement with the Tjauwata Group and basal Amadeus Basin cover successions, and the northward emplacement of a regional-scale basement nappe structure (Petermann Nappe Complex). Synchronous with the transport of this nappe complex was the development of deep crustal mylonitic fabrics in the Mann Ranges in PETERMANN RANGES. These fabrics are interpreted to represent the root zone of the nappe structure, which was subsequently exposed due to movement along the Woodroffe Thrust (Scrimgeour *et al* 1999). Structural features of this north-vergent structural system that dominate the HULL and BLOODS RANGE region include the Piltardi Detachment Zone and the Petermann Nappe Complex.



Figure 16. Isoclinally folded Dean Quartzite within Piltardi Detachment Zone near ET375514. Looking west.

Piltardi Detachment Zone (PDZ)

The PDZ forms a 2-8 km-wide zone that extends for approximately 150 km southeast into PETERMANN RANGES and is inferred to continue eastward into AYERS ROCK. This zone acts as the basal detachment along which an internally duplexed wedge, the Petermann Nappe Complex, was transported northwards and inserted within Neoproterozoic successions of the Amadeus Basin (Scrimgeour *et al* 1999). The PDZ incorporates the Ilyaralona and Piultarana Ranges in HULL, where Musgrave basement, lower Tjauwata Group and basal Amadeus Basin are structurally interleaved along steeply north-dipping shear zones. Within the detachment, the Dean Quartzite is strongly deformed, with the development of a pervasive muscovite shear fabric and isoclinal folding (**Figure 16**), whereas the Pinyinna beds are phyllitic to schistose in character. A well developed quartz stretching lineation on the muscovite foliation surface in the Dean Quartzite plunges north to northwest. S-C fabrics parallel to this lineation give a consistent top-to-north sense of movement (**Figure 17**). Within the PDZ, stratigraphic successions between thrust boundaries are generally right way up, although intraformational isoclinal folding is common. This is consistent with microfabrics and structural vergences observed within the eastern extension of the PDZ in PETERMANN RANGES (Scrimgeour *et al* 1999). The PDZ is interpreted to have been rotated from a flat or shallowly south-dipping orientation into its present north-dipping orientation during ongoing north-vergent deformation.

South of the PDZ, the Dean Quartzite and Kulail Sandstone in the Manananna Range form a regional-scale, north-vergent, basement-cored asymmetric fold, with a south-dipping axial plane, that rotates from steeply to shallowly dipping along strike. At the western end of the range, the axial plane is steep, preserving only the lower limb. Further to the east at ET363353, a remnant of the flat-lying upper limb remains, whereas the lower limb is overturned as a result of shallowing of the axial plane. Within the Pottoyu Hills, east–west-trending, south-dipping shear zones and amphibolite dykes that crosscut the Pottoyu Granite Suite have a strongly developed south-plunging stretching lineation, and kinematic indicators that suggest a reverse sense of movement.

Petermann Nappe Complex

The Petermann Nappe Complex is an internally duplexed basement wedge, transported northwards by movement on the PDZ. This nappe complex was originally described by Forman (1966b) as a regional-scale recumbent fold. Despite structural repetition within the basement wedge, right-way-up successions are typically preserved between thrusts. In Bloods Range near the northern margin of this basement wedge, north-vergent thrusts have resulted in repetition of the basal Amadeus Basin successions. At Mount Harris, the Mount Harris Basalt is thrust over Dean Quartzite, which is

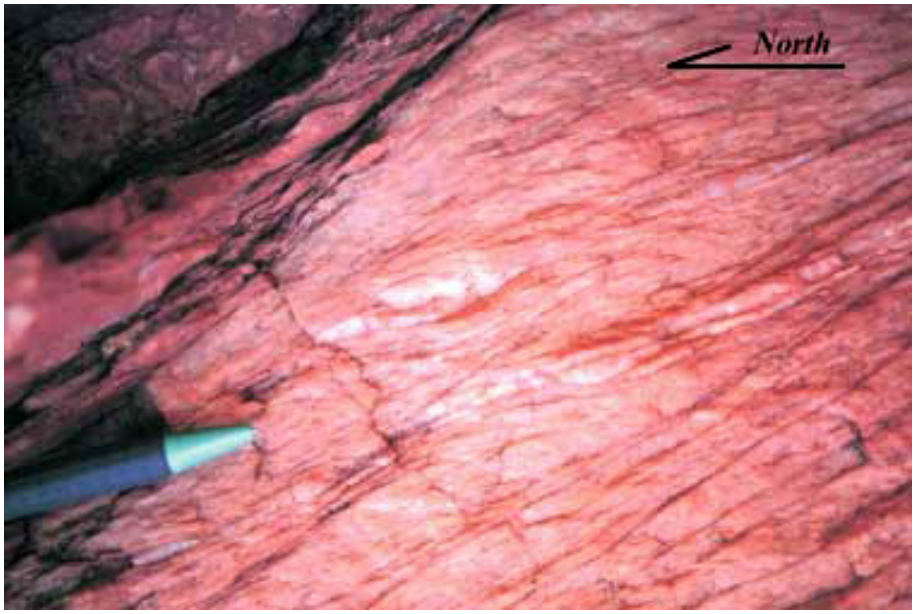


Figure 17. S-C fabrics in Dean Quartzite indicating top to north kinematics within Piltardi Detachment Zone near ET451427.

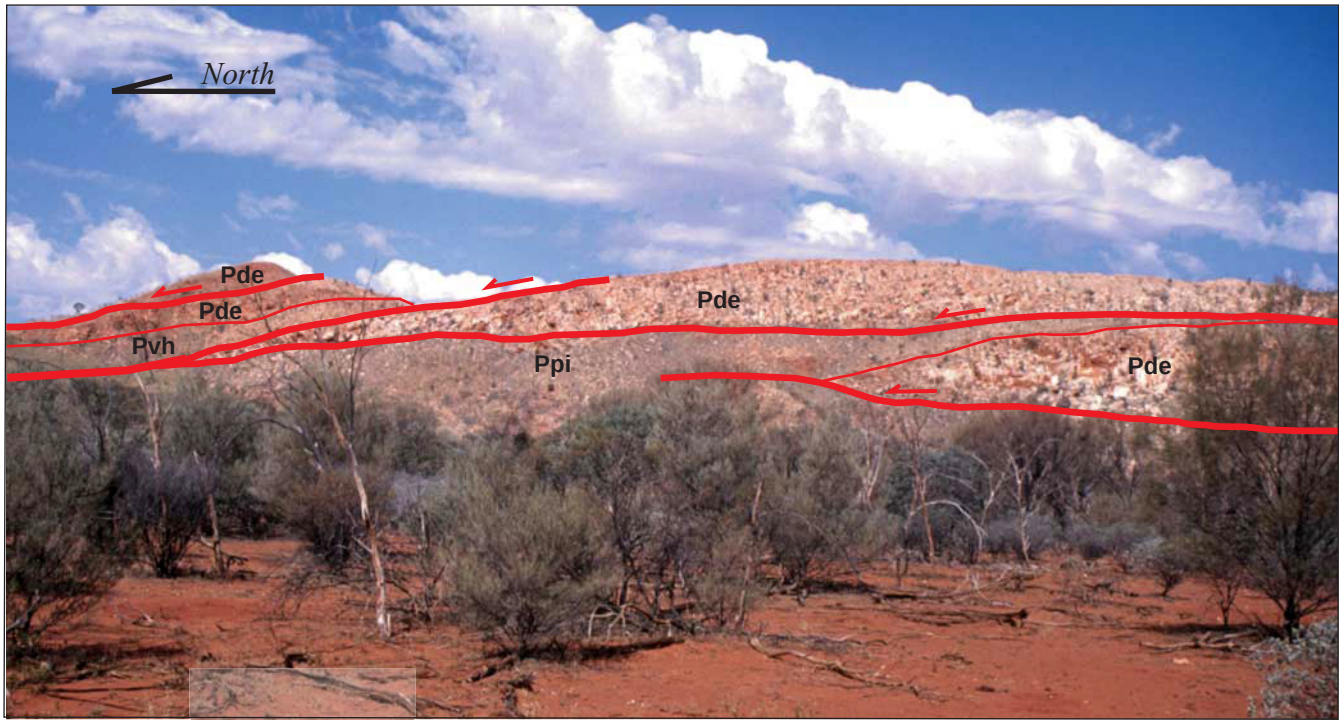


Figure 18. Stacked thrust sheets of Mount Harris Basalt (Pvh), Dean Quartzite (Pde) and Pinyinna beds (Ppi) at northern margin of Petermann Nappe Complex near ET533767.

itself internally duplexed and interleaved with Pinyinna beds (**Figure 18**). North-vergent duplexing is interpreted to continue beneath cover immediately to the north of Bloods Range, with the resultant duplex stack rotated into a steeply north-dipping monocline (**Figure 19**).

At the northern margin of the basement wedge, Winnall and Inindia beds have been detached from the northward propagating system and have accommodated shortening by forming a passive roof duplex that was backthrust southwards along the Bloods Backthrust Zone. Detachment of the Winnall and Inindia beds occurred within the Pinyinna beds, which acted as a decollement horizon. In Hull and Bloods Range, the Winnall beds outcrop exclusively to the north of the Bloods Backthrust Zone. A lack of structural interleaving of the Winnall and Inindia beds within the north-vergent duplex system supports the interpretation that these units were transported passively southwards during emplacement of the Petermann Nappe Complex.

North of the Mannanana Range, muscovite foliation associated with deformation during the Petermann Orogeny parallels the general west-northwest–east-southeast strike of the basement nappe. To the east of Kulail Outstation, a second overprinting muscovite foliation is evident in the Kulail Sandstone and generally trends north–south. To the north of Mount Skene and in the Mount Hastie region, macroscale asymmetric folding of the first generation foliation is evident with east- to southeast-dipping axial planes. This asymmetric folding is probably related to the second-generation foliation. This later west- to northwest-vergent deformation on the western margin of Hull is

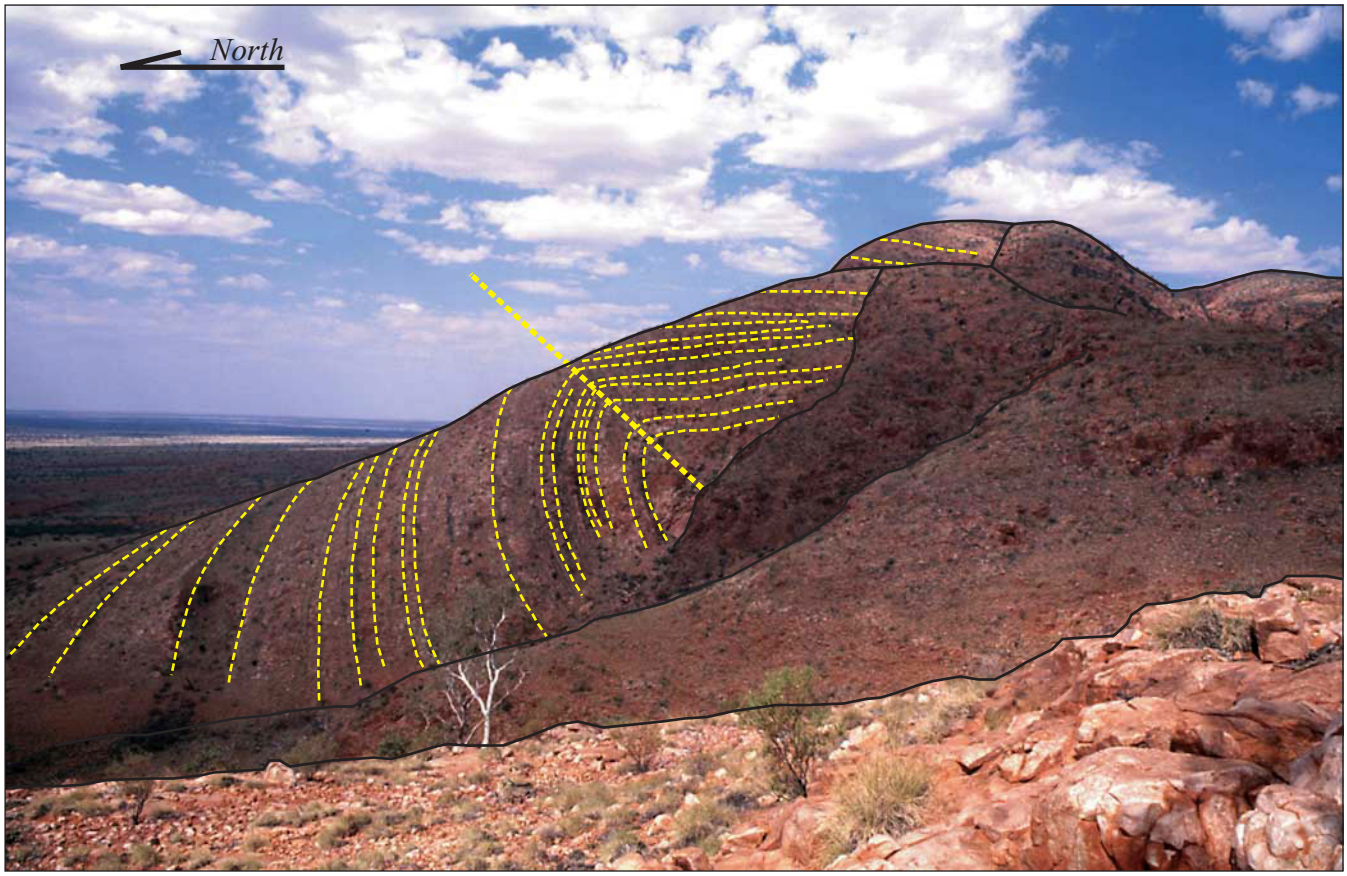


Figure 19. North-verging monocline on northern margin of Petermann Nappe Complex near ET598761.

interpreted to be the result of lateral space accommodation during emplacement of the basement nappe.

Abundant, generally steep north–south-oriented faults crosscut the Bloods and Rowley Ranges with offsets in the order of tens of metres. This late-stage brittle deformation is interpreted to be the result of vertical space accommodation during the final phase of nappe emplacement.

Metamorphism

All Proterozoic units in southern BLOODS RANGE were affected by metamorphism during the 570-530 Ma Petermann Orogeny. Metamorphic grade in HULL and BLOODS RANGE varies from epidote amphibolite facies in the southwest to lower greenschist facies in the north. The general distribution of metamorphic facies and the location of important isograds are shown on **Figure 20**.

Quantitative thermobarometry was not possible on samples collected from HULL and BLOODS RANGE, due to a lack of appropriate low-variance mineral assemblages. However, at ET211318 in PETERMANN RANGES, 4 km to the south of HULL, a gabbro has partially recrystallised during the Petermann Orogeny to garnet, hornblende, plagioclase and quartz. This assemblage gives P-T conditions of 550°C and 5.3-6.2 kbar using the thermobarometers of Graham and Powell (1984) and Kohn and Spear (1990). Metamorphic grade immediately to the north on HULL is slightly lower, with epidote and hornblende (± biotite) occurring in mafic rocks, and epidote, biotite and muscovite in deformed granite. These assemblages are consistent with epidote amphibolite facies conditions of 450-550°C at 5 kbar.

The epidote amphibolite–greenschist facies transition, defined by the appearance of chlorite in mafic rocks, is shown in **Figure 20**. North of the amphibolite–greenschist facies transition, and south of the Mannanana and Dean Ranges, mafic rocks contain the assemblage epidote-chlorite-hornblende-quartz-plagioclase ± biotite ± actinolite, implying upper greenschist facies conditions (400-500°C). The Piultarana and Ilyaralona Ranges and isolated outcrops at ET929469 locally contain metamorphic biotite, suggesting that they were metamorphosed to at least middle-upper greenschist facies.

England (1972) documented a kyanite-pyrophyllite-muscovite-quartz assemblage in the Dean Quartzite in the portion of the Mannanana Range east of approximately ET280420. Further west in the Mannanana Range, the assemblage pyrophyllite-muscovite-quartz occurs in aluminous layers of the Dean Quartzite, but kyanite is absent, suggesting a decrease in metamorphic grade. The breakdown of kyanite to pyrophyllite is believed to occur at 400-450°C, at pressures greater than 3 kbar, which is broadly consistent with the mineralogy in nearby mafic rocks.

The region between the Ilyaralona and Bloods Ranges reached middle-lower greenschist facies (300-400°C), with the assemblage chlorite-epidote-actinolite-quartz-albite ± muscovite in mafic lithologies. Metamorphic grade decreases to the north, but the continuing presence of fine-grained muscovite in strained rocks within Bloods Range suggests that the it was at least lowermost greenschist facies. Outcrops of the Pinyinna beds in the Pinyinna Range show little or no evidence of metamorphism and all rocks to the north of this reached sub-greenschist facies.

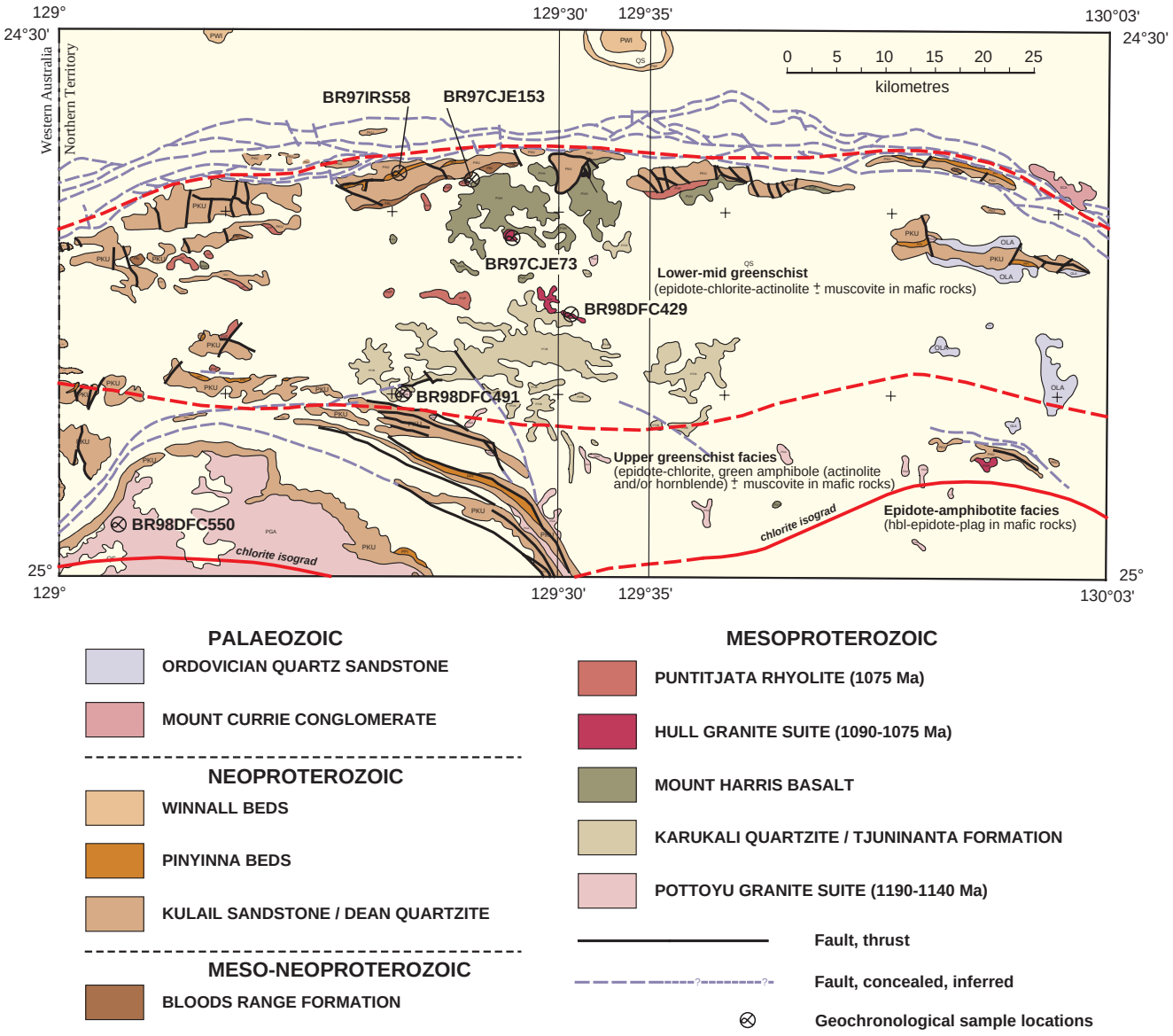


Figure 20. Map of HULL and BLOODS RANGE, showing distribution of metamorphic facies and geochronological sample locations.

Although quantitative pressure estimates have not been possible in BLOODS RANGE, approximate depth of burial can be estimated on the basis of the apparent geotherm of 25-30°C per km, as suggested by P-T estimates in the Pottoyu Hills on PETERMANN RANGES. On this basis, the possible depth of burial during metamorphism can be estimated to be 14-17 km (4-5 kbar) for Mannanana Range (consistent with the stability of kyanite), 10-15 km (3-4 kbar) for the Walu region and 8-10 km (2-3 kbar) for Bloods Range.

Outcrops of Mount Currie Conglomerate in southeastern IMBUMBUNNA and adjacent regions of AYERS ROCK contain metamorphic epidote, and locally, actinolite, suggesting metamorphism under greenschist facies conditions.

GEOCHEMISTRY

Mafic dykes and basalt

By M Green

Whole-rock elemental compositions of seven basalts from the Mount Harris Basalt (**P**vh) and seven Alcurra dolerite dykes (**P**dl) were determined at Amdel Laboratories Ltd. Most elements were analysed by glass-fusion or acid-digestion ICPMS and ICPOES, with abundances typically well above detection limits (**Appendix 2**). Sample populations are small and hence the defining of trends is statistically suspect. Nevertheless, the geological correlatives and petrogenesis of these two units can be constrained.

In HULL and BLOODS RANGE, the Mount Harris Basalt and Alcurra dolerites have been variously affected by post-magmatic alteration, and to use whole-rock compositions to constrain magmatic processes, it is therefore critical to identify which elements have been immobile at the whole-rock scale. Element mobility can be readily monitored using bivariant plots, as elements that have retained magmatic abundances should define magmatic trends, whereas altered elements should show great scatter. Examples are shown in **Figure 21** where SiO_2, CaO, Al_2O_3, MgO and Cr define negative trends (immobile compatible elements), Zr, Nb and La define positive trends (immobile incompatible elements), and Na_2O and Rb show great scatter (mobile elements). This

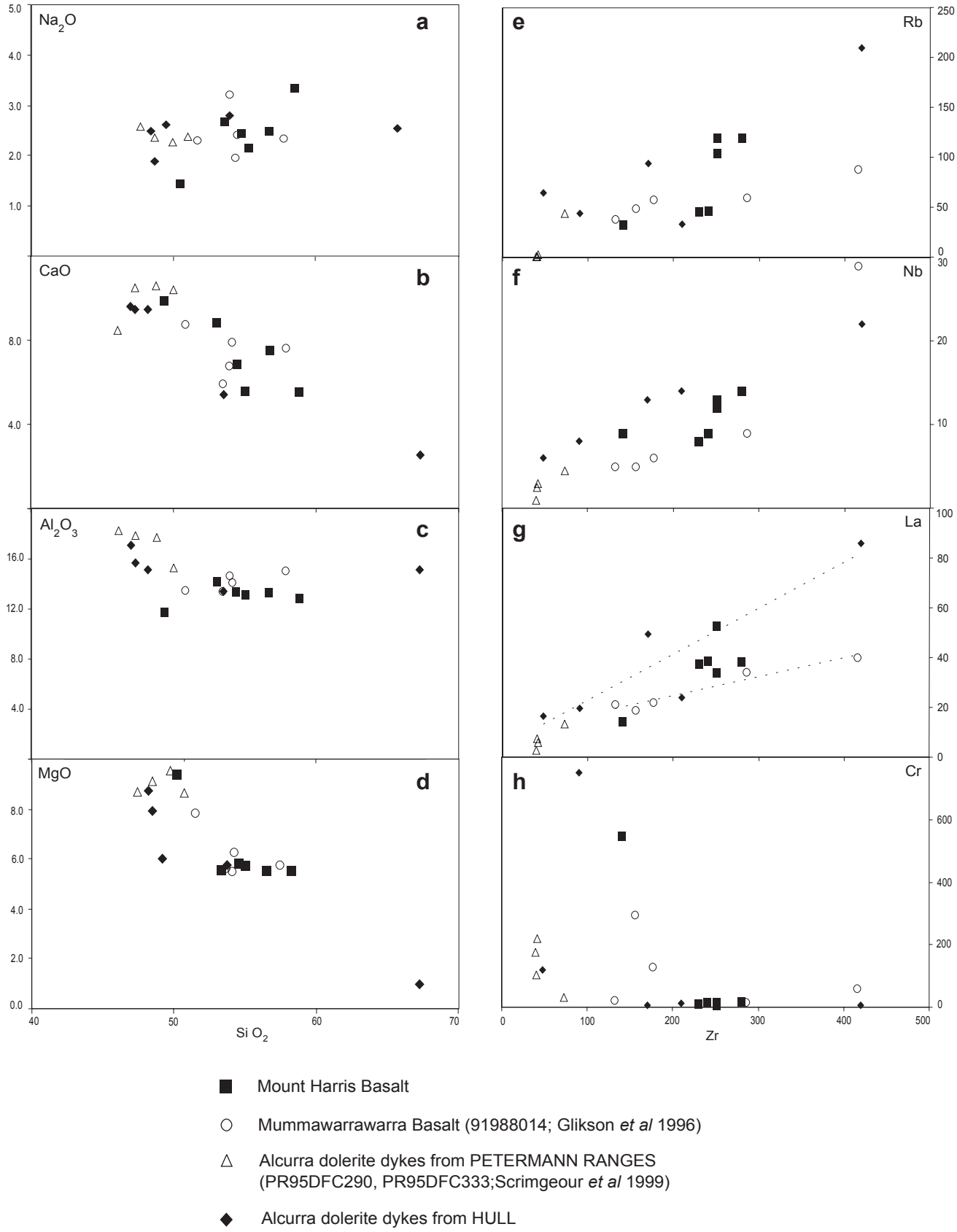


Figure 21. Major and minor element bivariant plot. (**a-d**) Harker diagrams. (**e-h**) Trace elements versus Zr. Other Musgrave mafic rocks plotted for comparison.

is consistent with studies of low-grade metamorphosed mafic rocks (Shiano *et al* 1993). Petrogenetic interpretations of Mount Harris basalts and Alcurra dolerites are based on the immobile elements.

Normalised plots

Compared to N-MORB (Sun and McDonough 1989), Mount Harris basalts and Alcurra dolerites have relatively uniform

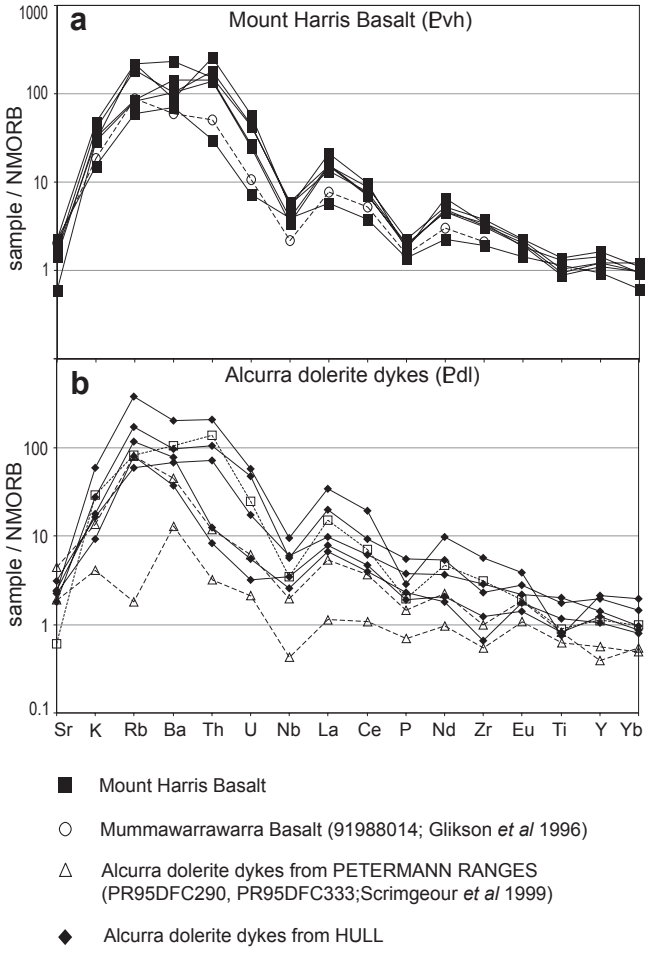


Figure 22. N-MORB-normalised diagrams (Sun and McDonough 1989) for (**a**) Mount Harris Basalt, and (**b**) Alcurra dolerite dykes. Other Musgrave mafic rocks plotted for comparison.

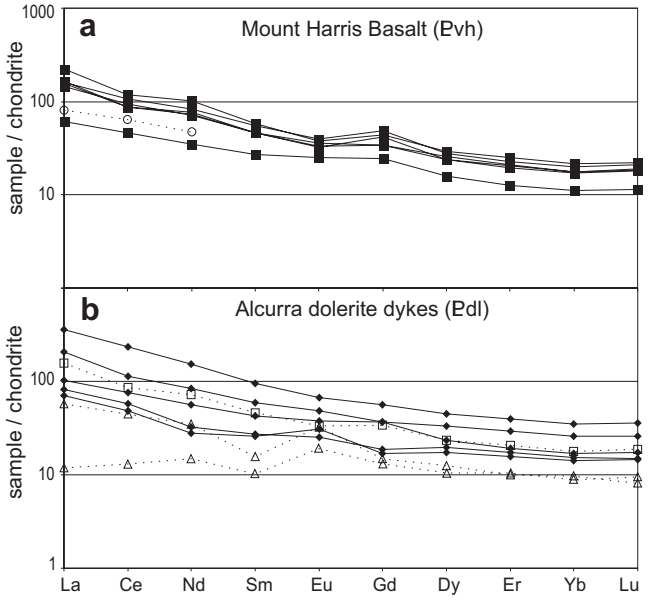


Figure 23. Chondrite-normalised diagrams (Sun and McDonough 1989) for (**a**) Mount Harris Basalt, and (**b**) Alcurra dolerite dykes. Symbols as for Figure 22. Other Musgrave mafic rocks plotted for comparison.

background signatures with overall negative slopes produced by greater concentrations of incompatible elements (**Figure 22**). The dolerites have greater variability than the basalts. Although most elements have preserved their original magmatic abundances, some irregularities in K, Rb and Ba reflect post-magmatic alteration of these elements. The basalts and dolerites are enriched in large ion lithophile elements (Rb, K, Ba), L-MREE (La, Ce, Nd, Eu) and highly incompatible elements (Th, U, Nb), whereas Ti, Y and Yb have typical N-MORB abundances. There are distinct negative Nb and P anomalies, and some samples have small negative Zr and Ti anomalies. Chondrite-normalised (Sun and McDonough 1989) REE plots of Mount Harris basalts and Alcurra dolerites have uniform negative slopes, with LREE enrichment relative to HREE, and increasingly steeper slopes towards the LREE (**Figure 23**). Mount Harris basalts have small negative Eu anomalies, suggesting derivation from a plagioclase cumulate source, whereas some Alcurra dolerites have slight positive Eu anomalies, suggesting plagioclase accumulation (Fujimaki *et al* 1984).

Correlations

Geochemical similarities and field relationships suggest the eruption age of the Mount Harris Basalt to be synchronous with the Mummawarrawarra Basalt in the western Musgrave Block at about 1080 Ma (Glikson *et al* 1996, Sheraton and Sun 1997). Basalts from both successions have remarkably similar whole-rock compositions, consistent with their formation by similar petrogenetic processes (**Figures 22a, 23a**), although subtle trend variations defined in bivariant plots (Figure 21) suggest some minor differences during partial melting and fractional crystallisation. In short, the Mount Harris and Mummawarrawarra Basalts have very close petrogenetic relationships, but form distinct concomitant successions.

Geologically and geochemically distinct suites of dolerite dykes have been identified in the Musgrave Block (Nesbitt *et al* 1970, Glikson *et al* 1996, Sheraton and Sun 1997), with outcropping dykes in HULL and BLOODS RANGE interpreted as the 1080 Ma Alcurra dolerite (previously known as Kulgera dykes in KULGERA; Camacho *et al* 1991, Zhao 1992, Zhao and McCulloch 1993, Edgoose *et al* 1993, Glikson *et al* 1996, Sheraton and Sun 1997). Dolerite dykes in HULL and BLOODS RANGE have similar normalised patterns as Alcurra dykes from elsewhere in the Musgrave Block (Zhao 1992, Scrimgeour *et al* 1999, Young *et al* 2002), but with greater enrichment of incompatible elements (**Figures 22b, 23b**). The most primitive Alcurra dykes outcrop in the eastern Musgrave Block (Zhao 1992, Edgoose *et al* 1993). Dolerites become progressively more enriched to the west and the most evolved Alcurra dykes are found in HULL and BLOODS RANGE. Trace element similarities between these widespread dykes are consistent enough to interpret the 1080 Ma dykes throughout the Musgrave Block as forming during the same magmatic event. Compositional differences are probably due to varying degrees of partial melting, fractional crystallisation and crystal accumulation.

Although Alcurra dolerite dykes cut the Mount Harris Basalt, both units have interpreted magmatic ages of

1080 Ma and remarkably similar compositions (**Figures 22b, 23b**), consistent with strong petrogenetic links. The mafic-ultramafic Giles Complex in the western Musgrave Block was also emplaced at about 1080 Ma (Glikson *et al* 1996), suggesting that all of the mafic magmatism may be related to a single widespread event. The interpretation that various intrusions in the Giles Complex crystallised from separate batches of variably fractionated parent melts is consistent with the relationship between the Mount Harris and Mummawarrawarra basalts. One interesting point is that the Giles Complex may not be the centre of the Alcurra dolerite, as the most primitive Alcurra dykes are found in Kulgera, and so the Giles Complex may be a peripheral magmatic province to an even larger magmatic event.

Petrogenesis

Mount Harris basalts and Alcurra dolerites are enriched in incompatible elements relative to typical oceanic basalts (N-MORB) and this is consistent with the addition of crustal material to a depleted mantle source. There are three general processes to obtain such crustal compositions in mantle-derived melts: addition of incompatible elements in an active subduction zone; derivation of magmas from enriched sublithospheric mantle (ancient subduction-related enrichment?); or assimilation of crustal material during passage of mafic magmas through continental crust (Barley 1986). Assuming that the aforementioned links between the Giles Complex, Mount Harris basalts and Alcurra dolerites are valid, then an active subduction setting is inconsistent with the geological evidence because: (1) there was no known regional tectonism during the 1080 Ma period of magmatism; (2) the Giles Complex was emplaced deeply into continental crust; (3) there was only limited volcanism; and (4) the distribution of Alcurra dykes is too extensive (Glikson *et al* 1996, Sheraton and Sun 1997). The most likely tectonic scenario to account for the mafic magmatism is therefore a thermal perturbation in the mantle, perhaps a mantle plume, beneath older continental basement.

Previous interpretations have favoured crustal enrichment of Musgrave mafic magmatic rocks as being due to partial melting of an enriched source in the subcontinental lithosphere with little or no assimilation of continental material (Zhao 1992, Zhao and McCulloch 1993, Glikson *et al* 1996, Sheraton and Sun 1997, Scrimgeour *et al* 1999). Some geochemical characteristics, such as the decoupling of Nb and P from other incompatible elements, are difficult to reconcile without crustal assimilation. During typical mafic magmatic processes, such as mantle melting, Nb and U have identical compatibilities, with both slightly less compatible than La (Hofmann *et al* 1986, Jochum *et al* 1991, Sims and DePaolo 1997). Therefore, if the Nb anomaly is solely a source feature, the size of the anomaly should not change significantly, as Nb, U and La should behave similarly during mafic magmatism. The Nb anomaly, however, increases appreciably with incompatible element enrichment (**Figure 24**), indicating that either Nb is behaving differently than would be expected during normal mantle melting processes or that Nb depletion is caused by a different process. However, Nb did behave as a highly incompatible element (**Figure 21**), consistent with typical mafic magmatic processes.

The decoupling of Nb and P from the other incompatible elements can be explained by varying degrees of crustal contamination, where the contaminants have very low concentrations of Nb and P, but are enriched in other incompatible elements (eg Musgrave granitoids). In this scenario, incompatible elements are added to the magma much faster than Nb or P, so that larger Nb anomalies reflect

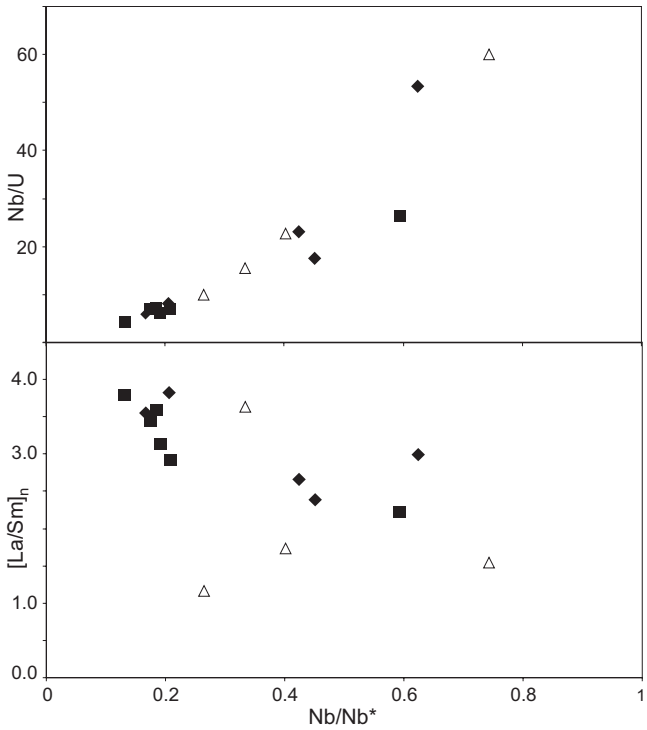


Figure 24. Nb/Uand $[La/Sm]_n$ versus Nb/Nb*, where La/Sm are chondrite-normalised (Sun and McDonough 1989) and Nb* is magnitude of N-MORB-normalised Nb anomaly [Nb* = Nb/0.5(U+La)]. Symbols as for Figure 22.

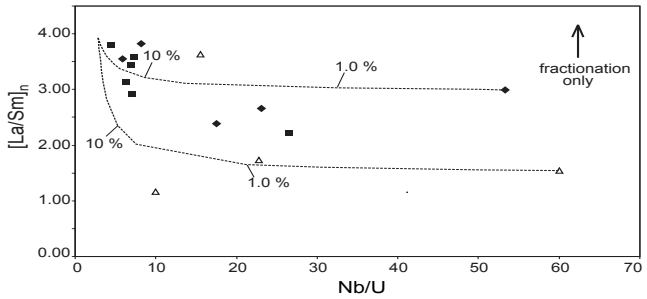


Figure 25. Crustal contamination measured using $[La/Sm]_n$ versus Nb/U, where La/Sm are chondrite normalised (Sun and McDonough 1989). Symbols as for Figure 22. Two mixing lines are shown between least contaminated samples (BR97DFC12c, PR95IRS360a) and assumed contaminant (Walu Granite, BR97CJE75). Percentages indicate degree of contamination. Nb and U are not fractionated, so fractionation moves compositions to higher $[La/Sm]_n$ values only.

greater contamination. Country-rock xenoliths have been reported in undeformed and unaltered Alcurra dykes in KULGERA (Camacho 2002) providing direct evidence of crustal assimilation. The amount of crustal assimilation can be estimated using Nb/U ratios since these elements have identical partition coefficients during typical mafic magmatic processes, but there are profound differences between the Nb/U ratio of depleted mantle and continental crust (Sims and DePaolo 1997, Sylvester *et al* 1997). Using the 1080 Ma Walu Granite (BR97CJE75) as a proxy contaminant and the two mafic rocks with the greatest Nb/U ratios, and hence the least contamination, to represent the depleted mantle the remaining mafic rocks have assimilated <20% crustal material (except BR98CJE74 at about 40%, **Figure 25**). Such estimates are consistent with thermal constraints derived from models of generic crustal assimilation (Reiners *et al* 1995).

In brief, 1080 Ma mafic magmatism in the Musgrave Block was due to partial melting of depleted mantle, perhaps associated with a mantle plume, and mantle-derived magmas assimilated <20% crustal material during passage through the basement. These mafic magmas also underwent typical partial melting and fractional crystallisation processes.

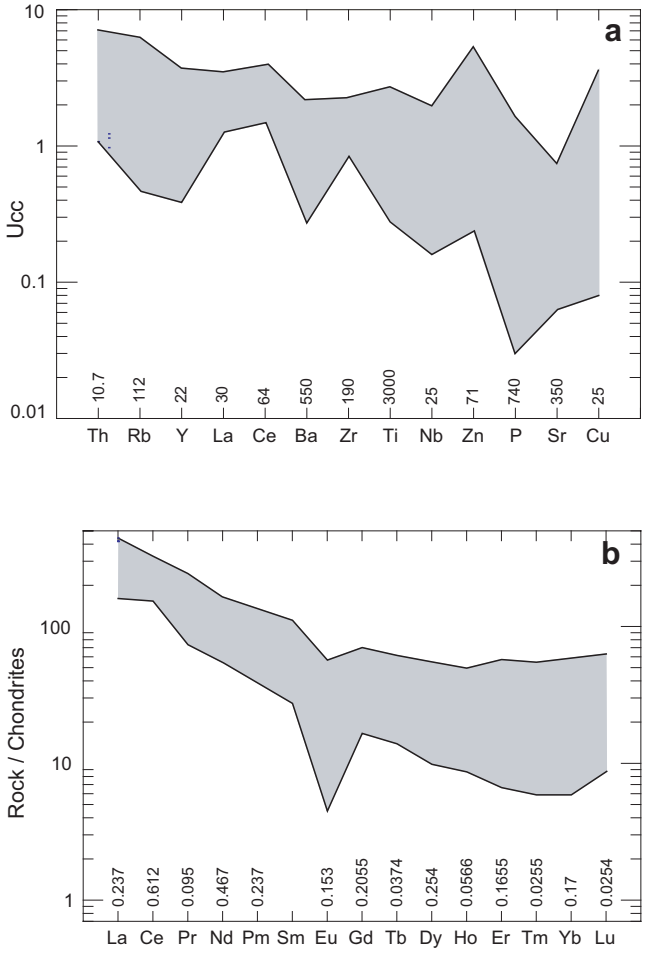


Figure 26. Normalisation plots for granites of Pottoyu Granite Suite. (**a**) Upper continental crust (Ucc)-normalised plots. Normalising values from Taylor and McLennan (1985). (**b**) Chondrite-normalised rare earth element plots. Normalising values from Sun and McDonough (1989).

Granites and felsic volcanics

1190-1140 Ma granites

Whole rock geochemistry was obtained for eight samples taken from the Pottoyu Granite Suite (as defined on PETERMANN RANGES), the Amputjuta Dacite and the Ilyaralona Granite (**Appendix 3**). Geochemical data for fourteen samples from the undivided Pottoyu Granite Suite

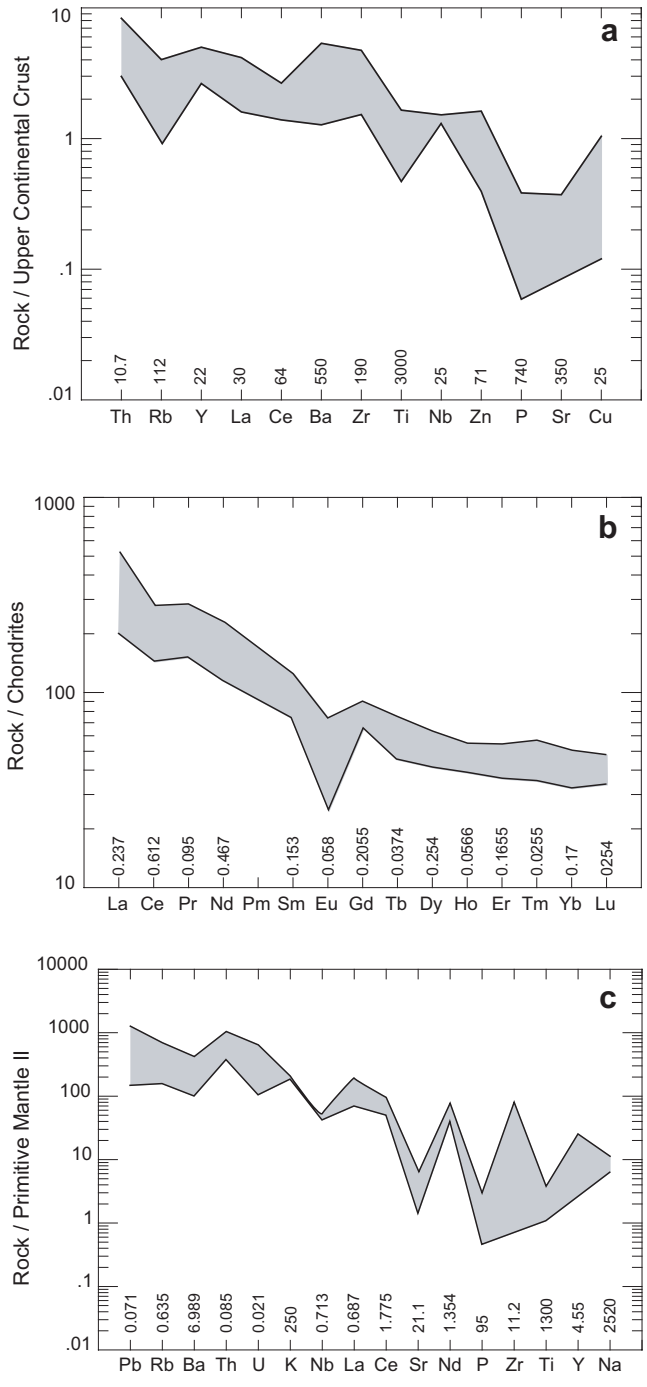


Figure 27. Normalisation plots for granites of Hull Granite Suite. (**a**) Upper continental crust-normalised plots. Normalising values from Taylor and McLennan (1985). (**b**) Chondrite-normalised rare earth element plots. Normalising values from Sun and McDonough (1989). (**c**) Primitive mantle-normalised rare earth element plots. Normalising values from Sun and McDonough (1989).

on PETERMANN RANGES (Edgoose *et al* in press) are included on the following geochemical plots for comparative purposes.

On the Wilson (1989) total alkali versus silica diagram for plutonic rocks, the samples plot in the granite to quartz diorite range and straddle the alkaline/subalkaline boundary. Upper continental crust (UCC)-normalisation plots indicate

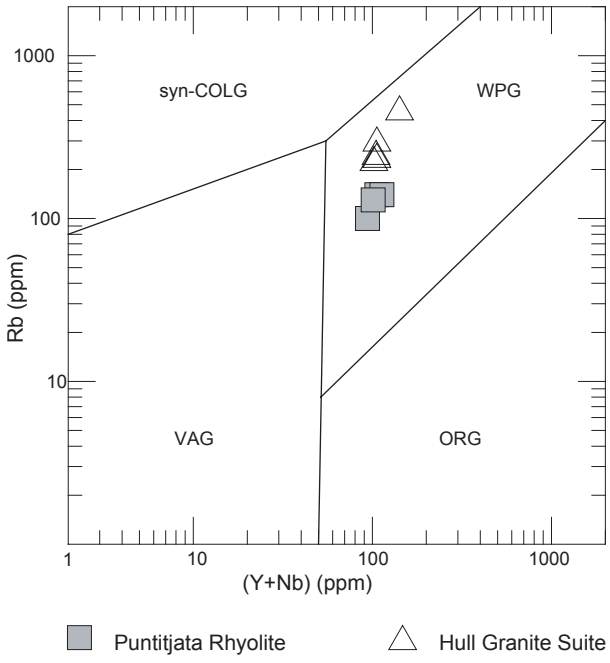


Figure 28. Tectonic discrimination diagram (after Pierce *et al* 1984) showing that Hull Granite Suite and Puntitjata Rhyolite samples plot in WPG (within plate granites) field. VAG – volcanic-arc granites, syn-COLG – syn-collisional granites, ORG – ocean-ridge granites.

negative anomalies in P, Ti and Sr (**Figure 26a**). The chondrite-normalised REE pattern for these samples shows LREE enrichment with a marked negative Eu anomaly (**Figure 26b**). These characteristics are consistent with fractionated or residual apatite, plagioclase and titanite. Geochemical analysis on the Pottoyu Granite Suite on PETERMANN RANGES suggested that this magmatic suite was probably derived from an amphibolite facies tonalitic source (Scrimgeour *et al* 1999).

1090-1075 Ma granites and felsic volcanics

Five samples from small granite bodies and five samples of the Puntitjata Rhyolite, all outcropping north of the Mannanana Range, were analysed for whole rock geochemistry (**Appendix 3**). Similarities in plot trends for both intrusives and extrusives on the UCC- (**Figure 27a**), chondrite- (**Figure 27b**) and primitive mantle- (**Figure 27c**) normalisation diagrams suggest a highly fractionated suite from a common source. The Hull Granite Suite and the Puntitjata Rhyolite exhibit several geochemical characteristics indicative of A-type granites such as enrichment in LREE, low levels of Eu and Sr, high levels of HSFE such as Zr, Nb and Y, and a high Ga/Al ratio (Best and Christiansen 2001). The samples also plot clearly in the WPG (within-plate granites) field of the Rb versus Y+Nb discrimination plot (**Figure 28**).

GEOCHRONOLOGY

Prior to Second Edition mapping, no geochronological data existed for HULL and BLOODS RANGE. Within this current study, a total of six samples were collected for geochronological analysis, five to obtain a magmatic age and one for detrital provenance data. Two techniques of dating zircon were used: U-Pb SHRIMP and Pb-Pb Kober evaporation. A complete list of all geochronological data for HULL and BLOODS RANGE is given in **Table 2** and locations of samples are illustrated in **Figure 20**.

SHRIMP U-Pb geochronology

SHRIMP U-Pb zircon geochronology was undertaken by Precise Radiogenic Isotope Services (PRISE), Australian National University on two samples from HULL and BLOODS RANGE: from the Walu Granite of the Hull Granite Suite to constrain the age of granite intrusion; and from the Pinyinna beds to obtain a maximum deposition age for the unit. A full tabulation of the data, images of zircons and concordia diagrams were given in Armstrong (1998).

Analyses of zircons obtained from the Walu Granite (BR97CJE73) determined no inheritance and showed that they have abundant magmatic compositional zoning, recognisable in normal transmitted light and

ROCK TYPE	SAMPLE NO.	LOCATION (GDA 94)	METHOD	Age (Ma)
Ilyaralona Granite (Pgi)	BR98DFC491	North of Ilyaralona Range; 535181mE, 7253660mN	Pb-Pb zircon evaporation	1163 ± 4 (magmatic)
Amputjutu Dacite (Pga)	BR98DFC550	South of Dean Range; 506017mE, 7240572mN	Pb-Pb zircon evaporation	1153 ± 3 (magmatic)
Walu Granite (Pgwa)	BR97CJE73	8.7 km NW of Walu Outstation; 546300mE, 7269000mN	SHRIMP U-Pb zircon	1084 ± 9 (magmatic)
Rowley Granophyre (Pgr)	BR98DFC429	3 km SW of Walu Outstation; 551843mE, 7261231mN	Pb-Pb zircon evaporation	1075 ± 2 (magmatic)
Puntitjata Rhyolite (Pvp)	BR97CJE153	South of Bloods Range; 540800mE, 7274700mN	Pb-Pb zircon evaporation	1075 ± 2.5 (magmatic)
Pinyinna beds (Ppi)	BR97IRS58	Bloods Range; 533820mE, 7275200mN	SHRIMP U-Pb zircon	1058 ± 31 (detrital) 1198 ± 23 (detrital) 1540-1790 (detrital)

Table 2. Summary of geochronological data from HULL and BLOODS RANGE.

cathodoluminescence imaging. U-Th-Pb isotopic compositions and concentrations were derived from fifteen zircons. With the exception of two analyses, discordant due to recent Pb loss, the data plotted as a group on the concordia for which a weighted mean $^{207}Pb/^{206}Pb$ age of 1084 ± 9 Ma was calculated (uncertainty given with 95% confidence limits, MSWD = 0.56).

Zircons separated from the Pinyinna beds (BR97IRS58) were characteristically rounded with little preservation of pristine crystal faces. Features such as magmatic zoning and possible cores were present and very bright cathodoluminescence indicated low concentrations of uranium. Sixteen analyses were undertaken producing a concordia plot that suggested a number of age populations. Two well defined groupings gave weighted mean $^{207}Pb/^{206}Pb$ ages of 1058 ± 31 Ma and 1198 ± 23 Ma, with 95% confidence limits, whereas the remaining data yielded scattered ages ranging from the oldest grain with an apparent $^{207}Pb/^{206}Pb$ age of 1786 ± 6 Ma (1σ) to approximately 1540 Ma.

Single grain Pb-Pb evaporation dating

Zircons from four felsic magmatic samples from HULL and BLOODS RANGE were dated using the single zircon Pb-Pb 'evaporation' or 'Kober' technique (Kober 1986, 1987). Two samples were from intrusives of the Pottoyu Granite Suite, one was from a granite of the Hull Granite Suite and one was from the Puntitjata Rhyolite (**Table 2**, **Figure 20**). The Kober technique involves a series of incremental 'heating steps' of zircons to resolve any isotopic heterogeneities. Although SHRIMP U-Pb analysis is a preferable method for precise geochronology of complex zircons, ages of an equally high resolution can be derived from simple magmatic zircons using the 'Kober' method (eg Dougherty-Page and Bartlett 1999, Dougherty-Page and Foden 1996). As the samples from HULL and BLOODS RANGE were obtained from units that had undergone greenschist-grade metamorphism, producing no new zircon growth, the 'Kober' technique was used as a cost-effective means of dating. Analyses were undertaken with a Finnigan MAT 261 mass spectrometer at the University of Adelaide. More detailed tabulation of the data can be found in Close *et al* (2003).

Zircons from the Ilyaralona Granite (BR98DFC491) contained few inclusions, were highly transparent and had adamantine crystal faces. Visual inspection indicated a single phase of zircon crystallisation. Six zircons were analysed through a total of twenty-nine heating steps. Most heating steps fell within a well-defined age plateau of 1163 ± 4 Ma (1σ), but nine plotted at older ages than the plateau. This may indicate an inherited component [minimum age 1183 ± 4 Ma (2σ)], or may be an artefact of the analysis.

Zircons separated from the Amputjuta Dacite (BR98DFC550) yielded two different coloured populations, suggesting two episodes of zircon crystallisation. Five zircons from one phase were analysed over eleven heating steps which produced a well-defined plateau age of 1153 ± 3 Ma (1σ), interpreted as the crystallisation age. A zircon from the second phase, interpreted as an inherited xenocryst, yielded two heating step ages significantly older than the main plateau. The older of these, 1380 ± 26 Ma (2σ), represents the minimum age of inheritance.

Petermann Survey	
Client	NT DME[1]
Contractor	Austirex International Ltd
Survey area	COCKBURN, DUFFIELD, POTTOYU, PETERMANN, HULL, BLOODS RANGE
Date of survey	September-October 1985
Kilometres flown	38 018 km
Flight line direction	North–south
Flight line spacing	500 m
Tie line direction	East–west
Tie line spacing	5000 m
Flying height	100 m above ground level
Aircraft	VH-FGS Rockwell Shrike Commander 500S
Gamma spectrometer	33.56 litre 256 channel Exploranium GR800D
Time sample interval	0.75 s
Sample interval	60 m
Magnetometer	Scintrex VIW 2321-H6 Cesium vapour with Sonotek AADC 2C1AB compensator
Time sample interval	0.25 s
Sample interval	20 m

Table 3. Specifications of Petermann airborne surveys. [1]Department of Minerals and Energy, now Minerals and Energy group.

The Rowley Granophyre sample (BR98DFC429) produced zircons that were generally small and colourless, with simple pyramid morphology, interpreted as representing a single crystallisation event. Five zircons were analysed in a series of twenty-nine heating steps, that produced a well-defined plateau age of 1075 ± 2 Ma (1σ).

A heterogeneous population of zircons from the Puntitjata Rhyolite (BR97CJE153) were characterised by euhedral to fragmented morphologies, clear to reddish colouring, and some frosting and pitting of crystals. These features suggest a single crystallisation phase, possibly from a pyroclastic eruptive event. Four of the analysed zircons yielded a plateau age of 1075 ± 2.5 Ma (1σ), whereas one zircon, interpreted as inherited, gave an age of about 1120 Ma.

GEOPHYSICS

By K Slater

Airborne geophysical survey coverage over HULL and BLOODS RANGE was undertaken during the Petermann survey, flown by the then Northern Territory Department of Mines and Energy in 1985. The survey was flown at an altitude of 100 m with a line spacing of 500 m. Reprocessing of the magnetic data was undertaken by Pitt Research Pty Ltd in 1998. Specifications of airborne geophysical surveys conducted over HULL and BLOODS RANGE are summarised in **Table 3**.

Total magnetic intensity (TMI) and radiometric (total count, potassium, thorium and uranium) data from the airborne survey have been gridded with a cell size of 125 × 125 m. The TMI data are presented as a hue, saturation, intensity (HSI) image. Colours are assigned to the TMI values (red high, blue low), and gradients are enhanced with synthetic sun illumination from the northeast (azimuth 045°, elevation 45°). Radiometric data are presented as a red-

green-blue (RGB) composite image, where the potassium channel is displayed in red, the thorium channel in green and the uranium channel in blue.

The geophysical interpretation over southern BLOODS RANGE has been published as a special edition 1:250 000 map adjoined to PETERMANN RANGES (Slater 2000).

GEOLOGICAL HISTORY

The oldest units on HULL and BLOODS RANGE are syn- to post-Musgravian granites of the Pottoyu Granite Suite, including the Amputjuta Dacite, undivided Pottoyu Granite Suite and Ilyaralona Granite. These granites form part of an extensive magmatic event from 1190-1140 Ma that dominates the northern Musgrave Block. They are interpreted to be the result of prolonged heating and melting of the lower to middle crust leading to intrusion into the middle to upper crust (Scrimgeour *et al* 1999).

Intrusives of the Pottoyu Granite Suite were subsequently uplifted and exhumed to allow the localised deposition of the Karukali Quartzite, which probably represented a restricted shallow marine incursion. Basin infill then changed to rift-style sedimentation with the deposition of the Tjauwata Group, which is characterised by the onset of subaqueous mafic volcanism within successions of dominantly quartzose sandstone, minor dark grey siltstone and epiclastics (*Tjuninanta Formation*). The generally clean, well sorted nature of the quartz-rich sediments suggests a basement provenance with little local input from the volcanic source, and the presence of pillow basalts indicates that deposition continued in a subaqueous environment. Sediment supply to the basin diminished as mafic and felsic volcanism (*Mount Harris Basalt* and *Puntitjata Rhyolite*) continued in a subaerial environment. Shallow-level intrusions of small granitic bodies into this volcanic pile (*Hull Granite Suite*) were followed by regionally extensive intrusion of the *Alcurra dolerite*. This package of bimodal intrusives and extrusives is coeval with the 1078 Ma emplacement of the mafic to ultramafic Giles Complex in the western Musgrave Block, and was probably the result of crustal anatexis related to mafic intrusion. Geochemical evidence from 1080 Ma mafic rocks suggests that they were derived from partial melting of depleted mantle, possibly related to a mantle plume, and were affected by assimilation of crustal material.

Volcanic activity decreased as deposition continued in an alluvial environment *(Bloods Range Formation*). This laterally variable succession, comprising polymictic conglomerate and epiclastic rocks was probably deposited in a high-energy braided fluvial system, with material derived from the underlying volcanics. Continuing minor felsic volcanic flows disrupted established drainage patterns to allow the deposition of fine-grained detritus.

A much more subdued topography is indicated by the transitional to shallow marine conditions of the overlying transgressive succession of the Amadeus Basin. A change from rift-style to sag-style sedimentation is indicated, coinciding with the onset of widespread subsidence over much of central Australia, and this is consistent with the depositional hiatus/erosional surface observed between the Tjauwata Group and Amadeus Basin. Initial deposition was deltaic (*Kulail Sandstone*). This was followed by shallow marine quartz sandstone (*Dean Quartzite*), which was replaced as the basin deepened, by marine siltstone and carbonate at about 800 Ma (*Pinyinna beds*). The dominant provenance of Musgrave-age zircons in the Pinyinna beds clearly indicates that at least part of the Musgrave Block or its equivalents was exposed at some time during the deposition of this succession.

Sedimentation continued intermittently in the region during the Neoproterozoic, with the deposition of sandstone in a variably fluvial to marine environment (*Inindia beds*, not exposed in HULL and BLOODS RANGE), followed by a later influx of clastic sand and silt in a fluvial to shallow marine environment (*Winnall beds*). Isopach data has been interpreted to suggest that the Neoproterozoic successions thickened southwest towards and over the margin of the Musgrave Block (Sandiford and Hand 1998). Disconformities separate the Pinyinna beds, Inindia beds and Winnall beds, suggesting that intermittent tectonism or movement of salt diapirs in the Pinyinna beds/Bitter Springs Formation occurred during this period.

A major intraplate orogenic event, the Petermann Orogeny, affected the region during the interval 570-530 Ma. This orogeny was associated with north-verging dextral oblique compression and resulted in significant crustal shortening and thickening. Basal units of the Amadeus Basin underwent intense isoclinal folding, thrusting and duplexing under kyanite-grade amphibolite facies conditions at mid crustal levels (6-7 kbar, 600-650°C), and these rocks are now exposed in the Petermann Ranges region. Metamorphic grade decreased to greenschist facies at upper crustal levels (Bloods Range region). The Petermann Nappe Complex, a large basement-cored, internally duplexed nappe, accommodated much of the north-directed transport along the Piltardi 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 decollement surface. This allowed passive thrusting of the Winnall and Inindia beds southward over the north-verging basement wedge, along the Bloods Backthrust Zone. Late-stage duplexing during the Petermann Orogeny led to the rotation of the Piltardi Detachment Zone into a north-dipping orientation, as well as the formation of a monocline along the Bloods Backthrust Zone. Localised west- to northwest-vergent folding within the basement wedge is attributed to space accommodation.

The present occurrence in the Mann Ranges (southern PETERMANN RANGES) of rocks that were at >40 km depth during the Petermann Orogeny (Scrimgeour *et al* 1999) implies that this event must have resulted in the development of significant topography. A thick conglomerate that infills the Mount Currie Sub-basin probably represents proximal foreland deposits associated with this event.

Erosion of the significant topography formed by the Petermann Orogeny was largely achieved by the Ordovician, when quartz sand and minor silt deposited in a shallow sea that extended across HULL onlapped remnant topographic features. Further tectonism occurred to the north in the Amadeus Basin during the Devonian-Carboniferous Alice Springs Orogeny, which led to tilting and gentle folding in the Bloods Range region, and possible minor reactivation of some Petermann Orogeny structures.

The Cenozoic history of HULL and BLOODS RANGE 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, two periods of extensive deep weathering are known: the first occurred from the end Cretaceous to early Palaeocene; the second occurred during the late Eocene. The earlier of the two periods resulted in widespread chemical weathering and the development of laterite profiles, with deep leaching in underlying pallid zones. Laterites preserved in the sheet areas probably relate to this cycle of weathering and it was also associated with the culmination of widespread peneplanation in the region. The later Eocene phase largely affected sediments in Cenozoic basins, such as the Ayers Rock Basin (AYERS ROCK).

By the early Cenozoic, the landscape was generally subdued with extensive flat, lateritised plains cut by shallow drainage, and broad, smooth profile uplands at the site of the present-day 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 surface of the lateritic plains. Bevelled crests on many of the upland features, particularly in the Petermann Ranges, are remnants of the former upland surface. Peak dry conditions occurred about 18 000 ybp and coincided with the maximum expansion of sand plains and dune fields. The present day, slightly wetter climate has resulted in widespread vegetation stabilising the aeolian environment and for some reactivated drainage systems to breach their sand cover for some distance before disappearing below the surface.

ECONOMIC GEOLOGY

As part of this project, a regional assay sampling program of quartz veins and prospective lithologies was conducted by NTGS; results are presented in **Appendix 4**.

Copper and base metals

Occurrences of secondary copper minerals (malachite, chrysocolla and chalcocite) in veins have been recorded in the area of low hills 5-10 km northeast of Tjuninanta (ET313555 and ET372552; Fruzzetti and Morlock 1972). These occurrences are associated with rare azurite, and specular hematite and ilmenite are sometimes associated with malachite. Chalcocite occurs within calcite-filled fractures, related to quartz and quartz orthoclase veins that intrude sheared basalt and schistose sediments of the Tjuninanta Formation. Five follow-up diamond drillholes were undertaken by the Mines Branch of the NT Administration in 1971 to test surface copper grades of up to 26%. Drilling did not detect significant mineralisation at depth. People from the Docker River Community carried out a small surface mining operation at this time to exploit the surface enrichment.

Planet Mining undertook a comprehensive sampling program within outcrop of Pinyinna beds across the area in 1968 (MacMahon and Partners 1968, Tassell 1969). The distribution of Pinyinna beds was determined from aerial photograph interpretation and BMR mapping in 1962. It was concluded that the anomalous copper and base metal values resulted from weathering or surface oxidation and do not represent enrichment at depth. The Bloods Range beds (as defined in BMR mapping) and the Mount Harris Basalt were assessed and interpreted to have low potential.

Silver and gold

Secondary lead minerals, galena, silver and gold were found with secondary copper minerals in a quartz vein intruding the Mount Harris Basalt by BMR (Forman 1966a). This vein was resampled by NTGS (sample BR97DFC97, **Appendix 4**) and found to contain anomalous Ag (89 ppm), Bi (220 ppm), Cu (1.94%), Pb (2.08%), Au (101 ppb). Elevated levels of Ag (4.5 ppm) and Cu (1.1%) were also found in a sample of malachite-stained Tjuninanta Formation (sample BR98DFC493, **Appendix 4**). No further significant gold values have been identified in any assaying conducted by NTGS or Planet Mining.

Economic potential

The very limited exploration that has occurred to date in HULL and BLOODS RANGE has not identified significant mineralisation. However, the presence of a rift basin containing both felsic and mafic volcanics, and associated sediments, beneath the main stratigraphy of the Amadeus Basin, suggests that there is potential for mineralisation in the area. There is also evidence of significant fluid flow following deposition of the volcanic units of the succession (eg alteration in the Mount Harris Basalt). This rift package probably forms the most prospective part of the Northern Territory section of the Musgrave Block. The generally low metamorphic grade and likelihood of significant fluid flow along structures developed during the Petermann Orogeny provide a focus for future exploration.

Moderate potential for gold and possibly copper mineralisation within the 1190-1140 Ma granites of the Musgrave Block was suggested by Budd *et al* (2002), based on oxidisation, fractionation and the strongly metaluminous, Sr-depleted, Y-undepleted nature of the suites. Geophysical interpretation of HULL and BLOODS RANGE indicates that these granites have considerable subsurface extent.

Groundwater

Groundwater resources in HULL and BLOODS RANGE are not well known. From 1963 to 1997, 83 bores were drilled for water in the sheet areas. Nearly all were to obtain water supplies for the Docker River Community and to source water for the siting and construction of outstations in the area. Many failed to intersect an aquifer and in many others, the water was unsuitable for human consumption. Average water depths were between 30-50 m, with a few nearing 100 m. Water quality varies enormously, with Total Dissolved Solids (TDS) ranging from a minimum of 340 mg/L to a maximum of about 5000 mg/L. The relatively shallow water levels indicate that most aquifers around the Docker River Community occur in unconsolidated deposits, sourced by

local recharge from the nearby ranges and underground flow from the Docker River.

Other tested aquifers include possible Pinyinna beds (clay was recorded at the base of some bores around the Docker River Community), Mount Harris Basalt south of Mount Harris and around Walu Outstation, and Amputjuta Dacite and Pottoyu Granite in Learmonth Park. Most of these rock units would be considered largely impermeable; therefore water is likely to be present in fracture systems. This could account for the variability of the presence of water and water quality even between relatively nearby bores.

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Geochronology (Zircon Pb-Pb evaporation) was undertaken by Jon Dougherty-Page at the University of Adelaide. SHRIMP analysis was done by Richard Armstrong from the Research School of Earth Sciences. Information for the *Groundwater* section was provided by the Natural Resources Unit of the Department of Lands, Planning and Environment[3], Alice Springs. The manuscript was formatted by Tim Munson.

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APPENDIX 1 - Definitions of new stratigraphic units

Amputjuta Dacite (new name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002.
Derivation of name: Amputjuta Outstation, southwestern HULL at 24°55'49.54"S, 129°07'27.48"E (512550mE, 7242750mN).
Synonymy: Previously described as unnamed Precambrian porphyroblastic schist, quartz-feldspar porphyry (Forman 1966).
Parent unit: Forms part of the 1190-140 Ma Pottoyu Granite Suite (Scrimgeour *et al* 1999).
Distribution: Arcuate belt around the margin of Learmouth Park, southwestern HULL.
Geomorphic expression: Low rounded hills.
*Type locality:*4.5 km southwest of Amputjuta Outstation at location 24°56'53.04"S, 129°04'52.42"E (508200mE, 7240800mN).
Thickness: n/a.
Lithology: Porphyritic hypabyssal dacite with fine-grained phenocrysts of feldspar; less abundant equigranular leucogranite.
Relationships and boundary criteria: Intrudes the undivided Pottoyu Granite Suite; overlain by Kulail Sandstone.
Age and evidence: Mesoproterozoic. Pb-Pb evaporation dates on zircon have yielded an age of 1153 ± 3 Ma.
Correlatives: Geochemically similar, thus tentatively correlated with the undivided Pottoyu Granite Suite (1190-1140 Ma) and Ilyaralona Granite (1163 ± 4 Ma).
Comments: Shallow-level intrusive. Previous given 'informal' name of Manananna Porphyry (Forman 1966). Ambiguous intrusive relationships with Pottoyu Granite are seen in the field, but geochemical signatures are similar suggesting that the Amputjuta Dacite is probably a late co-magmatic phase of the Pottoyu Granite. Possibly is high-level intrusive equivalent.

Ilyaralona Granite (new name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002.
Derivation of name: Ilyaralona Range, southeastern HULL.
Synonymy: Previously described as unnamed Precambrian granite (Forman 1966).
Parent unit: Forms part of the 1190-1140 Ma Pottoyu Granite Suite (Scrimgeour *et al* 1999).
Distribution: Small area of outcrop on northern side of Ilyaralona Range.
Geomorphic expression: Low rounded hills.
Type locality: Best exposure 3.5 km north of Ilyaralona Range at 24°49'52.26S, 129°20'54.06"E (535200mE, 7253700mN).
Thickness: n/a.
Lithology: Coarsely porphyritic muscovite granite.
Relationships and boundary criteria: Granite outcrops in the vicinity of basalt associated with the Tjuninanta Formation. No obvious age relationships from outcrop evidence.
Age and evidence: Mesoproterozoic. Pb-Pb evaporation dates on zircon have yielded an age of 1163 ± 4 Ma (Close *et al* 2003).
Correlatives: Geochemically similar to undivided Pottoyu Granite Suite (1190-1140 Ma) and Amputjuta Dacite (1153 ± 3 Ma).

Tjauwata Group (new name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002..
Derivation of name: Tjauwata Outstation at location 24°54'54.28"S, 129°07'20.29"E (512350mE, 7244450mN).
Synonymy: Lower section equivalent to Bloods Range beds of Forman (1966).
Constituent units: Karukali Quartzite, Tjuninanta Formation, Mount Harris Basalt, Puntitjata Rhyolite, Bloods Range Formation.
Distribution: Central HULL and BLOODS RANGE. South of Bloods and Rowley Ranges, north of Ilyaralona Range and the Mount Berteaux region, PETERMANN RANGES. Extends west into WA on southern RAWLINSON and northeastern SCOTT.
Geomorphic expression: Low hills and footslopes below scarps of strike ridges of Dean Quartzite and Kulail Sandstone.
Type locality: Type localities for the constituent units are given in their respective formal definitions.
Thickness: Greater than 1 km; maximum thickness unknown due to discontinuous outcrop and structural thickening.
Lithology: Basal conglomeratic quartzite, overlain by interlensed silicified, epidotised amygdaloidal metabasalt, quartzite, quartz-muscovite schist, dark grey phyllitic schist and felsic volcaniclastics. These sediments and volcanics are overlain by variably silicified and epidotised amygdaloidal metabasalt with minor quartzite, metamorphosed porphyritic rhyolite and polymictic pebble conglomerate, quartzite-cobble conglomerate, immature sandstone, red and dark purple fine sandstone and siltstone, epiclastic and volcaniclastic rocks, and rare tuff.
Depositional environment: Subaqueous, initially a shoreline depositional setting, then alluvial and fluvial environments. Limited evidence suggests initial basalt flows were deposited in a subaqueous environment.

Relationships and boundary criteria: Unconformably overlies undivided Pottoyu Granite Suite. Disconformably overlain by basal sediments of the Amadeus Basin (Kulail Sandstone and Dean Quartzite).

Age and evidence: Meso-Neoproterozoic. Younger than 1190-1150 Ma Pottoyu Granite Suite and older than the 850 Ma Dean Quartzite. The Puntitjata Rhyolite lies within the upper stratigraphy of the Tjauwata Group and is dated at 1075 ± 2 Ma. Shallow-level granites such as the Rowley Granophyre and Walu Granite intrude the middle stratigraphic section of the Tjauwata Group and are dated at 1075 ± 2 Ma and 1084 ± 9 Ma, respectively.

Correlatives: The Tjauwata Group probably correlates with unnamed quartzite, basal conglomerate, sheared porphyry, quartz-feldspar porphyry, sheared basalt and quartz sericite schist in adjacent RAWLINSON and SCOTT in WA. Correlated with the Tollu Group of the Bentley Super Group in the western Musgrave Block (Daniels 1974).

Comments: Thrust repetition within the Tjauwata Group, as a result of the 570-520 Ma Petermann Orogeny, has led to difficulties in determining precise stratigraphic relationships and the true thickness of the succession.

Karukali Quartzite (new name)

Proposers: DF Close and CJ Edgoose.

Registered in Stratigraphic Units Database: 21/01/2002.

Derivation of name: Karukali Outstation at location 24°54'15.57"S, 129°21'09.06"E (535600mE, 7245600mN).

Synonymy: Previously described as the basal unit of the Mount Harris Basalt (Forman 1966).

Constituent units: Nil.

Distribution: Scattered outcrops in central-western BLOODS RANGE, in areas 5 km northeast and 13-17 km southeast of Walu Outstation.

Geomorphic expression: Scarps and dip slopes of isolated low hills.

Type locality: 17 km southeast of Walu Outstation at location 24°49'58.95"S, 129°36'45.31"E (561900mE, 7253400mN). Lower contact is quartz gravel beds and quartz pebble conglomerate above coarsely porphyritic biotite granite of the undivided Pottoyu Granite Suite; upper contact is obscured by 0.5 m of scree material.The stratigraphic succession is equigranular, silicified quartzite overlain by epidotised, silicified metabasalt of the Tjuninanta Formation. Thickness of section is 10 m.

Thickness: 5-10 m.

Lithology: Quartzite and quartz-muscovite schist, often rich in hematite and magnetite, minor quartz pebble conglomerate.

Depositional Environment: Shoreline.

Relationships and boundary criteria: Unconformably overlies undivided Pottoyu Granite Suite of the Musgrave Block and is overlain by basal units of the Tjauwata Group in a probable disconformable relationship, although stratigraphic contact is not well exposed. The Karukali Quartzite is crosscut by mafic dykes probably associated with the 1080 Ma Alcurra dolerite.

Age and evidence: Mesoproterozoic. Unconformably overlies the 1190-1140 Ma undivided Pottoyu Granite Suite and is intruded by mafic dykes interpreted to belong to the 1080 Ma Alcurra dolerite.

Correlatives: Probably a distal equivalent of the MacDougall Formation, basal Tollu Group (Daniels 1974) that outcrops in the MacDougall Bluff Region in Western Australia.

Tjuninanta Formation (new name)

Proposers: CJ Edgoose and DF Close.

Registered in Stratigraphic Units Database: 21/01/2002.

Derivation of name: Tjuninanta Outstation, south-central HULL, at location 24°51'07.86"S, 129°13'50.25"E (523300mE, 7251400mN).

Synonymy: Formerly part of Bloods Range Beds and Mount Harris Basalt from BMR First Edition mapping (Forman 1966).

Constituent units: None named, but has been divided into three informal lithotypes: 1) silicified, epidotised metabasalt; 2) quartzite, quartz muscovite schist, phyllitic schist; and 3) volcaniclastics.

Distribution: East-central HULL and central BLOODS RANGE.

Geomorphic expression: Low to medium ridges and low hills.

Type locality: Type locality: amygdaloidal basalt at 24°47'47.13"S, 129°30'09.32"E (550800mE, 7257500mN). Reference locality: quartz sandstone and grey phyllite at 24°48'12.67"S, 129°32'24.78"E (554600mE, 7256700mN). Reference locality: volcaniclastics at 24°51'23.69"S, 129°28'19.74"E (547700mE, 7250850mN).

*Thick*ness: The succession is structurally repeated and therefore thickness is not known.

Lithology: Basalt, volcaniclastics/felsic volcanics, quartz sandstone, quartzite, phyllite, rare diagenetic chert.

Depositional environment: Includes extrusive rocks and intercalated sediments deposited in a shallow water setting, possibly marine.

Relationships and boundary criteria: Overlain by Mount Harris Basalt, gradational contact. Conformably overlies Karukali Quartzite.

Age and evidence: Mesoproterozoic. Extrusive components are interpreted to be co-magmatic with Mount Harris Basalt and Puntitjata Rhyolite (1075 ± 2.5 Ma).

Correlatives: Potential correlatives are unnamed sediments within volcanic successions in adjoining parts of WA (Horwitz and Daniels 1966, Forman 1966, Daniels 1974).

Comments: Formerly mapped as Bloods Range beds, Mount Harris Basalt, and unnamed porphyry (Forman 1966). The basalt is equivalent to the Mount Harris Basalt, but has been separated out because it is interbedded with felsic volcaniclastic rocks and sediments. Forms part of the newly defined Tjauwata Group.

Mount Harris Basalt (redefinition of unit)
Proposers: DF Close and CJ Edgoose.
Derivation of name: Mount Harris at location 24°38'11.52"S, 129°30'51.48"E (552050mE, 7275200mN).
Synonymy: Previously described as epidotized amygdaloidal basalt, tuff, agglomerate and quartzite, possibly including quartz-feldspar porphyry (Forman 1966).
Constituent units: Nil.
Distribution: Northeastern section of HULL, northwestern section of BLOODS RANGE, northeastern section of SCOTT and southeastern section of RAWLINSON (WA).
Geomorphic expression: Low to moderate rounded hills.
Type locality: 10.5 km southwest of Mount Harris at location 24°40'12.93"S, 129°24'50.84"E (541900mE, 7271500mN).
Thickness: Estimated minimum thickness of 1-2 km. Lower stratigraphic contact not exposed. Strong deformational overprint has resulted in structural thickening of unit.
Lithology: Amygdaloidal basalt, epidotised and silicified basalt with rare crystalline quartz sandstone.
Depositional Environment: Limited evidence suggests a possible subaqueous depositional environment.
Relationships and boundary criteria: Overlain by Puntitjata Rhyolite or Bloods Range Formation. Lower stratigraphic contact not exposed.
*Age and evid*ence: Mesoproterozoic. Intruded by the 1084 ± 9 Ma Walu Granite and by mafic dykes equivalent to the 1080 Ma Alcurra dolerite. Overlain by the Puntitjata Rhyolite (1075 ± 2 Ma).
Correlatives: Mummawarrawarra Basalt of the Tollu Group. The Smoke Hill Felsic Volcanics of the Tollu Group crosscut the Mummawarrawarra Basalt and are dated at 1078 ± 5 Ma (Sun *et al* 1996).
Comments: Redefinition of unit includes a minimum 1-2 km thick succession of basalt with rare sedimentary interbeds. No quartz-feldspar porphyry subunit. Strong layering evident in outcrop. Due to thrust-stacking and strong foliation overprint during the 570-530 Ma Petermann Orogeny, the stratigraphic thickness is estimated as a minimum only.

Puntitjata Rhyolite (new name)
Proposers: CJ Edgoose and DF Close.
Registered in Stratigraphic Units Database: 21/01/2002..
Derivation of name: Puntitjata Outstation, north-central HULL at 24°40'27.27"S, 129°17'42.13"E (529850mE, 7271090mN).
Synonymy: Previously described as unnamed quartz-feldspar porphyry (Forman 1966).
Constituent units: Nil.
Distribution: Scattered exposures across central HULL and central-western BLOODS RANGE.
Geomorphic expression: Footslopes below scarp slopes; rare low rises in plains.
Type locality: 11 km west of Mount Harris at location 24°38'32.24"S, 129°24'13.16"E (540850mE, 7274600mN).
Thickness: n/a.
Lithology: Rhyolite, tuff, minor volcaniclastics.
Relationships and boundary criteria: Interpreted to overlie Mount Harris Basalt. Overlain by Bloods Range Formation or Kulail Sandstone.
Age and evidence: Mesoproterozoic. Pb-Pb evaporation dating of zircon has yielded an age of 1075 ± 2 Ma (Close *et al* 2003).
Correlatives: Correlated with the Smoke Hill Felsic Volcanics of the Tollu Group in the western Musgrave Block, dated at 1078 ± 5 Ma (Sun *et al* 1996).
Comments: Extrusive.

Bloods Range Formation (variation of published name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002.
Derivation of name: Bloods Range, northeastern HULL and northwestern BLOODS RANGE.
Synonymy: Bloods Range beds, Bloods Range Beds (Forman 1966).
Constitiuent units: Nil.
Distribution: Mount Berteaux region (northwestern PETERMANN RANGES), Manananna Range, Mount Skene Range, Mount Hastie area, Bloods Range, Rowley Range (HULL and BLOODS RANGE).
Geomorphic expression: Footslopes below scarps of strike ridges of Dean Quartzite and Kulail Sandstone, rarely as isolated low hills.
Type locality: Upper and lower stratigraphic contacts are exposed on southern slope of Bloods Range, 11 km west of Mount Harris at location 24°38'12.71"S, 129°24'21.98"E (541100mE, 7275200mN). Lower contact is polymictic conglomerate with interlayered quartzose sandstone beds above weathered porphyritic Puntitjata Rhyolite. Upper contact is interlayered red

siltstone and quartz sandstone beds with a 50 cm top layer of leached clay below quartzofeldspathic beds of Kulail Sandstone. Thickness of section is approximately 80 m.

Thickness: Laterally variable, on average approximately 100 m.

Lithology: Polymictic pebble conglomerate, quartzite-cobble conglomerate, immature sandstone, red and dark purple fine sandstone and siltstone, epiclastic and volcaniclastic rocks, rare tuff. Thicknesses and lithologies vary from outcrop to outcrop. Sediments are very locally derived, therefore succession varies considerably with composition of source.

Depositional environment: Fluvial and probably lacustrine environments contemporaneous with extrusive activity.

Relationships and boundary criteria: Unconformably overlain by Kulail Sandstone; overlies Puntitjata Rhyolite, Mount Harris Basalt and Musgrave Block granites.

Age and evidence: Meso-Neoproterozoic. Older than Dean Quartzite (850 Ma) and younger than Puntitjata Rhyolite (1075 ± 2.5 Ma).

Correlatives: Originally correlated with Dixon Range beds (WA) which were defined by Forman (1966) as conformable beneath the Dean Quartzite. However, redefinition precludes this correlation as the contact between the Bloods Range Formation and the Kulail Sandstone/Dean Quartzite in the Bloods Range region is defined by an erosional disconformity.

Comments: Forms the uppermost unit of the Tjauwata Group. The former Bloods Range beds also included parts of the newly defined Tjuninanta Formation and Kulail Sandstone. The true thickness of the succession is difficult to measure, due to both upper and lower stratigraphic contacts being rarely exposed in same section, and the development of a strong foliation during the 570-530 Ma Petermann Orogeny.

Kulail Sandstone (new name)

Proposers: CJ Edgoose and DF Close.

Registered in Stratigraphic Units Database: 21/01/2002..

Derivation of name: Kulail Outstation, central-western edge of HULL at 24°42'46.82"S, 129°0'22.42"E (500630mE, 7266830mN).

Synonymy: Formerly mapped as part of Dean Quartzite (Forman 1966).

Constituent units: Nil.

Distribution: Western and central-northern areas in HULL and central-northwestern BLOODS RANGE.

Geomorphic expression: Cliffs and scarps on south face of Dean, Bloods and Rowley Ranges, low scrubby hills east of Kulail Outstation.

Type locality: Southern slope of Bloods Range, 11 km west of Mount Harris at location 24°38'02.97"S, 129°24'18.4"E (541000mE, 7275500mN). Lower stratigraphic contact is an erosional unconformity defined by Kulail Sandstone overlying interlayered quartz sandstone and red shale beds of Bloods Range Formation, the upper 50 cm of which is leached clay. Upper stratigraphic contact is gradational, with lenses of quartz gravel in a quartzofeldspathic matrix grading into clean, equigranular quartz sandstone beds of Dean Quartzite. Approximate thickness of section is 100 m.

Thickness: Variable. Appears to thin from a minimum 150 m on the southern edge of Bloods Range to 60 m on the southern edge of Rowley Range.

Lithology: Quartz sandstone, sometimes gritty quartzofeldspathic sandstone and minor quartzite. Possible rare, poorly preserved mafic volcanics.

Depositional environment: Alluvial to shallow marine, possibly deltaic.

Relationships and boundary criteria: Overlain with conformable/gradational contact by Dean Quartzite. Disconformably overlies Bloods Range Formation.

Age and evidence: Similar age to Dean Quartzite (850 Ma).

Correlatives: Nil.

Hull Granite Suite (new name)

Proposers: CJ Edgoose and DF Close.

Registered in Stratigraphic Units Database: 21/01/2002.

Derivation of name: Hull River, central HULL.

Synonymy: unnamed Precambrian granites (Forman 1966).

Constituents: Imbumbunna Granite, Rowley Granophyre, Walu Granite.

Distribution: Central-eastern HULL and southeastern BLOODS RANGE.

Geomorphic expression: Low outcrops and rounded hills.

Type locality: Type localities for constituent units are given in their respective formal definitions.

Thickness: n/a.

Lithology: Texturally variable granites ranging from medium-grained, equigranular to coarsely porphyritic with euhedral K-feldspar phenocrysts up to 3 cm in size. Mineralogy comprises quartz, K-feldspar, plagioclase, biotite, muscovite with or without epidote and garnet.

Relationships and boundary criteria: Walu Granite intrudes Mount Harris Basalt. Rowley Granophyre and Walu Granite are crosscut by mafic dykes interpreted to belong to the 1080 Ma Alcurra dolerite. Imbumbunna Granite unconformably underlies the 850 Ma Dean Quartzite.

Age and evidence: Mesoproterozoic. Pb-Pb evaporation dating of zircon has yielded an age of 1075 ± 2 Ma for the Rowley Granophyre and U-Pb SHRIMP zircon dating has yielded an age of 1084 ± 9 Ma for the Walu Granite (Close *et al* 2003).

Correlatives: Correlated with the 1071 ± 5 Ma Angatja Granite on PETERMANN RANGES (Scrimgeour *et al* 1999) and with other 1080-1050 Ma granites documented in the western Musgrave Block by Sun *et al* (1996).
Comments: Variably deformed during the 570-530 Ma Petermann Orogeny.

Imbumbunna Granite (new name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002..
Derivation of name: Imbumbunna Hills, central eastern BLOODS RANGE.
Synonymy: Previously described as unnamed Precambrian granite (Forman 1966).
Parent unit: Forms part of Hull Granite Suite.
Distribution: Single occurrence in southeastern section of BLOODS RANGE.
Geomorphic expression: Low, bouldery outcrop.
Type locality: 18.5 km northeast of Shaw Creek at location 24°53'24.04"S, 129°55'12.57"E (592940mE, 7246920mN).
Thickness: n/a.
Lithology: Coarsely porphyritic biotite-muscovite-epidote-garnet granite. Characteristic euhedral K-feldspar laths.
Relationships and boundary criteria: Overlain by 850 Ma Dean Quartzite (basal Amadeus Basin sediments).
Age and evidence: Mesoproterozoic. Geochemically grouped with granites of the 1090-1075 Ma Hull Granite Suite.
Correlatives: Geochemically similar to Walu Granite (1084 ± 9 Ma) and Rowley Granophyre (1075 ± 2 Ma).
Comments: Foliation, weakly developed during the 570-530 Ma Petermann Orogeny.

Rowley Granophyre (new name)
Proposers: DF Close and CJ Edgoose.
Registered in Stratigraphic Units Database: 21/01/2002..
Derivation of name: Rowley Range, north-central HULL.
Synonymy: Previously described as unnamed Precambrian granite (Forman 1966).
Parent unit: Forms part of Hull Granite Suite.
Distribution: Series of outcrops 4 km west-southwest of Walu Outstation.
Geomorphic expression: Low, bouldery hills.
Type locality: 4 km west-southwest of Walu Outstation at 24°44'54.97"S, 129°29'22.35"E (549500mE, 7262800mN).
Thickness: n/a.
Lithology: Porphyritic biotite-epidote granite with fine-grained phenocrysts of feldspar.

Relationships and boundary criteria: Isolated outcrops, intruded by mafic dykes interpreted to belong to the 1080 Ma Alcurra dolerite.
Age and evidence: Mesoproterozoic. Pb-Pb evaporation dating of zircon has yielded an age of 1075 ± 2 Ma (Close *et al* 2003).
Correlatives: Geochemically similar to Walu Granite (1084 ± 9 Ma) and Imbumbunna Granite.
Comments: Granophyric texture suggests intrusion at upper crustal levels. Foliation, variably developed during the 570-530 Ma Petermann Orogeny.

Walu Granite (new name)
Proposers: CJ Edgoose and DF Close.
Registered in Stratigraphic Units Database: 21/01/2002..
Derivation of name: Walu Outstation, western BLOODS RANGE at location 24°44'25.26"S, 129°31'35.74"E (553250mE, 7263700mN).
Synonymy: Previously described as Precambrian unnamed granites (Forman 1966).
Parent unit: Forms part of the Hull Granite Suite along with Imbumbunna Granite and Rowley Granophyre.
Distribution: One area of outcrop, 8.5 km southwest of Mount Harris.
Geomorphic expression: Low bouldery hills.
Type locality: Isolated outcrop at 24°41'09.48"S, 129°26'52.01"E (545300mE, 7269750mN).
Thickness: n/a.
Lithology: Medium-grained, equigranular biotite granite.
Relationships and boundary criteria: Intrudes Mount Harris Basalt.
Age and evidence: Mesoproterozoic. U-Pb SHRIMP zircon dating has yielded an age of 1084 ± 9 Ma (Close *et al* 2003).
Correlatives: Geochemically similar to Imbumbunna Granite and Rowley Granophyre.
Comments: Locally developed weak foliation from the 570-530 Ma Petermann Orogeny.

APPENDIX 2. Geochemical analyses of mafic dykes and volcanic rocks from HULL and BLOODS RANGE; dl – Alcurra dolerites, Pvh – Mount Harris Basalt, silic Pvh – silicified Mount Harris Basalt.

Sample No	BR97 DFC9	BR97 DFC12c	BR97 DFC13	BR97 DFC102	BR97 DFC103	BR97 DFC120	BR98 CJE74	BR98 CJE78	BR98 CJE91	BR98 CJE92a	BR97 CJE92b	BR98 CJE493a	BR98 CJE493b	BR99 CJE559
Unit	dl	dl	dl	dl	dl	dl	Pvh	Pvh	dl	Pvh	Pvh	Pvh	Pvh/dl?	silic Pvh
AMG (mE)	508121	506532	507952	551482	552672	554109	544520	545658	547344	547344	547344	541776	541776	543619
AMG (mN)	7240764	7237210	7236908	7273912	7273927	7273157	7270697	7270197	7270192	7270192	7270192	7271643	7271643	7273902
SiO_2	53.5	47.0	47.3	48.2	55.0	54.4	56.7	46.9	48.2	48.2	49.3	53	58.8	65.6
TiO_2	2.200	1.020	1.460	2.550	1.730	1.670	1.32	0.835	2.53	3.65	1.450	1.19	1.12	1.17
Al_2O_3	13.4	17.1	15.7	15.1	13.2	13.4	13.3	16.5	13.1	12.8	11.8	14.2	12.9	12.2
Fe_2O_3	15.50	11.70	14.80	13.50	13.10	13.00	10.8	10.5	14.8	16.1	13.1	11.1	10.4	8.82
FeO	7.4	6.2	6.9	7.7	7.0	7.4	4.9	6.9	9.3	8.4	8.2	3.1	3.8	4
MnO	0.32	0.24	0.23	0.18	0.17	0.18	0.14	0.18	0.23	0.19	0.21	0.17	0.15	0.12
MgO	3.45	8.04	6.83	3.86	3.45	3.57	3.11	8.26	6.4	4.38	9.1	3.22	3.13	1.14
CaO	5.40	9.59	9.47	9.46	5.62	6.88	7.54	10.9	9.44	8.91	9.88	8.87	5.56	2.32
Na_2O	3.03	2.55	1.61	2.74	2.04	2.48	2.55	1.76	2.43	1.39	0.94	2.86	3.86	2.79
K_2O	1.97	0.67	1.27	1.17	3.39	2.94	2.09	0.71	1.03	0.99	1.1	2.34	2.08	4.43
P_2O_5	0.64	0.22	0.27	0.44	0.26	0.23	0.2	0.17	0.46	0.37	0.16	0.22	0.23	0.38
LOI	1.06	2.33	1.64	2.12	2.38	1.60	1.13	3.38	1.09	2.41	2.47	1.63	1.19	0.88
Rb	94	44	65	33	120	105	120	32	35	24	33	47	46	145
Ba	600	230	490	420	1450	650	550	190	260	430	440	900	650	1300
Sr	160	200	220	280	200	155	145	200	230	410	200	130	54	105
Cs	6.5	2.3	9.5	1	1.2	1.1	1.3	0.4	1.3	0.4	0.3	0.1	0.2	0.4
Pb	750	31.5	11.5	11.5	14.5	21.5	20.5	36	17	24.5	9.5	17	10	9.5
La	49.5	19.5	16.5	24.0	38.5	34.0	53	9	28	37	14.5	39	37.5	72
Ce	70.0	35.0	29.5	46.5	66.0	57.0	73	18	56	72	28	54	53	135
Pr	10.0	4.1	3.4	7.0	10.5	9.5	12	2.3	8	10.5	4.2	8.5	8.5	17.5
Nd	39.5	15.0	13.0	26.5	38.5	33.0	48	9.5	33	40.5	16.5	35.5	34	64
Sm	9.0	4.2	4.0	6.5	8.5	7.0	9	2.7	8.5	9.5	4.2	7	7	12.5
Eu	2.80	1.45	1.80	2.20	2.30	1.90	2.2	1.05	2.6	2.9	1.45	2.1	1.95	3.1
Gd	7.5	3.8	3.5	7.5	10.0	8.5	9	3.6	10.5	10.5	5	7	7	12
Tb	1.35	0.75	0.67	0.94	1.15	0.95	1.4	0.5	1.3	1.2	0.64	1.15	1.1	1.65
Dy	8.5	5.0	4.4	6.0	7.0	6.0	7.5	3.5	8.5	7	4	6.5	6	11
Ho	1.75	1.05	0.92	1.25	1.45	1.25	1.5	0.76	1.8	1.4	0.83	1.25	1.2	2.1
Er	4.9	2.9	2.6	3.2	3.8	3.2	4.2	2.1	4.6	3.5	2.1	3.5	3.4	6
Tm	0.75	0.45	0.40	0.45	0.55	0.50	0.55	0.35	0.7	0.5	0.3	0.45	0.45	0.9
Yb	4.40	2.60	2.40	2.90	3.40	2.90	3.7	2	4.3	3	1.9	3	3	6
Lu	0.65	0.38	0.37	0.44	0.53	0.46	0.56	0.32	0.66	0.45	0.29	0.47	0.48	0.85
Y	55.0	34.0	29.5	39.5	45.0	40.5	34.5	22.5	51	41.5	26.5	34	31	59
Th	12.5	1	1.5	8.5	18.5	21.5	30.5	2.9	6.5	11.5	3.6	17	16.5	17.5
U	2.2	0.15	0.26	0.8	2.0	2.1	2.7	0.35	0.8	1.3	0.34	1.25	1.15	1.8
Zr	170	90	48	210	280	250	250	59	300	310	140	240	230	470

APPENDIX 2. (continued).

Sample No	BR97 DFC9	BR97 DFC12c	BR97 DFC13	BR97 DFC102	BR97 DFC 103	BR97 DFC120	BR98 CJE74	BR98 CJE78	BR98 CJE91	BR98 CJE92a	BR97 CJE92b	BR98 CJE493a	BR98 CJE493b	BR99 CJE559
Unit	**dl**	**dl**	**dl**	**dl**	**dl**	**dl**	**Pvh**	**Pvh**	**dl**	**Pvh**	**Pvh**	**Pvh**	**Pv h/dl?**	**silic Pvh**
Hf	1.0	<1	<1	5.0	7.0	6.0	5	3	7	8	4.0	5	5	5
Nb	13.0	8.0	6.0	14.0	14.0	13.0	12	5	19	25	9.0	9	8	22
Ta	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	<2	<2	<2	2
Sc							20					25	25	15
Ni	21	185	110	34	35	45	46	145	97	100	250	75	68	<2
Co	48	48.5	62	38	35	38	33	50	44	49	56	35	32	15
V	250	280	250	370	260	300	260	185	340	360	270	280	230	41
Cr	5	750	120	13	20	5	16	175	220	58	550	15	13	11
Cu	48	38	135	100	210	175	80	115	180	270	170	88	56	12
Zn	280	150	120	170	130	125	115	99	170	190	140	99	100	105
Sn														3
W				0.2	0.7	0.7		0.1	0.8	0.4	0.2			<5
Mo	1.4	1.7	0.8	2.3	1.5	1.3	0.9	2.3	9	2.9	1.0	0.6	0.6	2.3
Ga	23.5	16.5	19.5	27.5	22.5	24	21	18.5	25	28.5	20.5	21.5	17	21
Mn							1050					1350	1150	750
P							900					1000	1000	1550
Ag	0.6	0.3	0.2	0.3	0.4	0.3	0.4	0.1	0.4	0.6	0.2	0.4	0.3	0.5
Bi	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	0.2	0.2	0.2
Cd	0.50	<0.1	<0.1	0.2	<0.1	<0.1	0.1	0.2	0.2	0.1	<0.1	0.1	<0.1	<0.1
In	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.1	0.1
Sb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Se	0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Te	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Tl	0.5	0.2	0.4	0.2	0.6	0.6	0.6	0.3	0.3	0.1	0.4	0.2	0.2	0.8
Be	2	<2	<2				10					9	8	3
As				2.5	3.5	4		4	4	3.5	3			

APPENDIX 3. Geochemical analyses of granites and felsic volcanic rocks from HULL and BLOODS RANGE: Pgp – Undivided Pottoyu Granite Suite, Pga – Amputijuta Dacite, Pgm – Imbumbunna Granite, Pgr – Rowley Granophyre, Pvp – Puntitjata Rhyolite, Pgi – Ilyaralona Granite, Pgwa – Walu Granite.

Sample No	BR97 DFC2a	BR97 DFC10	BR97 DFC12a	BR97 DFC63	BR97 DFC69	BR97 DFC75	BR97 DFC78	BR97 DFC88	BR97 DFC94	BR97 DFC182	BR97 DFC388	BR98 DFC429	BR98 DFC491	BR98 DFC550	BR97 CJE73	BR97 CJE153	BR98 CJE309	BR98 CJE479d
Unit	**Pgp**	**Pga**	**Pga**	**Pgp**	**Pga**	**Pgp**	**Pgm**	**Pgr**	**Pgr**	**Pvp**	**Pvp**	**Pgr**	**Pgi**	**Pga**	**Pgwa**	**Pvp**	**Pvp**	**Pvp**
Age (Ma)												1075 ± 2	1163 ± 4	1153 ± 3	1089 ± 9	1075 ± 2.5		
AMG (mE)	506337	506478	506532	538749	514235	516227	592938	549245	548983	537612	510250	551843	535181	506017	546300	540800	514300	539277
AMG (mN)	7238849	7239681	7237210	7233167	7241898	7241477	7246917	7262666	7263341	7272343	7264730	7261231	7253660	7240572	7269000	7274700	7267800	7262981
SiO_2	67.3	66.9	65.7	70.0	67.3	77.1	70.8	74.3	71.9	73	69.5	74	72.3	65.8	70.8	71.0	71.4	69.9
TiO_2	0.940	0.875	0.965	0.565	0.940	0.140	0.385	0.250	0.235	0.585	0.825	0.275	0.45	0.835	0.470	0.675	0.375	0.585
Al_2O_3	15.1	14.9	15.3	14.8	14.3	12.2	14.0	12.0	11.2	11.6	12.6	12.6	13.4	14.3	12.8	12.1	13.5	11.8
Fe_2O_3	5.33	4.91	4.83	2.72	5.04	1.27	3.16	2.41	2.60	4.32	5.86	2.51	2.93	4.78	4.33	5.54	3.44	6.01
FeO	1.6	1.5	2.0	0.8	1.4	0.2	1.8	1.0	1.1	1.9	0.4	1.1	0.3	1.5	1.9	0.4	0.4	1.9
MnO	0.14	0.12	0.12	0.07	0.16	0.02	0.08	0.04	0.05	0.04	0.04	0.05	0.02	0.1	0.09	0.01	0.03	0.05
MgO	0.97	1.03	1.60	0.65	1.00	0.10	0.59	0.09	0.08	0.19	0.18	0.24	0.73	1	0.36	0.09	0.07	0.12
CaO	2.53	3.02	4.12	1.93	2.12	0.30	1.25	0.52	0.67	0.71	0.35	0.74	0.53	2.78	1.34	0.55	0.13	1.33
Na_2O	2.63	2.60	4.09	2.85	3.17	2.45	2.87	3.04	2.99	2.02	2.58	2.99	1.97	2.66	3.03	2.35	3.84	2.14
K_2O	4.24	4.22	1.37	5.35	4.55	5.23	5.56	5.89	5.36	6.77	6.11	5.53	5.22	5.14	5.56	7.17	5.69	6.24
P_2O_5	0.33	0.30	0.36	0.14	0.36	0.01	0.10	0.02	0.02	0.11	0.13	0.04	0.11	0.33	0.06	0.13	0.06	0.11
LOI	1.03	1.17	1.49	1.29	1.06	0.77	1.36	0.51	4.77	0.33	0.71	0.38	1.36	1.23	0.89	0.62	0.65	0.79
Rb	210	185	53	250	240	700	450	230	220	200	100	240	260	220	290	140	140	130
Ba	1250	1300	320	1150	1200	280	800	750	750	1450	2950	800	700	1350	700	1850	700	1700
Sr	210	22	230	160	140	24	130	36	44	29	51	36	46	170	69	34	30	100
Cs	6.5	10.5	3.5	11.0	14.5	26.5	2.9	0.3	0.3	0.4	1.4	1.6	10	6.5	0.6	0.3	0.9	0.7
Pb	23	24.0	48.5	40.0	22.5	18.0	51.0	39.5	40.5	76	15.5	40	12	13	90	10.5	13	25
La	86.0	73.0	95.0	84.0	70.0	45.0	94.0	85.0	87.0	96	92	130	83	77	70	48	105	125
Ce	145.0	125.0	175.0	135.0	125.0	94.0	160.0	150.0	150.0	195	115	170	99	110	120	89	140	160
Pr	19.0	16.5	23.0	17.5	16.0	7.0	22.0	20.5	21.0	24	19.5	27	14.5	18	16	14.5	23.5	27
Nd	71.0	62.0	61.0	63.0	60.0	25.5	71.0	69.0	70.0	82	78	105	51	74	54	54	94	105
Sm	14.5	12.5	17.0	12.0	12.5	4.2	13.5	13.5	13.5	15.5	16	18	8	14	11.5	13	16.5	19
Eu	3.90	3.50	3.30	3.20	3.50	0.26	1.45	1.70	1.70	3.3	4.2	2	2	3.6	2	3.1	2.6	4.3
Gd	11.5	10.0	13.5	10.0	10.0	4.0	16.0	15.0	15.0	13.5	14.5	18	7	13.5	13.5	14	16.5	18
Tb	1.90	1.65	2.30	1.60	1.65	1.00	2.00	1.75	1.70	1.9	2.3	2.8	1.1	2.1	1.7	1.7	2.5	2.7
Dy	11.5	9.5	14.0	9.5	10.0	8.5	14.0	11.0	10.5	12	13.5	15.5	6	11.5	11.5	11	15	14.5
Ho	2.30	1.95	2.80	1.95	2.00	2.10	3.00	2.40	2.20	2.4	2.6	3	1.2	2.3	2.5	2.4	2.9	2.8
Er	6.5	5.5	8.0	5.5	5.5	7.5	9.0	6.5	6.0	7	7.5	8.5	3.4	6.5	7	6.5	8.5	8
Tm	0.95	0.80	1.15	0.85	0.85	1.40	1.45	1.00	0.90	1.05	1.05	1.15	0.5	0.9	1.15	0.95	1.2	1.05
Yb	6.00	4.80	7.50	5.50	5.00	10.00	8.50	6.00	5.50	7	6.5	7.5	3.2	6	7	6	8	6.5
Lu	0.91	0.72	1.10	0.82	0.81	1.60	1.20	0.94	0.86	0.99	1.05	1.1	0.5	0.88	1.1	0.89	1.2	1
Y	59.0	63.0	68.0	47.5	47.5	44.0	110.0	70.0	69.0	66	58	73	33.5	58	76	72	75	68
Th	24.5	24.0	34.0	31.0	22.0	73.0	89.0	54.0	51.0	47	32	70	32	25	56	37	34	51

APPENDIX 3 (continued).

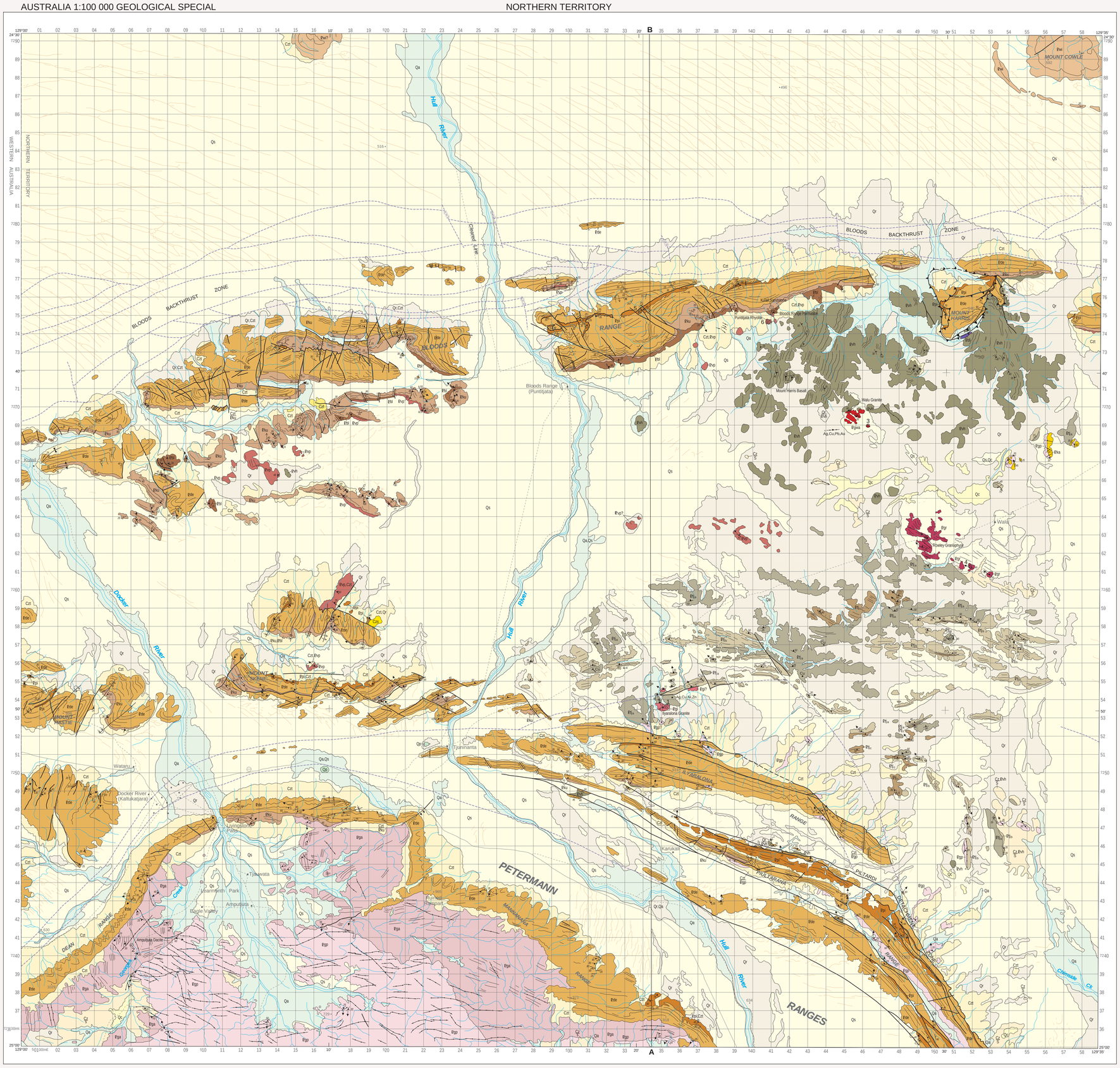
Sample No	BR97 DFC2a	BR97 DFC10	BR97 DFC12a	BR97 DFC63	BR97 DFC69	BR97 DFC75	BR97 DFC78	BR97 DFC88	BR97 DFC94	BR97 DFC182	BR97 DFC388	BR98 DFC429	BR98 DFC491	BR98 DFC550	BR97 CJE73	BR97 CJE153	BR98 CJE309	BR98 CJE479d
Unit	**Pgp**	**Pga**	**Pga**	**Pgp**	**Pga**	**Pgp**	**Pgm**	**Pgr**	**Pgr**	**Pvp**	**Pvp**	**Pgr**	**Pgi**	**Pga**	**Pgwa**	**Pvp**	**Pvp**	**Pvp**
U	2.7	3.00	4.30	4.10	2.90	13.00	13.50	6.50	5.50	4.9	2.2	7.5	3.2	2.6	10.5	2.2	3.1	3.1
Ti																		
Zr	420	410	470	410	410	210	290	440	410	600	900	420	190	440	440	750	550	700
Hf	3.0	3	2	2	3	5	10	13	11	5	17	10	6	8	12	16	12	13
Nb	22.0	22	31	25	22	49	32	36	33	30	36	32	14	19	30	34	38	33
Ta	2	<2	3	3	2	7	4	2	2	3	3	3	2	2	3	2	4	3
Sc		5	5	<5	5	<5				10	<5	<5	<5	10			<5	5
Ni	8	9	23	7	7	4	3	5	5	12	14	3	12	6	9	<2	7	<2
Co	10	10.0	10.5	4.3	8.0	0.8	3.7	0.8	0.7	3.4	6.5	1.3	4.7	8	3.1	1.3	0.9	2.4
V	50	46	51	20	43	3	22	3	3	18	65	4	45	53	12	13	21	4
Cr	7	8	13	9	5	7	6	29	11	12	9	<2	7	3	16	8	<2	3
Cu	15	29	42	36	88	11	5.5	9.5	10.0	17	18	11	3	<2	26	7	3	11
Zn	99	86	70	56	115	17	89	79	115	59	58	92	32	91	74	28	30.5	115
Sn										3								
W									1.4	5	0.8	0.7			1	0.6		
Mo	1.5	1.3	6.0	2.0	1.9	2.1	1.2	6.0	5.0	2.9	1.5	3	0.8	0.3	3.4	2.5	0.8	1
Ga	21	20.0	22.0	18.0	18.0	19.0	25.0	25.5	24.0	16	16	20	16	19	24.5	21	22.5	14.5
Mn										260	340	360	200	800			230	430
P										440	550	100	500	1450			180	460
Ag	0.5	0.6	0.6	0.5	0.5	0.8	0.7	0.7	0.6	0.7	1.4	0.9	0.3	0.6	0.7	0.7	1	1.1
Bi	0.2	0.3	0.3	0.3	0.7	1.4	0.20	<0.1	0.10	<0.1	0.3	0.1	0.4	0.2	0.2	1	0.3	0.1
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.1
In	0.1	0.10	0.15	0.10	0.20	0.10	<0.05	0.10	0.10	0.1	0.1	0.15	<0.05	0.1	0.1	0.05	0.1	0.1
Sb	<0.5	<0.5	<0.5	0.50	<0.5	<0.5	<0.05	<0.05	<0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05	<0.5	<0.5
Se	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05	<0.05	<0.5	0.5	<0.5	<0.5	<0.5	<0.05	<0.05	<0.5	<0.5
Te	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Tl	0.9	0.9	0.3	1.2	1.2	2.9	1.7	0.9	0.8	1	0.7	1	1.1	1	1.2	0.8	0.9	0.7
Be	<2	<2	<2	<2	2	<2				3	8	11	11	10			12	10
As															1	1		

APPENDIX 4. Assay analyses of samples from HULL and BLOODS RANGE; . dl – Alcurra dolerite, Ꝑvh – Mount Harris Basalt, Ꝑka – Karukali Quartzite, Ꝑtj$_a$ - Tjuninanta Formation, Ꝑgp – Undivided Pottoyu Granite Suite, Ꝑde – Dean Quartzite, Ꝑpi Pinyinna beds, Ꝑbl – Bloods Range Formation, Ꝑvp – Puntitjata Rhyolite, Ꝑku – Kulail Sandstone.

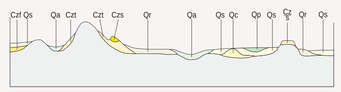
Sample No	AMG (mE)	AMG (mN)	Host Rock	Ag (ppm)	As (ppm)	Bi (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Mo (ppm)	Ni (ppm)	Pb (ppm)	P (ppm)	Sb (ppm)	V (ppm)	Zn (ppm)	Au (ppb)	Au Dpl (ppb)	Pt (ppb)	Pt1 (ppb)	Pd (ppb)	Pd1 (ppb)
BR97DFC9	508121	7240764	dl	<0.5	--	<5	<1	31	<2	30	73400	1150	1	11	170	--	--	--	180	0.8	--	<0.2	--	<0.2	--
BR97DFC12	506532	7237210	dl	<0.5	--	<5	<1	34	400	94	38600	950	1	135	14	--	--	--	150	0.8	--	7.6	--	4.2	--
BR97DFC96	548918	7268768	undeformed qtz vein	<0.5	43	5	<1	11	4	84	6.53%	4.61%	13	4	34	130	<5	8	300	1.4	1.8	0.2	0.2	0.4	0.4
BR97DFC97	544380	7268738	undeformed qtz vein	89	12	220	<1	48	8	1.94%	5.61%	250	3	11	2.08%	180	<5	16	88	101	--	<0.2	--	0.8	--
BR97DFC101	552601	7272884	dl	<0.5	<1	20	<1	31	34	3	7.76%	600	1	47	6	1600	<5	280	110	3.6	--	11	--	3.4	--
BR97DFC117	557388	7268083	Pka	<0.5	<1	5	<1	<1	10	2	12.4%	160	1	<1	14	95	<5	29	18	0.6	0.8	0.4	0.4	<0.2	<0.2
BR97DFC121	560303	7255853	quartz vein within Ptj$_a$	<0.5	<1	<5	<1	<1	<2	2	4050	20	<1	<1	<3	20	<5	3	2	0.8	--	<0.2	--	<0.2	--
BR97DFC129	561270	7253339	Pka	<0.5	<1	<5	<1	7	3	17	6.38%	95	<1	3	8	500	<5	24	14	<0.2	--	0.6	--	<0.2	--
BR97DFC161	531750	7272949	ferruginous fault breccia	<0.5	13	<5	<1	<1	6	3	19.3%	115	34	2	6	115	<5	41	31	1.4	--	0.6	--	0.2	--
BR98DFC492	534946	7253705	undeformed qtz vein	<0.5	--	<5	<1	4	3	9	28800	270	<1	4	<3	--	--	--	17	0.6	--	<0.2	--	<0.2	--
BR98DFC493	535467	7254146	schist within Ptj$_a$	4.5	--	<5	<1	45	15	11000	53700	950	1	79	12	--	--	--	130	0.8	--	0.8	--	1	--
BR98DFC501	535028	7254332	Pvh	<0.5	--	<5	<1	19	9	320	42500	360	<1	42	4	--	--	--	30	2.8	--	3.6	--	2.6	--
BR98DFC551	507060	7236960	Pgp	<0.5	--	<5	<1	6	4	13	17700	360	1	3	20	--	--	--	48	0.6	--	<0.2	--	<0.2	--
BR98DFC604	532933	7248593	gossan within Pde	<0.5	--	<5	3	4	12	13	304000	50	<1	75	<3	--	--	--	180	0.2	--	0.4	--	0.8	--
BR98DFC629	633188	7234234	gossan within Ppi	2	--	<5	<1	43	5	7	466000	470	2	115	10	--	--	--	200	8	5	20	10	2	2
BR97CJE106	553545	7258038	gossan within Pbl	<0.5	12	<5	<1	5	17	75	30.0%	230	3	18	26	2000	<5	44	100	0.4	--	0.6	--	2	--
BR97CJE119	547876	7258920	quartz vein	<0.5	<1	<5	<1	<1	5	3	8300	60	<1	1	<3	50	<5	35	3	2.4	--	<0.2	--	<0.2	--
BR98CJE305	511826	7267035	silicified Pvp	<0.5	--	<5	<1	<1	2	3	20900	155	<1	2	6	--	--	--	17	0.4	--	<0.2	--	<0.2	--
BR98CJE348	516664	7270505	gossan in Pku/Pbl	<0.5	--	<5	<1	<1	<2	74	287000	65	<1	92	<3	--	--	--	165	0.4	--	1.6	--	0.4	--
BR98CJE417	547765	7241616	black chert in Ppi	<0.5	--	<5	<1	<1	13	2	2350	85	<1	2	<3	--	--	--	<1	1.2	1.2	<0.2	<0.2	<0.2	<0.2
BR98CJE468	499228	7253553	dark shale in Pbl (Ptj?)	<0.5	--	<5	<1	1	7	2	27700	20	<1	4	4	--	--	--	6	<1	--	5	--	<1	--
BR98CJE474	544346	7253490	quartz vein	<0.5	--	<5	<1	2	5	3	15800	40	<1	4	6	--	--	--	5	0.6	--	0.6	--	0.2	--
BR98CJE475	542989	7252004	quartz vein	<0.5	--	<5	<1	<1	3	2	15300	30	<1	6	<3	--	--	--	10	0.6	--	<0.2	--	<0.2	--
BR98CJE484	512245	7254734	phyllite in Pbl (Ptj?)	<0.5	--	<5	<1	8	7	2	22100	75	<1	15	12	--	--	--	19	1	--	<5	--	2	--
BR98CJE498	543619	7273902	quartz vein	<0.5	--	<5	<1	1	<2	<1	10300	25	<1	3	<3	--	--	--	6	<0.2	--	<0.2	--	<0.2	--
BR99CJE553A	517330	7260285	weathered Pvp	<0.5	--	<5	<1	4	12	6	73300	95	<1	7	12	--	--	--	8	2	--	<5	--	<1	--
BR99CJE559	543550	7273481	Pvh	<0.5	--	<5	<1	13	7	3	50700	650	<1	1	14	--	--	--	78	7	--	<5	--	<1	--

HULL

AUSTRALIA 1:100 000 GEOLOGICAL SPECIAL — NORTHERN TERRITORY



QUATERNARY — CENOZOIC



- **Qp** — *Playa deposits: mud, clay, evaporite crusts and deposits*
- **Qa** — *Alluvium; sand, silt, clay, gravel*
- **Qs** — *Sand sheets and dune fields: sand, minor clay*
- **Qr** — *Colluvium and sheetwash plains*
- **Qc** — *Calcrete, minor silcrete*
- **Czf** — *Ferricrete, lateritic ironstone, often with calcrete*
- **Czs** — *Palaeosol; Lithified ferriginous soil with vertical worm burrows*
- **Czt** — *Talus; pebble, cobble, boulder deposits, locally lithified, often dissected*
- **Czr** — *Autochthonous soils over subcrop; coarse grit to silt, often with vadose calcrete*

PETERMANN OROGENY 570 - 530 Ma

AMADEUS BASIN — NEOPROTEROZOIC

- **Winnalli beds** — Ewi — *White sandstone, abundant trough crossbeds, rare chert fragments*
- *** Inindia beds** — Ein — *Quartz sandstone, medium to coarse-grained, may be massive or well-bedded, often ferruginised, sometimes quartzite; siltstone, red, yellow or pale, often strongly ferruginised; chert and jasper layers, often structureless, sometimes breccias; conglomerate*
  ** Appears only on the cross section.*
- **Pinyinna beds** — Epi — *Grey quartz-muscovite phyllite, red and grey siltstones, shales, grey and brown dolomite, rare tuffaceous beds*

TRANSGRESSIVE SEQUENCE

- **Dean Quartzite** — Ede — *White crystalline quartz sandstone, quartz-muscovite schist*
- **Kulail Sandstone** — Eku — *Red/purple crystalline quartz sandstone, abundant trough crossbeds, local heavy mineral horizons of hematite and magnetite*

TJAUWATA GROUP — MESOPROTEROZOIC — PROTEROZOIC

RIFT SEQUENCE

- **Bloods Range Formation** — Ebl — *Red shales, polymictic conglomerate, volcaniclastics, tuffaceous horizons and local lensoidal quartz sandstone beds*
- **Puntitjata Rhyolite ~1075 Ma** — Evp — *Porphyritic rhyolite*
- **Alcurra Dyke Swarm ~1078 Ma** — Edl — *Dolerite dykes locally recrystallised to epidote amphibolite*
- **Mount Harris Basalt** — Evh — *Variably silicified and epidotised, amygdaloidal basalt with rare lenses of crystalline quartz sandstone*
- **Tjuninanta Formation** — Eti(a-c) — *Interlensed silicified, epidotised amygdaloidal basalt (Eti$_a$), quartzite, quartz-muscovite schist and dark grey phyllitic schist (Eti$_b$), and volcaniclastics (Eti$_c$)*
- **Karukali Quartzite** — Eka — *White crystalline quartz sandstone, rounded quartz pebble conglomerate beds, local heavy mineral horizons of hematite and magnetite*

HULL GRANITE SUITE ~ 1090 - 1075 Ma

- **Walu Granite** — Egwa — ~1090 Ma — *Medium grained biotite-hornblende granite*
- **Rowley Granophyre** — Egr — ~1075 Ma — *Variably silicified and epidotised, amygdaloidal basalt with rare lenses of crystalline quartz sandstone*

MUSGRAVE BLOCK

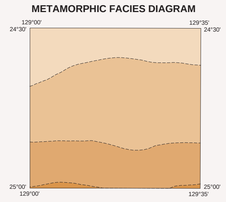
POTTOYU GRANITE SUITE ~ 1190 - 1140 Ma

- **Ampujuta Dacite ~ 1150 Ma** — Ega — *Finely porphyritic hypabyssal biotite dacite less abundant equigranular leucogranite*
- **Undivided Pottoyu Granite Suite** — Egp — *Coarsely porphyritic foliated biotite granite, typically with rapakivi textures, less abundant equigranular leucogranite*
- **Ilyaralona Granite ~1160 Ma** — Egi — *Coarsely porphyritic muscovite biotite granite*

GEOLOGICAL SYMBOLS

- *Geological boundary*
- *Fault; mapped, approximate*
- *Fault; concealed, inferred*
- *Fault; thrust*
- *Mafic dyke*
- *Quartz vein*
- *Trend of bedding*
- *Fault; concealed (interpreted from magnetic data)*
- *Prevailing strike and dip of strata*
- *Strike and dip of strata*
- *Strike and dip of inverted strata*
- *Strike and dip of foliation, plunge of intersection lineation*
- *Strike and dip of strata parallel to foliation, plunge of mineral elongation*
- *Strike and dip of foliation, second deformation episode*
- *Asymmetrical syncline, Double arrow indicates steeper limb*
- *Asymmetrical anticline, Double arrow indicates steeper limb*
- *Overturned anticline*
- *Overturned syncline*
- *Recumbent anticline showing dip of axial surface*
- *Younging direction*
- *Prospect*
- *Mineral Occurrence*
- *Geochronology sample location and reference number*
- *Cross section*
- *Type locality*

METAMORPHIC FACIES DIAGRAM

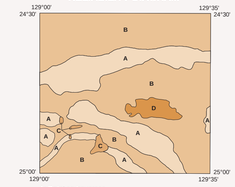


- Not metamorphosed
- Mid to lower greenschist facies [epidote - chlorite - actinolite ± muscovite in mafic rocks]
- Upper greenschist facies [epidote - chlorite - green amphibolite (actinolite and/or hornblende) ± muscovite in mafic rocks]
- Epidote amphibolite facies [hornblende - epidote - plagioclase in mafic rocks]

TOPOGRAPHICAL SYMBOLS

- *Sandridges*
- *Unsealed road*
- *Vehicle track*
- *Outstation*
- *Landing ground*
- *River, creek*
- *Waterhole*
- *Territory and state border*
- *Spot height*

RELIABILITY DIAGRAM



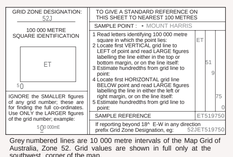
A: Detailed traverses

B: Airphoto interpretation with limited traverses

C: Access Unavailable

D: Access Unavailable - Structural data from: Australia. Northern Territory Administration. Mines Branch. Report MBR/72/2011

UNIVERSAL GRID REFERENCE



Grey numbered lines are 10 000 metre intervals of the Map Grid of Australia, Zone 52. Grid values are shown in full only at the southwest corner of the map.

GN TN MN

GRID CONVERGENCE 0.1°

GRID-MAGNETIC ANGLE 4.0°

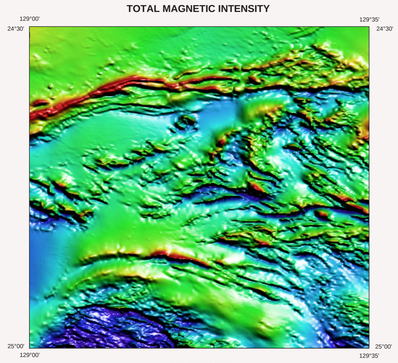
TRUE NORTH, GRID NORTH AND MAGNETIC NORTH ARE SHOWN DIAGRAMMATICALLY FOR THE CENTRE OF THIS MAP. MAGNETIC NORTH IS CORRECT FOR 2000, AND MOVES EASTERLY BY 0.1° IN ABOUT SIX YEARS. TO CONVERT A MAGNETIC BEARING TO A GRID BEARING ADD THE GRID-MAGNETIC ANGLE.

SCALE 1:100 000

1 0 1 2 3 4 5 6 7 8 9 10 Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
LATITUDE OF ORIGIN: 0°; LONGITUDE OF ORIGIN 129°
HORIZONTAL DATUM: GEODETIC DATUM AUSTRALIA 1994 (GDA 94)

TOTAL MAGNETIC INTENSITY



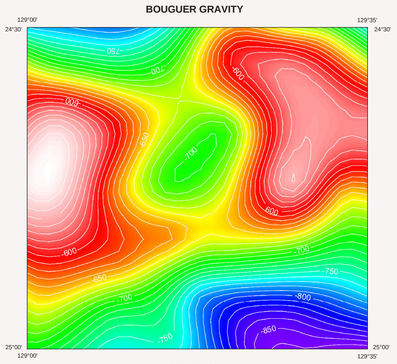
SCALE 1:500 000

HSI enhancement with NE sunangle

0 10 20 30 km

red - high; blue - low

BOUGUER GRAVITY



SCALE 1:500 000

0 10 20 30 km

white - high; purple - low (Gravity data acquired by AGSO)

µM S^{-2}

RADIOMETRIC TERNARY IMAGE

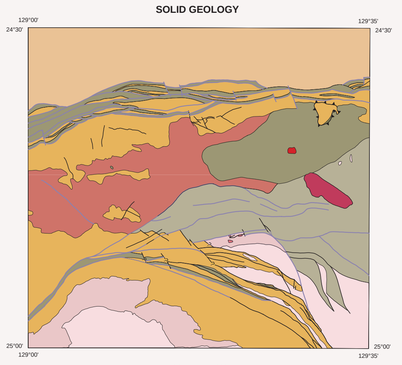


SCALE 1:500 000

0 10 20 30 km

K Th U

SOLID GEOLOGY



SCALE 1:500 000

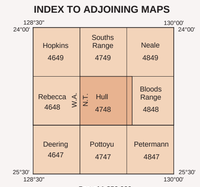
0 10 20 30 km

- *Undivided Neoproterozoic Amadeus Basin sediments*
- *Bloods Range Formation, Kulail Sandstone, Dean Quartzite, Pinyinna beds*
- *Puntitjata Rhyolite*
- *Walu Granite*
- *Rowley Granophyre*
- *Mount Harris Basalt*
- *Tjuntinanta Formation*
- *Ilyaralona Granite*
- *Ampujuta Dacite*
- *Undivided Pottoyu Granite Suite*
- *Fault; mapped*
- *Fault; thrust*
- *Fault; interpreted*
- *Fault; inferred*
- *Geological Boundary; approximate*

MAP LOCALITY



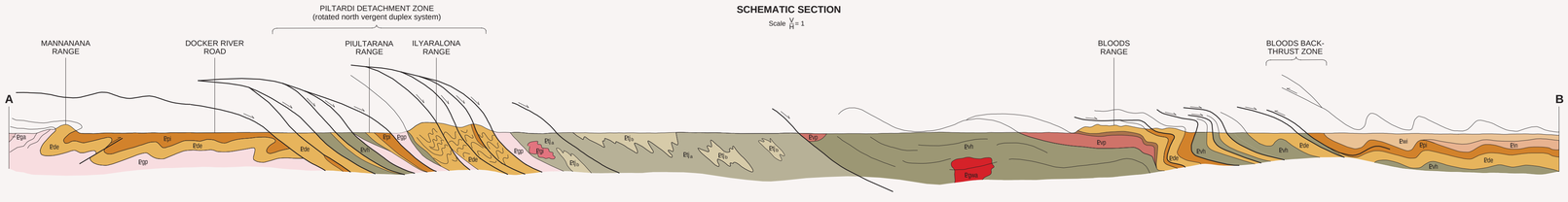
INDEX TO ADJOINING MAPS



Part of 1:250 000 SG52-03 BLOODS RANGE

SCHEMATIC SECTION

Scale $\frac{V}{H} = 1$



GEOCHRONOLOGY SAMPLE LOCATIONS

Ref No	Sample No	Location	Stratigraphic Unit
1	BR98DFC491	ET352537	Ilyaralona Granite
2	BR98DFC550	ET060406	Ampujuta Dacite
3	BR97CJE73	ET463690	Walu Granite
4	BR98DFC429	ET518613	Rowley Granophyre
5	BR97RS58	ET338753	Pinyinna beds
6	BR97CJE153	ET409747	Puntitjata Rhyolite

Geology: 1997-1999: D. F. Close, C. J. Edgoose, I.R. Scrimgeour
Geophysical interpretation: 2000: K. R. Slater
Compiled: 1999-2000: D. F. Close, C. J. Edgoose
Design: 2001: P. Carter
Digital cartography: 1998-2002: P. Carter, B. Bousfield
Original plot on demand created: 2002: 26th February 2002
Latest edited plot created: 2002: 30th July 2002

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Produced by, and plot on demand created by, Northern Territory Geological Survey, Cartographic Services, Department of Business, Industry and Resource Development, Alice Springs, Australia. Issued under the authority of the Minister for Business, Industry and Resource Development, the Honourable PAUL HENDERSON, MLA. Base map compiled by NTGS from 1:100 000 scale topographic data supplied by the National Mapping Division, Geoscience Australia, Department of Industry, Tourism and Resources.

This map is accompanied by a text **publication: CLOSE DF, EDGOOSE CJ and SCRIMGEOUR IR, 2002. Hull and Bloods Range 1:100 000 Geological Special, Northern Territory Geological Survey Explanatory Notes.**

It is recommended that this map be referred to as: **CLOSE DF, EDGOOSE CJ and SCRIMGEOUR IR, 2002. Hull Special First Edition (1:100 000 scale geological map) Northern Territory Geological Survey, Darwin.**

DIGITAL DATA: Map data are stored in Microstation format (DGN). Map information can be acquired from the NTGS as hardcopy plots and/or DGN/DXF digital files. Information on formats and release conditions is available from **NTGS Sales Counter, 3rd floor Centrepoint Building, Darwin. Phone (08) 8999 6443 or Minerals House, Alice Springs. Phone (08) 8951 5658.**

Northern Territory Geological Survey

Northern Territory Government — Department of Business, Industry and Resource Development

Richard Brescianini, Director, Northern Territory Geological Survey

HULL

SHEET - SPECIAL

FIRST EDITION 2002

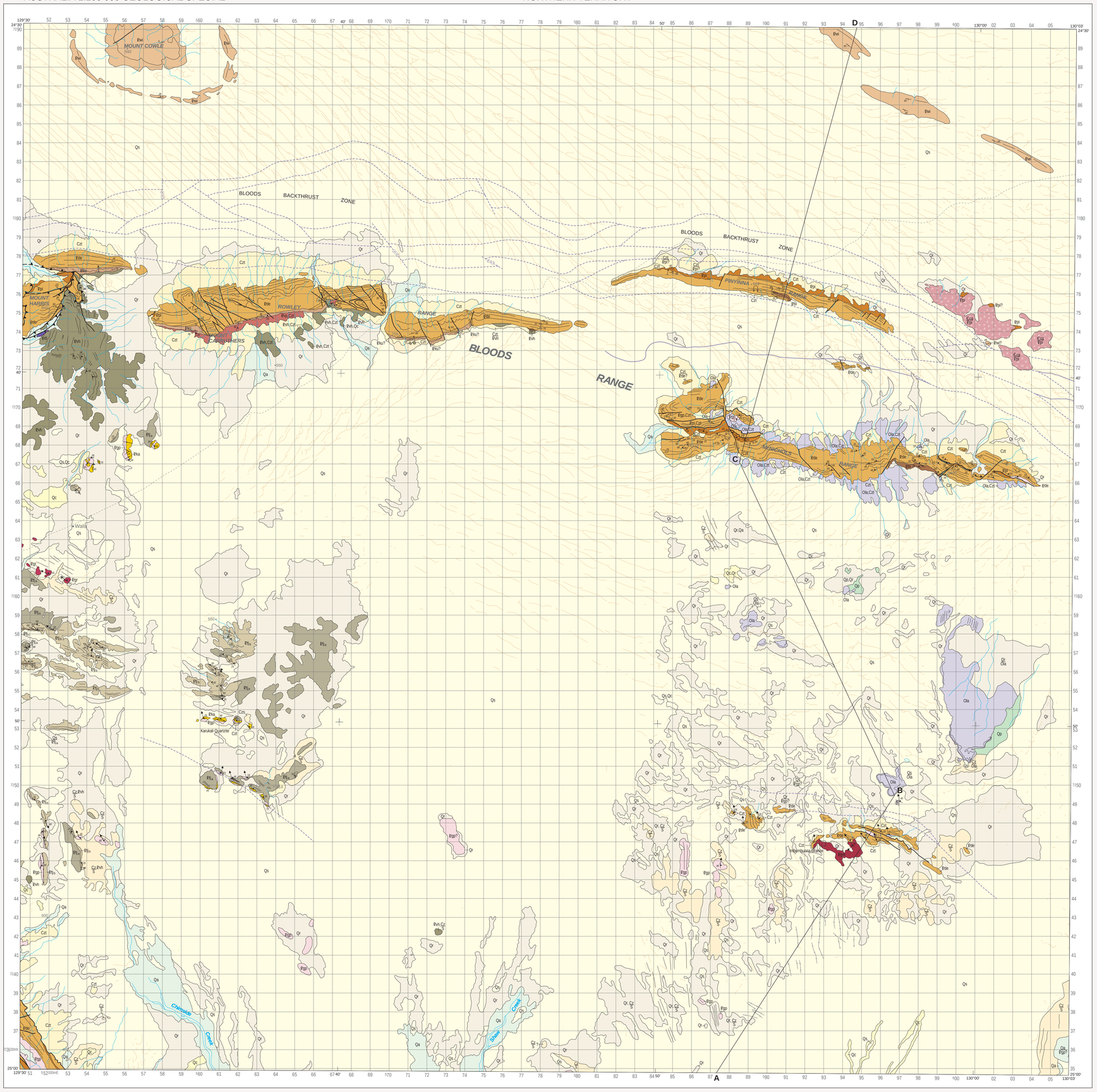
© NORTHERN TERRITORY GOVERNMENT, 2002

WARNING: Colours will fade with prolonged exposure to light.

BLOODS RANGE

AUSTRALIA 1:100 000 GEOLOGICAL SPECIAL

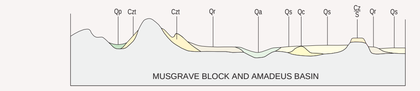
NORTHERN TERRITORY



SCALE 1:100 000

1 0 1 2 3 4 5 6 7 8 9 10 Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
LATITUDE OF ORIGIN: 0°; LONGITUDE OF ORIGIN 129°
HORIZONTAL DATUM: GEODETIC DATUM AUSTRALIA 1994 (GDA 94)



ALICE SPRINGS OROGENY 400 - 300 Ma

PETERMANN OROGENY 570 - 530 Ma

CENOZOIC	QUATERNARY	Qp	Playa deposits: mud, clay, evaporite crusts and deposits	
		Qa	Alluvium; sand, silt, clay, gravel	
		Qs	Sand sheets and dune fields: sand, minor clay	
		Qr	Colluvium and sheetwash plains	
		Qc	Calcrete, minor silcrete	
		Czs	Palaeosol: Lithified ferruginous soil with vertical worm burrows	
		Czt	Talus; pebble, cobble, boulder deposits, locally lithified, often dissected	
		Qz s	Autochthonous soils over subcrop; coarse grit to silt, often with vadose calcrete	
PALAEOZOIC	ORDOVICIAN	Ola	Larapinta Group	Red sandstone, locally bioturbated, conglomeratic horizons and minor siltstones
	CAMBRIAN	€Ca	Mount Currie Conglomerate	Ampilara member? Residual conglomerate with well rounded pebble to boulder size clasts of quartzite
PROTEROZOIC	NEOPROTEROZOIC	Ewi	Winnall beds	White sandstone, abundant trough crossbeds, rare chert fragments
		Ein	Inindia beds	Quartz sandstone, medium to coarse-grained, may be massive or well-bedded, often ferruginised, sometimes quartzite; siltstone, red, yellow or pale, often strongly ferruginised; chert and jasper layers, often structureless, sometimes breccias; conglomerate * Appears only on the cross section.
		Epi	Pinyinna beds	Grey quartz-muscovite phyllite, red and grey siltstones, shales, grey and brown dolomite, rare tuffaceous beds
		Ede	Dean Quartzite	White crystalline quartz sandstone, quartz-muscovite schist
		Eku	Kulail Sandstone	Red/purple crystalline quartz sandstone, abundant trough crossbeds, local heavy mineral horizons of hematite and magnetite
	MESOPROTEROZOIC	Ebl	Bloods Range Formation	Red shales, polymictic conglomerate, volcaniclastics, tuffaceous horizons and local lenticular quartz sandstone beds
		Evp	Puntitjata Rhyolite ~1075 Ma	Porphyritic rhyolite
		Edl	Alcurra Dyke Swarm ~1078 Ma	Dolerite dykes locally recrystallised to epidote amphibolite
		Egr	Rowley Granophyre ~1075 Ma	Finely porphyritic biotite-chlorite granophyre
		Egm	Imbumbunna Granite	Coarsely porphyritic biotite-muscovite-epidote-garnet granite
		Evh	Mount Harris Basalt	Variably silicified and epidotised, amygdaloidal basalt with rare lenses of crystalline quartz sandstone
		Et(a-c)	Tjuninanta Formation Et$_a$, Et$_b$, Et$_c$	Interlensed silicified, epidotised amygdaloidal basalt (Et$_a$), quartzite, quartz-muscovite schist and dark grey phyllitic schist (Et$_b$), and volcaniclastics (Et$_c$)
		Eka	Karukali Quartzite	White crystalline quartz sandstone, rounded quartz pebble conglomerate beds, local heavy mineral horizons of hematite and magnetite
		Egp	Pottoyu Granite Suite	Coarsely porphyritic foliated biotite granite, typically with rapakivi textures, less abundant equigranular leucogranite

AMADEUS BASIN — TJAUWATA GROUP — MUSGRAVE BLOCK

RIFT SEQUENCE

HULL GRANITE SUITE ~ 1090 - 1075 Ma

TRANSGRESSIVE SEQUENCE

POTTOYU GRANITE SUITE ~ 1190 - 1140 Ma

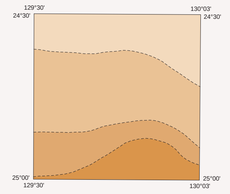
GEOLOGICAL SYMBOLS

- Geological boundary
- Fault; mapped
- Fault; concealed, inferred
- Fault; thrust, approximate
- Mafic dyke, interpreted in subcrop
- Quartz vein
- Trend of bedding
- Fault; concealed (interpreted from magnetic data)
- Fault; concealed, inferred (interpreted from magnetic data)
- Prevailing strike and dip of strata
- Strike and dip of strata
- Strike and dip of inverted strata
- Strike and dip of foliation, plunge of intersection lineation
- Strike and dip of strata parallel to foliation, plunge of mineral elongation or alignment
- Strike and dip of foliation, second deformation episode
- Younging direction
- Overturned anticline
- A — Cross section
- Type locality

TOPOGRAPHICAL SYMBOLS

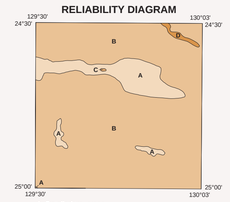
- Sandridges
- Vehicle track
- Outstation
- Landing ground
- River, creek
- • 634 Spot height

METAMORPHIC FACIES DIAGRAM



- Not metamorphosed
- Mid to lower greenschist facies [epidote - chlorite - actinolite ↑muscovite in mafic rocks]
- Upper greenschist facies [epidote - chlorite - green amphibolite [actinolite and/or hornblende↑ ± muscovite in mafic rocks]
- Epidote amphibolite facies [hornblende - epidote - plagioclase in mafic rocks]

RELIABILITY DIAGRAM



A: Detailed traverses
B: Airphoto interpretation with limited traverses
C: Access Unavailable
D: Structural Data from BLOODS RANGE 1:250 000 1st edition geological map

UNIVERSAL GRID REFERENCE

GRID ZONE DESIGNATION: 52

100 000 METRE SQUARE IDENTIFICATION: ET

IGNORE the SMALLER figures of any grid number; these are for finding the full co-ordinates. Use ONLY the LARGER figures of the grid number, example: 100 000mE

TO GIVE A STANDARD REFERENCE ON THIS SHEET TO NEAREST 100 METRES

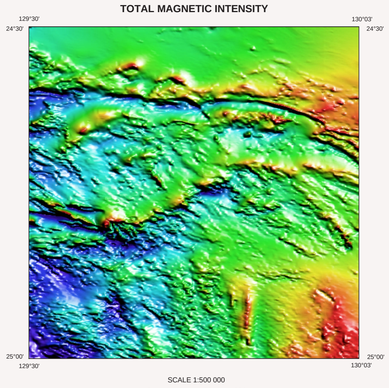
SAMPLE POINT → MOUNT HARRIS

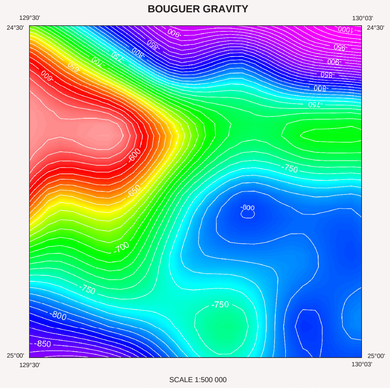
1 Read letters identifying 100 000 metre square in which the point lies: ET
2 Locate first VERTICAL grid line to LEFT of point and read LARGE figures labelling the line either in the top or bottom margin, or on the line itself: 51
3 Estimate hundredths from grid line to point: 9
4 Locate first HORIZONTAL grid line BELOW point and read LARGE figures labelling the line in either the left or right margin, or on the line itself: 75
5 Estimate hundredths from grid line to point: 0

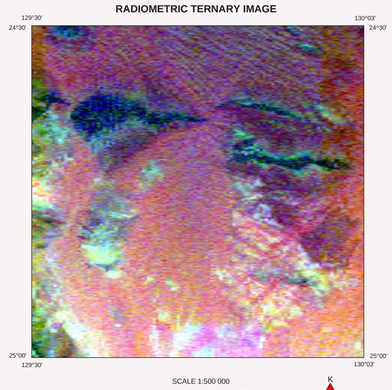
SAMPLE REFERENCE: ET519750

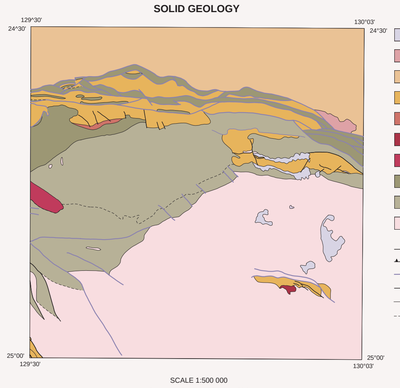
If reporting beyond 18° E-W in any direction prefix Grid Zone Designation, eg. 52JET519750

Grey numbered lines are 10 000 metre intervals of the Map Grid of Australia, Zone 52. Grid values are shown in full only at the southwest corner of the map.









- Larapinta Group
- Mount Currie Conglomerate
- Undivided Neoproterozoic Amadeus Basin sediments
- Bloods Range Formation, Kulail Sandstone, Dean Quartzite, Pinyinna beds
- Puntitjata Rhyolite
- Imbumbunna Granite
- Rowley Granophyre
- Mount Harris Basalt
- Tjuninanta Formation
- Undivided Pottoyu Granite Suite
- Fault; mapped
- Fault; thrust
- Fault; interpreted
- Fault; inferred
- Geological Boundary; approximate
- Intraformational boundary



MAP LOCALITY



INDEX TO ADJOINING MAPS

Souths Range 4749	Neale 4849	Unapproachable 4949
Hull 4748	Bloods Range 4848	Imbumbunna 4948
Pottoyu 4747	Petermann 4847	Olia Chain 4947

Part of 1:250 000 SG52-03 BLOODS RANGE

Geology:	1997-1999:	D. F. Close, C. J. Edgoose, I.R. Scrimgeour
Geophysical interpretation:	2000:	K. R. Slater
Compiled:	1999-2000:	D. F. Close, C. J. Edgoose
Design:	2001:	P. Carter
Digital cartography:	1998-2002:	P. Carter, B. Bousfield
Original plot on demand created:	2002:	26th February 2002
Latest edited plot created:	2002:	30th July 2002

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Produced by, and plot on demand created by, Northern Territory Geological Survey, Cartographic Services, Department of Business, Industry and Resource Development, Alice Springs, Australia. Issued under the authority of the Minister for Business, Industry and Resource Development, the Honourable PAUL HENDERSON, MLA.
Base map compiled by NTGS from 1:100 000 scale topographic data supplied by the National Mapping Division, Geoscience Australia, Department of Industry, Tourism and Resources.

This map is accompanied by a text publication: **CLOSE DF, EDGOOSE CJ and SCRIMGEOUR IR, 2002 Hull and Bloods Range 1:100 000 Geological Special, Northern Territory Geological Survey Explanatory Notes.**

It is recommended that this map be referred to as: **CLOSE DF, EDGOOSE CJ and SCRIMGEOUR IR, 2002 Bloods Range Special First Edition (1:100 000 scale geological map) Northern Territory Geological Survey, Alice Springs.**

DIGITAL DATA: Map data are stored in Microstation format (DGN). Map information can be acquired from the NTGS as hardcopy plots and/or DGN/DXF digital files. Information on formats and release conditions is available from **NTGS Sales Counter, 3rd floor Centrepoint Building, Darwin. Phone (08) 8999 6443 or Minerals House, Alice Springs. Phone (08) 8951 5658.**

Northern Territory Geological Survey

Northern Territory Government
Department of Business, Industry and Resource Development

Richard Brescianini, Director, Northern Territory Geological Survey

BLOODS RANGE

SHEET - SPECIAL

FIRST EDITION 2002

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WARNING: Colours will fade with prolonged exposure to light.