**1:250 000 Geological Map Series**

**Explanatory Notes**

**MOUNT PEAKE AND LANDER RIVER**

**SF 53-05, SF 53-01**

N DONNELLAN

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ABSTRACT

The geology of LANDER RIVER and MOUNT PEAKE mainly consists of granite, and metasedimentary and stratiform mafic igneous rocks of the Palaeoproterozoic Arunta Region in the southern two-thirds of the combined mapsheets, and Palaeozoic and Mesozoic rocks of the Wiso Basin in the north. Rocks of the Ngalia and Georgina basins occur in the southwest and southeast, respectively. Geophysical data indicate that very poorly outcropping rocks of the Ooradidgee and Hatches Creek groups of the Tennant Region are widespread underlying the Wiso Basin in central and northern LANDER RIVER, in southeastern LANDER RIVER and in a small area of adjacent northeastern MOUNT PEAKE. There is no evidence for a fundamental terrane boundary between the Arunta and Tennant regions at the time of deposition of the Lander Rock Formation or thereafter (ie post ca 1860 Ma). The Lander Rock Formation is at least in part correlated with the Ooradidgee Group, and the overlying Reynolds Range Group probably correlates with the Hatches Creek Group.

The Lander Rock Formation is formally divided into the Walabanba, Anningie, Woodalla and Mount Stafford members. It is interpreted to generally represent a predominantly more proximal succession than widely distributed turbiditic rocks of the Lander Rock Formation to the west. However, Woodalla Formation rocks in extreme southwestern MOUNT PEAKE are interpreted to be turbiditic. Rocks of the Lander Rock Formation are variably metamorphosed from greenschist to granulate facies.

A number of newly defined granites (Esther, Koonooonyeri, Redhackle and Windajong) are recognised, in addition to the previously defined Anmatjira Orthogneiss. Additional, generally poorly exposed granites have been mapped informally. The granites have been divided into 'early' and 'late' for descriptive purposes. The former are syn-tectonic with respect to the ca 1805–1790 Ma Stafford Event, which resulted in widespread folding and metamorphism in the Lander Rock Formation. Unnamed granite $E_g$ has an igneous crystallisation age of $1814 \pm 6$ Ma and therefore probably immediately predates the main tectonothermal Stafford Event. The Redhackle Granite is contemporaneous with the ca 1780–1770 Ma Yambah Event. The Stafford Event resulted in widespread deformation and metamorphism of the Lander Rock Formation, and the Yambah Event may have resulted in localised overprinting deformation in the Woodalla Member, in extreme southwestern MOUNT PEAKE. The early granites include megacrystic K-feldspar, rapakivi-textured and equigranular peraluminous biotite granites. These characteristics are considered typical of mesozonal intrusions in extensional, ensialic tectonic settings. The Aileron Province of the Arunta Region in MOUNT PEAKE is interpreted to reflect sedimentation and magmatism associated with extending continental crust. Late granites include the Strangways Event-aged 1730 Ma Windajong Granite, and a number of additional granites that are interpreted to be pre- or syn-Chewings Orogeny (ie deformed at 1590–1560 Ma). New zircon growth at ca 1579 ± 7 Ma has been recognised in the ca 1772 Ma Redhackle Granite. The Windajong Granite and the unnamed granite $E_g$ define discrete, subcircular gravity lows with little or no magnetic character, characteristics they share with the ca 1720–1700 Ma Devils Suite granites of the Tennant Region.

Outcropping Ngalia Basin stratigraphy is restricted to the Vaughan Springs Quartzite, which constitutes the Bau, Nanga and Yindjirib ranges in central and central-southern MOUNT PEAKE. Neoproterozoic rocks of the Georgina Basin outcrop in southeastern MOUNT PEAKE, where the Amesbury Quartzite, an unnamed basalt, and the Boko, Elyuah, Grant Bluff and Central Mount Stuart formations have been mapped. The Amesbury Quartzite is correlated with the Vaughan Springs Quartzite, and the unnamed basalt is correlated with ca 825 Ma Gairdner Event mafic rocks, which are considered to also include mafic volcanic rocks of the Bitter Springs Formation in the Amadeus Basin. The Boko Formation consists of a diamicrite, which probably correlates with 600 Ma Marinoan glacial deposits of the Adelaide Fold Belt, and an equivocal 'Cap Dolostone'. The overlying rocks are Ediacaran, and the Elyuah and Grant Bluff formations are now mapped, together with Central Mount Stuart Formation, in Central Mount Stuart and the Djilbari Hills. A mappable thickness of the Elkera Formation also probably outcrops, but pending further detailed work, this unit has not yet been separated from the Central Mount Stuart Formation in MOUNT PEAKE. Probable correlatives of the Gnallan-a-gea and Oorobra arkoses are recognised respectively above and below the 'Cap Dolostone', but these units are thin and have not been mapped separately. Non-outcropping Central Mount Stuart Formation underlies the southern Wiso Basin in LANDER RIVER, and has also been interpreted undercover in eastern MOUNT PEAKE.

Palaeozoic and Mesozoic rocks of the Wiso Basin are poorly exposed in northern LANDER RIVER, but have not been studied during this mapping program. There is one small outcrop of probable Devonian Dulcie Sandstone on the central-eastern boundary of MOUNT PEAKE. Non-outcropping Cenozoic (Willowra, Ngalahaldjiri and Ti-Tree) basins are recognised in MOUNT PEAKE. Cenozoic deposits include older colluvium, sheet sand and lag gravels, and analogous Quaternary detritus, together with calcrete and lacustrine deposits in abandoned watercourses. There is remnant ferricrete and silcrete, and the former defines a northwest-trending, fault-related breakaway that broadly divides aeolian sheet sand plains in southern and western MOUNT PEAKE, from alluvial and residual surficial deposits in northern and eastern parts of the mapsheet. In LANDER RIVER, sand plains dominate in the south and east, and dune sand in the northwest.

The only historical mineral production from MOUNT PEAKE and LANDER RIVER is minor tin production from the Anningie tin field. The region contains mineral occurrences containing a range of commodities, including orogenic gold in the Lander Rock Formation and mafic-hosted vanadiferous magnetite at the Murray Creek prospect. The area has also been explored for mafic-hosted nickel-copper sulfide mineralisation, calcrete- and sandstone-hosted uranium and Tennant Creek-style iron-oxide gold-copper-bismuth mineralisation.

1 Names of 1:250 000- and 1:100 000-scale mapsheets are given in large and small capitals, respectively, eg MOUNT PEAKE, ANNINGIE.
INTRODUCTION

LANDER RIVER extends between latitudes 20°00’S and 21°00’S, and longitudes 132°00’E and 133°30’E in the central Northern Territory. MOUNT PEAKE lies between the same longitudes and is immediately south of LANDER RIVER, bounded by latitudes 2°00’S and 22°00’S. Central Mount Stuart, in southeastern MOUNT PEAKE, is close to the geographical centre of Australia, and is approximately 200 km north-northwest of Alice Springs.

Grid references and map datum

Cited locations in this publication are based on Map Grid of Australia (MGA) zone 53 coordinates and the GDA94 map datum, and are deemed accurate to ± 50 m.

Habitation and access

The small township of Ti Tree is situated on the Stuart Highway immediately outside the southeastern boundary of MOUNT PEAKE (Figure 1). A formed unsealed road runs from the Stuart Highway to the Aboriginal Community of Willowra in northwestern MOUNT PEAKE. There is no permanent habitation in LANDER RIVER.

Part of Stirling Pastoral Lease (PL) occupies eastern MOUNT PEAKE and extends into southeastern LANDER RIVER. Anningie PL adjoins Stirling PL and extends through much of southeastern and central-eastern MOUNT PEAKE. Coniston PL extends into south-central, and Denison PL into southwestern MOUNT PEAKE. Station tracks allow access throughout these leases. The remainder of the area is Aboriginal Land Trust. The Ahakeye Aboriginal Land Trust extends into extreme southeastern MOUNT PEAKE, and the Pawu and Wirliyajarray aboriginal land trusts occupy central-western and north-central MOUNT PEAKE, respectively. The latter land trust extends into LANDER RIVER; the remainder of this mapheet is encompassed by the Karlantijpa Land Trust with the exception of a small portion of Stirling PL in the southeast, as noted above. The Central Deserts Aboriginal Land Trust extends into northwestern MOUNT PEAKE and southwestern LANDER RIVER.

Topography, drainage, climate and vegetation

The major physiographic divisions of LANDER RIVER and MOUNT PEAKE are shown in Figure 2. These mapsheets lie within the northern plains landform division of Perry et al (1962). Within these mapsheets, Mabbutt (1967) named the Hanson-Lander plains, which are encompassed by the stable
Figure 2. Physiography of MOUNT PEAKE and LANDER RIVER.
Cenozoic Tennant Creek Surface of Hays (1967). Both LANDER RIVER and MOUNT PEAKE have a northerly fall, the former between about 475 to 275 m (Offe 1979), and the latter from about 600 to 450 m (Kennewell and Offe 1978).

MOUNT PEAKE comprises a predominantly alluvial and red soil plain in the east and an aeolian sand plain in the west. A sand plain similarly occupies southern and eastern LANDER RIVER, whereas dune fields occupy the northwest. Alluvial red soils are also a significant component of the plain in southeastern LANDER RIVER.

Ingallan Creek and Lander River drain the Yundurbulu Range in south-central MOUNT PEAKE and trend north or north-northeast, before turning northwest, parallel to an old (Palaeoproterozoic) fault system. Locally, in southeastern MOUNT PEAKE, there is a northwest-trending ferricrete breakaway, broadly parallel to this same fault system. This suggests that the fault system has been active during Cenozoic times. Ingallan Creek merges with the Lander River near Willowra, and the latter continues northwestward across southwestern LANDER RIVER. In southeastern ANNINGIE, the northwest-trending scarp appears to have been eroded back from the northwest-trending fault line, and Murray, Salt and Ennugan (or Bloodwood) creeks drain northwest, from localised areas of high relief to the east of the ferricrete breakaway in this area. Anningie Creek follows a similar trend to Murray, Salt and Ennugan creeks, but extends southwest beyond the breakaway to drain from the Ennugan Mountains. Mount Peake Creek drains east from Conical Hill along the boundary of ANNINGIE and CONICAL HILL. All of these creeks in southeastern MOUNT PEAKE join the Hanson River, which extends along the eastern boundary of MOUNT PEAKE and LANDER RIVER. Both the Hanson and Lander rivers dissipate in the Tanami Desert.

Palaeodrainage in western MOUNT PEAKE is in part covered by sheet sand. Offe (1978) recognised that calcrete plains, marking palaeodrainage, occupy two linear depressions in MOUNT PEAKE. One depression runs north–south, parallel to Ingallan Creek, and the second is west of the Lander River in southeastern STUDHOLME. A similar line of calcrete and claypans extends west-northwest across northern LANDER RIVER.

Prominent hills in MOUNT PEAKE mainly comprise Neoproterozoic rocks, and according to Hays (1967) are erosional remnants of the Ashburton Surface. This surface predates the Andagera Formation in the Davenport Province (Stewart et al 1986), which is of probable latest Neoproterozoic (Ediacaran) age (Haines in Haines et al 1991). In southeastern MOUNT PEAKE, significant hills include mounts Esther (696 m), Judith (705 m), Browne (675 m) and Chisholm (722 m). Stuart (1865) reported that the high point he climbed and named Central Mount Stuart (846 m) was actually about 4 km north-northeast from his camp of the 22 April 1860 at the geographical centre of Australia. The Djjibari Hills (722 m) are immediately north of Mount Judith. The Bau Range in central MOUNT PEAKE, and the Yindijirbi and Nanga ranges in south-central MOUNT PEAKE consist of Vaughan Springs Quartzite; the highest points in each of these ranges are mounts Barkly (797 m), Denison (885 m) and Leichhardt (1024 m), respectively. The last named is the highest point in MOUNT PEAKE.

The Yundurbulu Hills in south-central MOUNT PEAKE and an area encompassing Mount Stafford in NAPPERBY, together with the Bilba Hills immediately to the northwest, largely constitute the outcrop area of the Palaeoproterozoic Mount Stafford Member (of the Lander Rock Formation) and Anmatjira Orthogneiss. Scattered outcrops of granite in MOUNT PEAKE typically form low domes or whalebacks and may have castellated tops. Some small outcrops take the form of castle koppies. The Anmatjira Orthogneiss forms a large inselberg in the Yundurbulu Range. Unnamed granite in the northern Ennugan Mountains also forms an inselberg rising to 735 m, about 25 km east of the Yundurbulu Range.

Lateritic weathering, and associated ferricrete and silcrete development in MOUNT PEAKE, which postdates a planation surface correlated with the Tennant Creek Surface, probably relates to the late Oligocene (Canaway Profile) in western Queensland (see under Cenozoic). Ferricrete outcrops as low rises throughout LANDER RIVER and MOUNT PEAKE, and is often flanked by ferruginous lag gravels. Where sand covered, low rises are mapped as Cenozoic sand (Czs). Ferricrete forms low hills or mesas in MOUNT PEAKE (Offe 1978). As mentioned above, ferricrete is also associated with a northwest-trending scarp in ANNINGIE, which probably reflects reactivation of a northwest-trending fault system that has been active since the Palaeoproterozoic. The alluvial red soil plain in eastern MOUNT PEAKE is probably deposited in an area from which the duricrust has largely been stripped; Mount Peake (546 m) and mesas in the immediate vicinity of Conical Hill are erosional remnants of this duricrust. The leached interval of the lateritic profile is exposed as areas of deeply weathered rock in an extensive area around Mount Rennie, and more locally at the head of Anningie Creek (not mapped).

LANDER RIVER and MOUNT PEAKE experience hot dry summers and mild winters. Climatic averages, produced by the Bureau of Meteorology for nearby Barrow Creek, indicate maximum daily temperature ranges from about 37°C in January to 22°C in July, with minimum daily temperatures of 24°C and 8°C, respectively. Data for Tennant Creek suggest the corresponding temperatures may be a degree or so warmer in LANDER RIVER. Barrow Creek has an average annual rainfall of 316 mm.

Kennewell and Offe (1979) reported that xerophytic vegetation characterises LANDER RIVER. Spinifex (Triodia spp) dominates on sand plains, and there is a light cover of Eucalyptus spp and Acacia spp shrublands. Vegetation is similar in MOUNT PEAKE, although mulga (Acacia aneura) forms dense woodlands in red soil country, for example immediately west of Mount Peake.

Previous and present geological investigations

These notes relate to Second Edition mapping of LANDER RIVER (Donnellan 2008a) and MOUNT PEAKE (Donnellan 2007a). This mapping was undertaken as part of a widening program of Second Edition mapping in the northern Arunta Region. It complements mapping in MOUNT THEO, MOUNT SOLITAIRE and HIGHLAND ROCKS, described by Vandenberg et al (in prep). The work contributes to the investigation of possible geological links (via the Aileron Province of the Arunta Region) between the Tanami and Tennant Creek goldfields.
Exploration and early geological observations and investigations in the two mapsheets are summarised by Offe (1978) for MOUNT PEAKE, and by Kennewell and Offe (1979) and Kennewell and Huleatt (1980) for LANDER RIVER. Offe (1978) reported that Stuart (in 1860) was the first explorer to visit the MOUNT PEAKE area, and he named Central Mount Stuart and the nearby Mount Esther. Stuart proceeded to the west and named the highest point in the Nanga Range Mount Denison; subsequently, this name has been transposed with that of the highest point in the Yindjirbi Range, which Stuart had called Mount Leichhardt (Offe 1978). Stuart was finally forced to retreat in May 1860 from a point near the confluence of MOUNT PEAKE, LANDER RIVER, MOUNT THEO and MOUNT SOLITAIRE, about 40 km northwest of the Studholme Hills in MOUNT PEAKE.

As reported by Offe (1978), Stuart (1865) described red sandstone (Central Mount Stuart Formation) and isolated hills of granite and quartz reefs in southeastern MOUNT PEAKE, sandstone and conglomerate in the Nanga Range, conglomerate at the foot of the Yindjirbi Range and sandstone at Mount Barkly (Vaughan Springs Quartzite). Brown (1896) presented a geological sketch map and made a brief description of the geology of Central Mount Stuart, and this area was also covered in a geological sketch map by Murray in George and Murray (1907). Davidson (1905) briefly described granite and quartz blows in northeastern MOUNT PEAKE and southeastern LANDER RIVER, together with altered sandstone in the former and ironstone in the latter.

The Bureau of Mineral Resources [BMR, now Geoscience Australia (GA)] First Edition MOUNT PEAKE map was derived from 1:100 000 scale mapping in the south-central sheet area and mapping of the remainder of the sheet at 1:250 000 scale was completed in 1974 (Offe 1978). The northwestern part of the sheet was mapped using a helicopter. Kennewell and Offe (1979) reported that LANDER RIVER was also mapped using a helicopter by BMR in 1975. Details of the geology of the Aileron Province (formerly referred to as the Northern Province of the Arunta Inlier by Stewart et al 1984), including MOUNT PEAKE and LANDER RIVER, were presented by Stewart et al (1980a).

Geological mapping in LANDER RIVER was integrated with data from shallow stratigraphic drilling in the northern Lander Trough by BMR in 1974, and results of a reflection and refraction seismic survey (the Hanson River Seismic Survey) over the Lander Trough in eastern LANDER RIVER (Ray Geophysics 1967, Kennewell et al 1977).

Kennewell and Huleatt (1980) reported that BMR contracted Wongela Geophysical Pty Ltd to carry out a gravity survey over most of the Wiso Basin, including LANDER RIVER and extending into MOUNT PEAKE (see also Flavelle 1965, Whitworth 1970, Fraser et al 1977). Gravity stations were at 7 km intervals. Aero Service Ltd (1964) flew an aeromagnetic survey over the southern Wiso Basin for Exoil Co Pty Ltd, identifying the Lander Trough, and American Overseas Petroleum Ltd also carried out a aeromagnetic survey encompassing much of the southern Wiso Basin (see Kennewell and Huleatt 1980). In 1976, the Geophysical Branch of BMR carried out an airborne magnetic and radiometric survey over MOUNT PEAKE (see Offe 1978).

Geological mapping for the Second Edition maps was undertaken using 1:50 000-scale colour aerial photography over the principal outcrop areas in eastern and southwestern MOUNT PEAKE. The remainder of MOUNT PEAKE and southern LANDER RIVER was mapped using RC10 (87.98 mm focal length camera) black and white photography at 1:81 000 and 1:85 000 scales, respectively. 1:25 000-scale colour photography was flown on behalf of North Flinders Mining Ltd in 1994 over southwestern MOUNT PEAKE, and this was kindly made available to NTGS. Mapping was compiled on Landsat 7 black and white images at 1:100 000 scale; these data were supplied by the Division of National Mapping, Geoscience Australia, Department of Resources, Energy and Tourism. Mapped geology was integrated with geophysical interpretation to produce First Edition 1:250 000-scale interpreted geology maps of MOUNT PEAKE and LANDER RIVER. Mapping and geophysical interpretation was aimed at elucidating the Palaeoproterozoic geology of these mapsheets.

Mapping over the main areas of Palaeoproterozoic outcrop in eastern and southern MOUNT PEAKE was undertaken by extensive foot traverses. Less intensive work was undertaken over Neoproterozoic outcrops in these areas. Mapping over the remainder of MOUNT PEAKE and southern LANDER RIVER was undertaken by helicopter traverses. The northern half of LANDER RIVER comprises only minor outcrops of the Wiso Basin stratigraphy and these were not remapped for the Second Edition.

Geophysical data used for the First Edition 1:250 000-scale interpreted geology maps include:

1. The Mount Peake Survey, which includes the southern half of LANDER RIVER; this was flown at 500 m line spacing and was processed by Kevron Geophysics for NTGS in 1995.
2. The Bonney Well Survey, which includes the northern half of LANDER RIVER; this was variously flown at 400 and 200 m line spacing by Australian Geophysical Surveys, and the data processed by Baignet Geoscience on behalf of NTGS in 1999.
3. BMR 11 km-spaced gravity data.

Details of bedrock intersected in exploration drilling, and available through open file company reports, were a useful additional source of information in the interpretation of the geophysical data.

REGIONAL GEOLOGICAL SETTING

LANDER RIVER and MOUNT PEAKE include elements of the Palaeoproterozoic Aileron Province of the Arunta Region, the Neoproterozoic to Palaeozoic Georgina and Ngalia basins (in MOUNT PEAKE) and the Palaeozoic Wiso Basin (in LANDER RIVER). Major elements of the regional geological context of LANDER RIVER and MOUNT PEAKE are shown in Figure 3.

The Arunta Region has a complex stratigraphic, structural and metamorphic history extending from the Palaeoproterozoic to the Palaeozoic (Stewart et al 1984, Shaw et al 1984, Collins and Shaw 1995, Scrimgeour 2003, 2004). The Arunta Region is divided into three provinces –
**Figure 3.** Regional geological setting of MOUNT PEAKE and LANDER RIVER.
the Aileron, Warumpi, and Irindina – with distinct protolith ages and complex stratigraphic and tectonic evolutions (Scrimeour 2003, 2004). The Aileron Province, which comprises most of the Arunta Region and similarly most of the outcropping Palaeoproterozoic stratigraphy in LANDER RIVER and MOUNT PEAKE, has depositional and intrusive ages that fall largely within the period ca 1860 – 1700 Ma, similar to the adjacent Tennant Region (Compton 1995, Maidment et al. 2006, Claoüé-Long et al. 2008b) and Tanami Region (Collins and Shaw 1995, Crispe et al. 2007). Regionally, the Aileron Province includes at least five stratigraphic packages that were deposited in the interval 1860 – 1740 Ma (Scrimeour 2003), and has been affected by multiple tectonic events including the 1805 – 1790 Ma Stafford Event, the 1780 – 1770 Ma Yambah Event, the 1735 – 1690 Ma Strangways Orogeny, the 1590 – 1560 Ma Chewings Orogeny and the 400 – 300 Ma Alice Springs Orogeny (Scrimeour 2006). The Warumpi and Irindina provinces are discrete younger terranes along the southwestern and eastern exposed margins of the Arunta Region. The Warumpi Province has precursor ages of 1700 – 1600 Ma (Close et al. 2003), whereas the Irindina Province of the eastern Arunta comprises high-grade metamorphic rocks with Neoproterozoic to Cambrian precursors (Buick et al. 2001).

The outcropping Palaeoproterozoic geology of MOUNT PEAKE is relatively simple. It comprises a succession of metapsammitic and metapelitic rocks (Lander Rock Formation), variably metamorphosed from greenschist to granulite grade. Stratiform amphibolites and retrogressed amphibolites outcrop locally. This succession extends northward into LANDER RIVER. The Lander Rock Formation is intruded by widespread granite, which is syn-tectonic with respect to the 1805 – 1790 Ma Stafford Event. There is a more localised distribution of Yambah- and Strangways-aged granite, and granite in the northern continuation of the Emnugan Mountains in south-central MOUNT PEAKE is inferred to be ca 1620 Ma.

There is no obvious terrane boundary between the Arunta and Tennant regions in LANDER RIVER, MOUNT PEAKE or BARROW CREEK. The geology of the Tennant Region is therefore outlined below: (1) as part of the regional context of the Aileron Province; and (2) because Tennant Region stratigraphy is interpreted to be at depth under cover throughout a large portion of LANDER RIVER, particularly to the north of the southern margin of the Lander Trough, and is further interpreted to be contiguous with that of the Aileron Province in extreme northeastern MOUNT PEAKE and southeastern LANDER RIVER.

The Tennant Region is divided into the Warramunga, Davenport, and Tomkinson Creek provinces. The oldest rocks exposed in the Tennant Region, the Warramunga Formation (ca 1860 Ma; Compston 1995, Maidment et al. 2006), Woodjenjerrie beds, Junalki Formation (ca 1860 Ma; Smith 2000, 2001) and the unconformably overlying Oroadidgee Group (ca 1840 – 1815 Ma; Blake and Page 1988, Claoüé-Long et al. 2008b) define the extent of the centrally disposed Warramunga Province. The Warramunga Formation is a polydeformed, sub- to lowermost-greenschist-facies, tuffaceous turbiditic succession. The Woodjenjerrie beds and the Junalki Formation are correlated with the Warramunga Formation and include intercalated volcanic rocks. However, sedimentary rocks of the Junalki Formation are interpreted to represent both shallower-water, and more proximal sedimentation than is represented by the Warramunga Formation. All of these rock units were deformed during the ca 1850 tectono-magmatic Tennant Event, and intruded by predominantly granitic rocks of the syn- to post-tectonic Tennant Creek Supersuite (ca 1850 – 1840 Ma). The Davenport and Tomkinson Creek provinces are coincident with the outcrop extent of the ca 1810 – 1790? Hatches Creek Group and the lithostratigraphically correlative Tomkinson Creek Group to the north and south of the Warramunga Province, respectively. Oroadidgee Group rocks extend southwestward into the Davenport Province, where they outcrop in the cores of anticlines.

The (ca 1840 – 1815 Ma) Oroadidgee Group postdates deformation associated with the ca 1850 Ma Tennant Event, but post-tectonic Tennant Event magmatism is represented by, for example, the Yungkulungu Formation ignimbrite within the Oroadidgee Group, which has an igneous crystallisation age of 1849 ± 5 Ma (Smith 2000). The Oroadidgee Group comprises bimodal volcanic rocks, and fluviatile and shallow-marine sedimentary rocks in the Davenport Province. It is lithostratigraphically similar in the Warramunga Province, except that mafic volcanic rocks are absent, at least in outcrop.

The Hatches Creek Group extends throughout the Davenport Province, and the northern limit of the basal Unimbra Sandstone is taken to define the northern limit of the Province. The Rising Sun Conglomerate is (in part) a probable local erosional remnant of Hatches Creek Group-aged strata within the Warramunga Province. The Hatches Creek Group is divided into the Wauchope and Hanlon subgroups, and is correlated with the Tomkinson Creek Group of the northern Tennant Region (Tomkinson Creek Province). The Hatches Creek Group is a predominantly layer-cake succession of ridge-forming quartz-rich sandstone (Unimbra, Couters and Erololla sandstones), recessive feldspathic and lithic sandstone, volcanic rocks, and in the Hanlon Subgroup, siltstone and minor calcareous rocks. The group represents predominantly fluviatile and shallow-marine or intertidal sedimentation and generally subaerial felsic volcanic rocks, including ignimbrite and lava. The Kudinda Basalt is the topmost lithostratigraphic unit of the Wauchope Subgroup of the HATCHES Creek Group. It is a geographically widespread flood basalt succession and is correlated with the Whittington Range Volcanic Member of the Tomkinson Creek Group (Blake 1984).

The Tomkinson Creek Group succession of the Tomkinson Creek Province is similar to that of the Hatches Creek Group. However, felsic volcanic rocks are absent or poorly represented in the former by comparison with the latter, and conversely, carbonate rocks are volumetrically more important in the Tomkinson Creek Group.

The ca 1820 – 1810 Ma Treasure Suite is mainly represented in outcrop by dacitic, rhyolitic, and basaltic volcanic rocks, and by shallow-level intrusive granophyres and porphyries, monzodiorite, diorite and gabbro. The ca 1710 Ma Devils Suite comprises granitic rocks that are interpreted (Blake et al. 1987) to postdate (Davenport Event) folding throughout the Tennant Region; this suite
is particularly well represented in the Hatches Creek Group of the Wauchope Fold Belt. Lamprophyre dykes are contemporaneous with the Devils Suite (Maidment et al. 2006). The age of the Davenport Event is not well constrained geochronologically. Blake et al. (1987) interpreted the ca 1720 Ma Elkedra Granite of the Devils Suite to postdate folding in Ooradidgee Group rocks and concluded that this was a lower age constraint on Davenport Event folding of both the Ooradidgee and Hatches Creek groups. However, the ca 1707 Ma Kaidwalla Granite is deformed, and may be syntectonic with respect to Davenport Event folding in the Hatches Creek Group. In the absence of a minimum age constraint on deposition of Hanlon Subgroup strata, it is possible that regional folding of the Hatches Creek Group could correlate with either the ca 1805–1790 Ma Stafford Event, the ca 1780–1770 Ma Yambah Event, or the 1740–1690 Ma Strangways Orogeny. The Bullion Schist and Lander Rock Formation were deformed during the Stafford Event and prior to deformation in the Hatches Creek Group. On this basis, and the fact that widespread deformation associated with the mainly thermal Yambah Event has not been recognised, a correlation between the Davenport Event and the Strangways Orogeny is preferred, and at this stage the age of the Davenport Event is inferred to be ca 1730–1700 Ma.

The Lander Rock Formation is considered, at least in part, a correlative of the Bullion Schist of the Aileron Province and the Ooradidgee Group of the adjacent Tennant Region. No correlatives of the Wauchope and Hanlon subgroups of the Hatches Creek Group have been recognised in outcrop in LANDER RIVER or MOUNT PEAKE. However, Hatches Creek Group stratigraphy can be extrapolated under cover from BONNEY WELL and BARROW CREEK into LANDER RIVER and extreme northeastern MOUNT PEAKE, using airborne magnetic data.

Outcrop of Reynolds Range Group rocks, the Mount Thomas Quartzite and Pine Hill Formation, is confined to Giles Range in southwestern MOUNT PEAKE.

At the outset of Second Edition mapping, important questions with respect to the geology of the Aileron Province that were relevant to LANDER RIVER and MOUNT PEAKE, included the following:

1. Is a lithostratigraphic subdivision of the monotonous Lander Rock beds stratigraphy possible?
2. What is the age and regional extent of tectono-thermal events affecting the Lander Rock Formation (and correlative stratigraphy)?
3. Do regional tectonic considerations consequently necessitate a chronostratigraphic subdivision of the Lander Rock beds?
4. What regional litho-, tectono- and chronostratigraphic correlations can be made between the Palaeoproterozoic geology of the Aileron Province and the apparently contiguous North Australian Craton (NAC), in particular, the Tennant and Tanami regions?

Neoproterozoic sedimentary rocks of the basal Georgina Basin succession locally unconformably overlie Palaeoproterozoic rocks of the Aileron Province in southeastern MOUNT PEAKE, eg at Central Mount Stuart and in the Djilbari Hills. Similarly, clastic sedimentary rocks of the basal unit of the Ngalia Basin succession, the Vaughan Springs Quartzite, are unconformable on Palaeoproterozoic rocks in the Bau, Yindjirbi and Nanga ranges in southern-central MOUNT PEAKE (ie in GILES and MOUNT PEAKE).

The Wiso Basin is a mostly shallow basin infilled by Palaeozoic sediments, which extends over about 160 000 km² in the central Northern Territory. The southern margin of the basin extends approximately east–west across southern LANDER RIVER and coincides with a reverse/thrust fault of post-Devonian Alice Springs Orogeny age. The southern portion of the Wiso Basin in LANDER RIVER coincides with the east-southeast-trending Lander Trough, within which early Palaeozoic (Cambrian and Ordovician) rocks are preserved, forming a wedge that thickens southwestwards from about 350 to 800 m. In LANDER RIVER, the early Palaeozoic succession comprises the Hanson River beds and undifferentiated rocks. This stratigraphic interval is unconformably overlain by the Devonian Lake Surprise Sandstone. Wiso Basin strata are poorly exposed in LANDER RIVER. The Palaeozoic succession unconformably overlies Protoreozoic basement that locally consists of probable Central Mount Stuart Formation and strata of the Palaeoproterozoic Hatches Creek and possible Ooradidge groups. In addition to the Palaeozoic rocks, there are very minor poor exposures of the probable Cretaceous to Paleogene Buchan Hill Beds in northeastern LANDER RIVER.

**PALAEPROTEROZOIC STRATIGRAPHY**

Palaeoproterozoic lithostratigraphic units of LANDER RIVER and MOUNT PEAKE are summarised in Table 1.

### Lander Rock Formation

The Lander Rock Beds were named and defined by Stewart et al. (1980a, b) after Lander Rock (282629mE 7537570mN) in northern NAPPERBY, where a succession of schistose metapelite and metapsammitic outcrops. The unit is now redefined as the Lander Rock Formation (see Appendix 1), allowing further subdivision of this lithostratigraphic unit.

In LANDER RIVER and MOUNT PEAKE, the Lander Rock Formation comprises metapelitic and metapsammitic rocks, including hornfels, slate, phyllite and schist. Four constituent members have been mapped: Woodalla, Walabanba, Anningie and Mount Stafford; these are described below and defined in the Appendix 1. The Woodalla Member is interpreted to be a turbiditic succession and correlates with the Lander Rock Formation in MOUNT DOREEN. The Mount Stafford Member is a localised, high-metamorphic-grade equivalent of the Woodalla Member. The Walabanba and Anningie members consist of interbedded slate and sandstone, and schist, respectively, and are interpreted to be more or less proximal shallow-water deposits.

Outcrop of the Lander Rock Formation is generally sparse in MOUNT PEAKE. However, there are good exposures of the formation, both in the Walabanba Hills and in the vicinity of Central Mount in ANNINGIE. In addition there is outcrop around Conical Hill (in CONICAL HILL and northwestern ANNINGIE) and minor scattered exposures in northern
MOUNT PEAKE, including around Mount Windajong, Fotheringham Hill and the Wanabanda Hills. The formation also outcrops immediately north of Giles Range and there is minor scattered outcrop east of Woodalla Bore in GILES, in southwestern MOUNT PEAKE. This patchy distribution of exposures suggests that the Lander Rock Formation is probably widespread underlying Cenozoic surficial cover in MOUNT PEAKE. This is consistent with airborne magnetic data, although magnetic and gravity data indicate that granite is also widespread. In many areas, geophysical data suggest that these two rock types (ie metasedimentary rocks and granite) are more or less intimately associated. There is minor outcrop of the Lander Rock Formation south of the Lander Trough in LANDER RIVER.

The Woodalla Member outcrops sparsely in southwestern MOUNT PEAKE and is probably correlative with more widespread, undivided turbiditic Lander Rock Formation in MOUNT DOREEN. The Mount Stafford Member is interpreted to be a higher metamorphic grade equivalent of the Woodalla Member. It has a restricted distribution in the Yundurbulu Range in northwestern REYNOLDS RANGE (in NAPPERBY) and southeastern MOUNT PEAKE. The remaining outcrops of Lander Rock Formation in LANDER RIVER and MOUNT PEAKE are either undivided or predominantly assigned to the Walabanba or Anningie members.

Stewart et al (1980a) mapped the Lander Rock Formation over a large area of the Aileron Province in NAPPERBY, MOUNT PEAKE, LANDER RIVER, MOUNT THEO and MOUNT SOLITAIRE, describing the unit as 'monotonously uniform and widespread.' Young et al (1995a) assigned a succession of pelitic and psammitic metasediments in MOUNT DOREEN to the Lander Rock Formation. There are isolated outcrops of the formation in northern MOUNT RENNIE, and on the basis of geophysical data, this formation is interpreted to be quite widespread in the northern part of that mapsheet. It is also present in the extreme north of MOUNT LIEBIG (Meixner et al 2004a, b).

<table>
<thead>
<tr>
<th>Unit, map symbol, thickness</th>
<th>Lithology</th>
<th>Stratigraphic relationships</th>
<th>Depositional environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coulters Sandstone*, Ehc</td>
<td>Sandstone, minor siltstone and altered mafic lava</td>
<td>Base not seen; unconformably overlain by Pm, Pva; intruded by granite (Pg, Pg, Pg, Pgk, Prk, Pgw) dolerite and gabbro</td>
<td>Shallow to deep-water marine</td>
</tr>
<tr>
<td>Newlands Volcanics*, Eha</td>
<td>Felsic ignimbrite, lava and tuff; minor sandstone and siltstone</td>
<td>Conformable with, and laterally transitional with Ehr; intruded by granite (Pg) and dolerite</td>
<td>Deep-water, turbiditic; possibly locally shallow-marine</td>
</tr>
<tr>
<td>Unnamed Sandstone, Ehs</td>
<td>Sandstone</td>
<td>Laterally transitional with Ehr; intruded by granite (Pg)</td>
<td>Deep-water, turbiditic</td>
</tr>
<tr>
<td>Ooradidgee Group</td>
<td>Schist, strataform mafic metaigneous rocks</td>
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<td></td>
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<tr>
<td>Undivided Ooradidgee Group*, Po</td>
<td></td>
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<tr>
<td>Treasure Volcanics*, Eht</td>
<td>Felsic lava and pyroclastic rocks, stratiform felsic and mafic intrusive igneous rocks, sandstone</td>
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<tr>
<td>Kurinelli Sandstone*, Eok</td>
<td>Sandstone, felsic and mafic lava and tuff, minor shale, slate and schist</td>
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<td></td>
</tr>
<tr>
<td>Lander Rock Formation, Elr</td>
<td>Metasedimentary, and strataform mafic (meta-) igneous rocks</td>
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</tr>
<tr>
<td>Mount Stafford Member, Ehr, ca 1000 m</td>
<td>Greenschist- to granite-facies metasedimentary rocks, hornfels, orthoamphibolite, migmactite</td>
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<td></td>
</tr>
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<td>Woodalla Member, Ehr, ca 500–1500 m?</td>
<td>Sandstone/wacke, siltstone/slate/phylite/schist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodalla Member, Ehr, ca 500–1500 m?</td>
<td>Metapelite, metapsammitic, and strataform mafic meta-igneous rocks</td>
<td>Intruded by granite (Pg), dolerite and gabbro</td>
<td>Shallow-marine</td>
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<tr>
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<td>Stratiform mafic rocks, subordinate metasedimentary rocks</td>
<td></td>
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</tr>
<tr>
<td>Unnamed lithofacies*, Ehr3</td>
<td>Stratiform mafic, and subordinate metasedimentary rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unnamed lithofacies*, Ehr2</td>
<td>Stratiform mafic igneous, and metasedimentary rocks</td>
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<tr>
<td>Unnamed lithofacies*, Ehr1</td>
<td>Stratiform mafic igneous, and metasedimentary rocks</td>
<td></td>
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</table>

Table 1. Mesozoic, Palaeozoic, Neoproterozoic and Palaeoproterozoic stratigraphic units of MOUNT PEAKE and LANDER RIVER. *Non-outcropping, interpreted from geophysical data, and lithology is inferred from geophysical character and/or outcrop in adjacent sheet areas.
Walabanba Member

In the Walabanba Hills in southeastern MOUNT PEAKE, outcropping Lander Rock Formation is predominantly slaty and is assigned to the Walabanba Member (new name; see Appendix 1). The succession consists of interbedded metapelitic and metapsammitic rocks, with intervals of feldspathic, micaceous and heavy mineral-bearing quartzite. Sandstone intervals are generally poorly outcropping, but where present, are typically hornfelsed and massive. Cross-bedding is locally preserved, defined by grain size variations and heavy mineral laminations, and forming medium to thick trough cross-bed sets. Metapelite has a well developed slaty cleavage (S$_1$), which is sub-parallel to bedding as is shown by local interbedding with thin to medium (ca 10 cm), laminated quartzite beds. This slate typically forms intervals from about one to a few metres thick that alternate with recessive intervals, eg at 303115mE 7600318mN (Figure 4a).

The slaty cleavage (S$_1$; Figures 4b, 5a and 5b) is axial planar to upright, asymmetric (F$_1$) folds in the Walabanba Hills. Superimposed, symmetric, open to close, plunging normal folds (F$_2$) are well developed and have a northwesterly striking axial planar crenulation cleavage (S$_2$; Figure 5c). A second crenulation cleavage (S$_3$) is associated with mesoscale, northeast-striking F$_3$ folds (Figure 5c–d). The noses of F$_3$ folds are often obliterated by the development of pencil slates (Figure 5e). These pencil slates are apparently the product of intersecting S$_1$ and S$_3$ (?) cleavage planes (as opposed to bedding–cleavage intersection), and in the field, the result is an initially confusing, close to ninety-degree re-orientation of bedding with no apparent fold nose. In addition to the above three foliations, a differentiated compositional layering is locally recognisable, sub-parallel to bedding and S$_1$. The significance of this (early) differentiated layering has not been resolved.

Recessive intervals within the Walabanba Member are typically of the order of 4–5 m, but can be up to about 10 m thick. Where they outcrop, they are identified as massive, locally heavy-mineral-laminated hornfelsed quartzite (Figure 6a). Locally, cross-bedding is well preserved (Figure 6b) in the quartzite and, in places (eg 303318mE 7600256mN), indicates overturning on the steeper limbs of asymmetric, upright F$_3$ folds.

Foliation is not generally recognisable in the quartzitic units. Local brittle deformation of fine quartz veins

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Figure 4. Walabanba Member of Lander Rock Formation. (a) Typical exposure of slate at 303116mE 7600318mN. View is along strike of bedding and S$_1$ (ca 155º), and parallel to F$_1$ fold axis. Bedding and cleavage dip northeast (left) and southwest (right). (b) Typical slate at 303116mE 7600318mN.
postdates granite emplacement and associated hornfels development (Figure 5f, 301055mE 7607703mN). It has not been established whether this brittle deformation has an consistent orientation regionally. It could be an expression of the Yambah or Davenport events, or the Chewings Orogeny. Stewart et al. (1980a) described quartz-rich hornfels interbedded with the metapelitic rocks in the Walabanba Hills as containing small amounts of plagioclase, microcline, biotite, muscovite and titanite. Colour banding, apparent in some hornfelsic intervals, probably reflects variable iron oxide content. This is consistent with the occurrence of heavy mineral laminations produced by winnowing in a shallow-water environment.

Quartz arenite intervals up to approximately 10 m thick are inconsistent with turbiditic sedimentation and thus the Walabanba Member is interpreted to represent shallow-water deposition. The Walabanba Member is more schistose proximal to granite contacts. These schistose metapelitic rocks comprise quartz, feldspar, muscovite, biotite and andalusite; the latter mineral is retrogressed to quartz-sercite.

**Anninigie Member**

Metasedimentary rocks of the Anningie Member (new name; see Appendix 1) have a well developed dominal $S_1$ schistosity or differentiated cleavage and are described...
as predominantly schistose, although they are locally more coarse grained and somewhat gneissic. No sedimentary structures are preserved; however, compositional variability subparallel to schistosity is interpreted to reflect relict bedding.

The schist has muscovitic and biotitic cleavage domains alternating with, or anatomising around microlithons of probable relict lithic clasts that now comprise a predominantly turbid, fine-grained, quartzose and sericitic matrix or mosaic around fractured quartz grains. Evidence for twinning has not generally been identified in these relict grains. However, some grains include coarse biotite flakes, and there are tabular areas of relatively coarse sericite/muscovite and quartz that are interpreted to be relict feldspar phenocrysts. Quartz typically shows undulose extinction, and fractured and broken grains are indicative of brittle-ductile deformation. The more gneissic rocks are mineralogically similar to the schist. They are of a comparable metamorphic grade, but are more quartzic and lithic. The mineralogy suggests that the sedimentary protolith was very potassic, and the provenance is interpreted to include a significant or dominant potassic or ultrapotassic, felsic volcanic component. Composite lithic clasts suggest reworking of a pyroclastic source. No sedimentary structures are preserved.

The slate and massive sandstone of the Walabanba Member contrast with the schistose character of the Anningie Member, and these contrasting textural characteristics are the basis of subdividing the Lander Rock Formation in ANNINGIE into the two members. The members are also mapped outside ANNINGIE, eg in southern LANDER RIVER. They are inferred to reflect a primary difference between interbedded clean sandstone and siltstone/pelite in the Walabanba Member versus wacke and/or semi-pelitic metasedimentary rocks in the Anningie Member. This could have resulted from a proximal to distal facies relationship. However, geophysical interpretation suggests that the Anningie Member is probably lower in the stratigraphy than the Walabanba Member. In contrast with the Walabanba Member, original bedding characteristics have been obliterated in the Anningie Member by its well developed, differentiated $S_1$ schistosity. The Walabanba Member is (as noted previously) locally more schistose in areas proximal to granite, whereas the Anningie Member is locally gneissic proximal to intrusive contacts (eg 301071mE 7605886mN).

Figure 6. Walabanba Member of Lander Rock Formation. (a) Massive sandstone interval (301055mE 7607636mN). (b) Cross-bedded and cross-laminated sandstone (301071mE 7605886mN).
Woodalla Member
The Woodalla Member (new name; see Appendix 1) is confined to southwestern MOUNT PEAKE. It is considered a correlative of turbiditic Lander Rock Formation metasedimentary rocks in MOUNT DOREEN and may be the lithostratigraphic equivalent of the Lander Rock Formation outcropping throughout much of the western Aileron Province. The Woodalla Member is also correlated in part with the Mount Stafford Member, which outcrops in south-central MOUNT PEAKE and adjacent NAPPERBY. The distinction between the Mount Stafford Member and Woodalla Member is one of metamorphic grade; the former represents low-P, high-T granulite-facies rocks according to Vernon et al. (1990), whereas the metamorphic grade of Woodalla Member in MOUNT PEAKE is very low, i.e., subto lowermost greenschist facies. The Woodalla Member comprises feldspathic quartzarenite interbedded with cleaved siltstone. Sandstone units vary from 10 cm to 2 m thick, and siltstone intervals vary from 10 cm to 1 m thick. Sandstone may be granular, massive, laminated or graded and contains a clay matrix after feldspar.

The Woodalla Member succession is interpreted to represent predominantly BCD or CD, and minor A-D (partial) Bouma sequences. Bouma sequences are characteristic of turbiditic sedimentation, and are comparable with those seen in the Lander Rock Formation in MOUNT DOREEN and REYNOLDS RANGE, but contrast with the shallower-marine sedimentology of the Anningie and Walabanba members. Low-grade metamorphic rocks (greenschist-facies micaceous schist) to the south of Mount Stafford in south-central MOUNT PEAKE and adjacent north-central NAPPERBY, are here included in the Woodalla Member, as opposed to Mount Stafford Member. These greenschist-facies rocks are sparsely chloritic, micaceous metapsammite and metapelite, and are interlayered with retrogressively metamorphosed mafic rocks.

Mount Stafford Member
This unit was originally named the Mount Stafford Beds by Shaw and Stewart (1975) and redefined as the Mount Stafford beds by Stewart et al. (1980b). The name is derived from Mount Stafford (257929mE 7563570mN) in NAPPERBY, immediately to the south of the boundary with MOUNT PEAKE, and a number of authors (following Stewart et al. 1980a), have postulated a correlation with the Lander Rock Formation. The reference area for the unit is around 251129mE 7562370mN, to the east of Tin Bore in NAPPERBY. This area is close to the muscovite-out isograd and the onset of incipient melting, and the low-grade, greenschist-facies rocks in this area are now included in the Woodalla Member. The remainder of the former Mount Stafford beds are here redefined as the Mount Stafford Member (see Appendix 1) of the Lander Rock Formation. Claoué-Long et al. (2008a) reported a maximum depositional age of 1866 ± 3 Ma for the Mount Stafford Member. The sample dated is from a low-grade (greenschist-facies or below) metasedimentary rock, which is here included in the Woodalla Member.

The Mount Stafford Member is confined to the Yundurbulu Range and Bilba Hills in northwestern REYNOLDS RANGE and southeastern MOUNT PEAKE, and has an areal extent of ca 260 km². The member comprises pelitic rocks within an aerially extensive high-T, low-P metamorphic aureole. The heat source for this extensive contact metamorphism is contentious. Mafic rocks outcrop locally in the Yundurbulu Range and underlying mafic rocks have been suggested as one possible heat source, but this is necessarily inferential. Collins and Williams (1995) indicated that temperature peaked in this regional-scale metamorphic aureole at Mount Stafford prior to the emplacement of the granitic phase of the Anmatjira Orthogneiss, which suggests that it is unlikely that outcropping granite provided the heat source for the metamorphism. In a detailed geochronological study of the Mount Stafford area, Rubatto et al. (2006) established that metamorphism was essentially coeval with granite intrusion at around 1802 ± 3 Ma, although they agreed that the granite could not be the heat source. A number of granites of Stafford Event age, in particular the (793 ± 3 Ma) Koonoonyeri Granite, apparently have inherited zircons (ca 1807 Ma) that only marginally predates the igneous crystallisation ages, as well as older zircon cores (Worden et al. 2006). Outcropping granite of about this age is represented in the Reynolds Range by the 1806 Ma Bootheby Orthogneiss (Worden et al. 2008). It is possible that granites of this age may have contributed to the heat source for the metamorphism at Mount Stafford, and it is further plausible that the granitic phase of the Anmatjira Orthogneiss may have been remobilised to its current crustal level comparatively late in the tectono-metamorphic Stafford Event.

The Mount Stafford Member locally passes laterally into the lower-grade Woodalla Member. Buick et al. (1999) reported a facies transition between the Woodalla Member and the generally more pelitic Mount Stafford Member. The Mount Stafford Member is comparable with cordierite-bearing granofels in the Lander Rock Formation at Wolfram Hill and Leopard Rock in MOUNT DOREEN; this granofels shows a prograde transition to more areally extensive transitional granite-facies gneiss to the south-southeast of Leopard Rock (Young et al. 1995a).

The high-grade metamorphic rocks that comprise the Mount Stafford Member have been intensively researched by a number of previous authors (Stewart 1980a, Vernon et al. 1990, Greenfield et al. 1996, 1998, White et al. 2003), primarily from a metamorphic perspective. A brief summary is presented here, and the metamorphic history of the unit is similarly summarised from previous studies in Metamorphism of the Lander Rock Formation. The sedimentary protolith to the Mount Stafford Member was a succession of sandstone, siltstone and mudstone that was interbedded on a centimetre to metre scale. Vernon et al. (1990) recognised that metamorphism has resulted in a reversal of grain size. Thus, original pelitic layers are now coarsely porphyroblastic andalusite and cordierite-bearing spotted hornfels (Figure 7, 260160mE 7563360mN). Andalusite, cordierite, sillimanite and locally pyroxene-bearing, spotted, even-grained and layered hornfels are now partially or largely retrogressed to greenschist-facies assemblages. Thus, cordierite is replaced by biotite-andalusite-quartz symplectites (Vernon et al. 1990). Stewart et al. (1980a) considered sedimentary structures to be rare in the Mount Stafford Member, and only identified bedding and cross-bedding in one quartzitic unit. In contrast, Vernon et al.
(1990) concluded that sedimentary structures (and primary igneous textures in mafic sills and dykes), including cross-bedding and graded bedding (e.g. at 259756mE 7563077mN), are commonly preserved or partially preserved. Stewart et al (1980a) interpreted the rocks to be a succession of metamorphosed deep-water sediments. Greenfield et al (1996) interpreted 10–50 cm-thick Bouma sequences in low-grade chlorite-mica schist to indicate that the succession is the right way up. They suggested that coarse porphyroblastic growth is associated with the inter-turbidite ‘E’ layer of the Bouma sequence.

The thickest identified succession of the former Mount Stafford beds, approximately 1300 m, is to the north-northwest of Tin Bore. As described above, this is now considered to include rocks currently mapped here as Woodalla Member. However, the Mount Stafford Member is still considered to be of a comparable thickness (or only slightly less), and is estimated to be about 1000 m thick.

Undivided Lander Rock Formation

Undivided Lander Rock Formation in the vicinity of Conical Hill, Mount Peake and Mount Rennie includes a poorly exposed succession of micaceous quartzo-feldspathic metapsammitic rocks, feldspathic hornfels, micaceous metapelite, schist, spotted schist, and minor slate and amphibolite. Consistent with the low metamorphic grade of the metasedimentary rocks, the amphibolites have been retrogressed to greenschist- and epidote-amphibolite-facies assemblages. These metasedimentary rocks are interpreted to have been a succession of interbedded sandstone, some granule bearing, and siltstone near the top of the Lander Rock Formation. The rocks are lithologically the same as the poorly exposed succession further east in the vicinity of Limestone Bore, and the latter rocks are similarly of low metamorphic grade.

Scattered outcrops in northeastern MOUNT PEAKE were described by Stewart et al (1980a) as micaceous hornfels, and these rocks are sillimanite and andalusite bearing. Airborne magnetic data indicate that this succession may correlate with the Walabanba Member.

Areas of Lander Rock Formation that were not visited in the present survey include isolated outcrops at Fotheringham Hill and immediately northeast of the Wanabanda Hills (not to be confused with the Walabanba Hills). According to Stewart et al (1980a), both include quartzite, together with two-mica schist in the former locality and muscovite-schist in the latter. Andalusite-bearing pebbly metapsammitic rocks also occur at Fotheringham Hill and tourmaline rock at Wanabanda Hills. From airborne magnetic data, these two localities are interpreted to represent the otherwise non-outcropping lowermost Lander Rock Formation. These rocks probably represent interbedded sandstone and siltstone/mudstone deposited in an intertidal or shallow water environment and derived from a weathered source terrane.

An isolated outcrop, approximately 10 km east of Conical Hill, comprises thickly bedded, tabular cross-bedded, laminated, well rounded and well sorted quartz arenite (Figure 8a, 3122646mE 7622970mN). The quartz arenite is approximately 20 m thick and is overlain by minor micaceous quartzo-feldspathic schist, and both poorly preserved and exposed rocks which are interpreted to be silicified microbial boundstone. Dykes and veins of granite, pegmatite and quartz are all generally parallel to bedding, but have crosscutting relationships locally. Quartz veins are sheared parallel to bedding, and show mesoscale folding (Figure 8b), and associated (apparently conjugate) crenulation cleavages. Figure 8c illustrates local boudinage features. These sedimentary rocks are deformed and predate granite emplacement; they are therefore interpreted to be Palaeoproterozoic. They are included in the Lander Rock Formation and could represent a thicker-than-usual development of quartzite, analogous to those seen in the Walabanba Member. Alternatively, these rocks could correlate with the Coulters/Illoquara sandstones of the Hatches Creek Group (Tennant Region). Correlation with the Coulters Sandstone would suggest that the overlying schist and silicified cryptomicrobial boundstone may be equivalent to the Frew River Formation.

Mafic rocks

All of the above lithological units include interlayered stratiform mafic rocks. Many of these are metamorphosed to epidote-amphibolite facies, and some have been further partially retrogressed to greenschist facies (quartz-bearing
Figure 8. Undifferentiated Lander Rock Formation. (a) Heavy-mineral-laminated, massive sandstone interval (photograph by Alison Dean, formerly NTGS; 312556mE 7622732mN). (b) Deformation in massive sandstone interval (312646mE 7622971mN). (c) Boudinage in massive sandstone interval (photograph by Alison Dean, formerly NTGS; 312556mE 7622732mN).
hornblende-epidote-actinolite-chlorite schist). More massive mafic intervals preserve primary igneous textures and are typically olivine gabbro, or dolerite with opitic to subopitic textures. Orthopyroxene is confined to marginal alteration of fractured olivine grains. Partially retrogressed, two-pyroxene-bearing, polygonally recrystallised mafic rocks are folded within the Mount Stafford Member.

Local outcrop (eg in the Walabanba Hills) and magnetic expression indicate that the mafic rocks are stratiform and largely conformable in MOUNT PEAKE. Some outcrops show a well developed, coarse opitic texture (eg 303823mE 7600572mN) and are interpreted to be intrusive doleritic or gabbroic sills. Others may represent extrusive rocks, but this has not been confirmed. Young et al (1995a) considered that amphibolite within the Lander Rock Formation succession in MOUNT DOREEN probably represented both extrusive flows and intrusive sills. Foliation development in some of the mafic and meta-mafic rocks in MOUNT PEAKE confirms that they predate deformation. Subophitic-textured mafic and meta-mafic rocks in MOUNT PEAKE flows and intrusive sills. Foliation development in some of the succession, and are separated by the predominantly mafic intervals in the Lander Rock Formation. This interval may be represented in isolated outcrops at Fotheringham Hill and immediately northeast of the Walabanba Hills in STUDHOLME. The recognition of three, discrete, highly magnetic intervals in the Lander Rock Formation that are separated by low-magnetic intervals suggests that intrusion (and/or extrusion) of mafic material probably occurred at three separate time intervals during deposition of the Lander Rock Formation.

The generally lower metamorphic grade of the Lander Rock Formation in MOUNT PEAKE, by comparison with that further to the west, has enabled a different geological (more stratigraphic) approach to be applied to the interpretation of the geophysical data in MOUNT PEAKE, in comparison to areas further west (eg Meixner et al 2004a, b, Goldberg et al 2005).

**Thickness of Lander Rock Formation**

Folding and the absence of marker beds have precluded measurement of a type section, and Lander Rock in NAPPERBY therefore remains the type locality and reference area for the Lander Rock Formation (Stewart et al 1980b). These authors estimated that the formation has a minimum thickness of a thousand metres in the Reynolds Range and Young et al (1995a) estimated the succession to be several thousand metres thick in MOUNT DOREEN.

On the basis of a probable correlation with the Junalki Formation, Woodenjerrie beds, Warramunga Formation, Bullion Schist and Ooradidgee Group rocks in the Tennant Region, it is possible that the Lander Rock Formation is of the order of 3–4 km thick in MOUNT PEAKE. However, only short intervals of the stratigraphy are exposed in this mapsheet, principally in the Walabanba Hills.

**Contact relationships**

There is no known outcropping basement to the Lander Rock Formation. It is overlain, apparently with angular unconformity, by the Mount Thomas Quartzite (basal unit of the Reynolds Range Group) in REYNOLDS RANGE (Stewart et al 1980a). Dirks and Wilson (1990) concluded that, although there is a tectonic unconformity in the northwestern Reynolds Range, the contact between the Lander Rock Formation and Reynolds Range Group is 'a normal stratigraphic contact' further southeast within this range. Stewart et al (1980a) interpreted a transitional contact between the Mount Stafford and Woodalla members in NAPPERBY and MOUNT PEAKE. However, as noted above, this is now considered to be a change in metamorphic grade, rather than a fundamental change in primary lithofacies. A probable high-angle reverse fault is present between the outcropping Woodalla and Mount Stafford members, but is not considered to negate inclusion of the Mount Stafford Member in the Lander Rock Formation. The implication is, therefore, that these units have a broad (at least partial) lateral and temporal equivalence. Furthermore, the two units appear to have a similar tectonic history (see below). Stewart et al (1980a) also concluded there is probably a rapid lateral transitional relationship between the Lander Rock Formation and an unnamed quartzo-feldspathic gneiss in DENISON (NAPPERBY) and possibly also beneath cover in GILES.

The Lander Rock Formation is intruded by the Anmatjira Orthogneiss (1795 Ma) and by the Koonoonyerri (1794 Ma), Redhackle (1772 Ma), Esther (1789 Ma) and Windajong (1730 Ma) granites in MOUNT PEAKE. The formation is also intruded by a number of unnamed granites in LANDER RIVER and MOUNT PEAKE. In NAPPERBY, it is intruded by the Anmatjira, Mount Airy and Yaningidjara orthogneisses, and by the Harverson Granite (Stewart et al 1980a). The NAPPERBY orthogneisses are interpreted to be part of the same suite(s) of rapakivi granite that includes the Anmatjira Orthogneiss and the Koonoonyerri Granite. The Harverson Granite is discordant with respect to deformation in the surrounding Lander Rock Formation, but is weakly deformed (Collins and Williams 1995, Buick et al 1999). This S-type granite has recently been redated and has an igneous crystallisation age of 1799 ± 3 Ma (Worden et al 2008). The Lander Rock Formation is also intruded by mafic rocks (eg at Waldrons Hill). A granite with an igneous crystallisation age of 1814 Ma crosscuts mafic rocks in the vicinity of Waldrons Hill and apparently puts a lower age limit on the mafic magmatism. The interval of Lander Rock Formation intruded by mafic rocks in the vicinity of Waldrons Hill is interpreted to be near the top of the succession. Consequently, 1814 Ma is a minimum age of sedimentation for the upper part of the Lander Rock Formation in LANDER RIVER and MOUNT PEAKE. This episode of mafic magmatism is also interpreted to include mafic rocks in south-central MOUNT PEAKE that outcrop locally at 266306mE 7577728mN. The mafic rocks at Waldrons Hill could be contemporaneous with dolerites intruding the Ooradidgee Group in the Kurinelli area of the Davenport Province. The latter have an intrusive age of 1811 ± 5 Ma (Claué-Long et al 2008b).

The Lander Rock Formation has a faulted contact with the Weldon Metamorphics and Tyson Creek Charnockite in the Anmatjira Ranges in NAPPERBY.
Lithostratigraphic units overlying the Mount Stafford Member are not exposed. The Mount Stafford Member surrounds undifferentiated, sillimanite-bearing, gneissic Lander Rock Formation in Denison, and these two lithostratigraphic units are correlated. The contact between the Woodalla and Mount Stafford members is a metamorphic zone boundary between low-P greenschist- and amphibolite-facies rocks. This boundary is variably defined by the disappearance of muscovite, the crystallisation of K-feldspar and onset of incipient melting, and formation of andalusite-cordierite-K-feldspar mineral assemblages, according to White et al. (2003), Greenfield et al. (1998) and Vernon et al. (1990), respectively.

The Mount Stafford Member is intruded by dolerite and granite. The dolerites are folded and metamorphosed, but are generally massive and poorly foliated. The granitic phase of the Anmatjira Orthogneiss in MOUNT PEAKE (or the ‘northern’ granite of Greenfield et al. 1998) crossescut metamorphic zones associated with aerially extensive contact metamorphism in the Mount Stafford Member. The granitic phase of the Anmatjira Orthogneiss (Stafford Granite of Collins and Williams 1995 and ‘eastern’ granite of Greenfield et al. 1998) is strongly foliated in NAPPERBY, but not in MOUNT PEAKE.

The Anmatjira Orthogneiss is an augen gneiss, but is a less intensely deformed rapakivi granite in the northwest (ie in the vicinity of Mount Stafford in MOUNT PEAKE), where it was originally called the Anmatjira Granite (Offe 1978). However, even in this area, the granite is foliated and is further crosscut by extensional shear zones (which have been reactivated). Greenfield et al. (1998) interpreted that migmatitisation of pelite in the Mount Stafford Member was contemporaneous with extension. Migmatite and the Anmatjira Orthogneiss are intimately inter-associated in a hybrid diatexite in the vicinity of 260250mE 7566000mN, and there is an apparent transitional contact between diatexite and megacrystic granite (Greenfield et al. 1996).

**Age of Lander Rock Formation**

Claoué-Long (2003) reported a maximum age of sedimentation for the Lander Rock Formation of about 1840 Ma, and further reported that a succession of rocks at the top of the Lander Rock Formation in the vicinity of Mount Thomas in NAPPERBY had a maximum age of sedimentation that was constrained by a younger population of zircons to 1805 ± 5 Ma. Subsequently, Claoué-Long (2005) suggested that these young zircons, in the age range 1820–1800 Ma (in addition to those similar to the typical Lander Rock Formation provenance spectrum), indicated that the Lander Rock Formation can be divided into two stratigraphic units. Claoué-Long et al. (2008a) reported that the Lander Rock Formation is characterised throughout its wide distribution by a dominant population of ca 1880–1840 Ma zircons, with subordinate older grains scattering down to about 2800 Ma. This geochronological subdivision has yet to be mapped, although an upper interval of Lander Rock Formation has been recognised and mapped in geophysical data, and approximately correlated with upper Ooradidgee Group rocks (eg Treasure Volcanics; Donnellan and Johnstone 2003). However, so far, no tectonic breaks have been identified within the Lander Rock Formation.

The average age of the youngest six zircons from the Lander Rock Formation in the Anningie Tin field is 1850 ± 7 Ma; the youngest two zircons are 1822 ± 56 Ma and 1842 ± 18 Ma (Claoué-Long, GA, pers comm, 2003), and the youngest coherent group comprises eighteen zircons with a maximum depositional age of 1862 ± 6 Ma (Claoué-Long et al. 2008a). A similar maximum deposition age of 1858 ± 5 Ma has been obtained from a coherent group of 26 zircons from a sample of granulite-facies Lander Rock Formation near the northeastern corner of NAPPERBY (Claoué-Long et al. 2008a). A sample of Lander Rock Formation from Clarke’s Mine in MOUNT DOREEN has a maximum depositional age of 1862 ± 6 Ma, based on a coherent population of sixteen zircons (Claoué-Long et al. 2008a). Claoué-Long (2003) established that the S-type Ngadarunga Granite in MOUNT DOREEN was derived from melted Lander Rock Formation, and that this was contemporaneous with metamorphism of the formation during the Stafford Event at 1803 ± 5 Ma. An 1880 Ma population of zircons, previously interpreted to constrain the crystallisation age of this granite (Young et al. 1995a, b), is inherited.

Contemporary (largely statistical) discussion surrounds the best method of constraining maximum depositional age from single crystal U-Pb SHRIMP geochronological data for sedimentary or metasedimentary rocks. Claoué-Long et al. (2008a) reported that, ‘conservatively’, the Lander Rock Formation has a maximum age of sedimentation of about 1860 Ma. Note that in this context, ‘conservatively’ is used to indicate a maximum depositional age, which is based on the age of a statistically defined, youngest coherent group of zircons, rather than on a single youngest (replicated) zircon age; see Claoué-Long et al. (2008a) for further details. These authors have argued that the youngest sandstone currently included in the Lander Rock Formation in the Reynolds Range, with a maximum depositional age of about 1808 Ma, belongs to a younger, post-Stafford Event interval of sedimentation. Stafford Event magmatism places a lowermost age constraint on sedimentation of the Lander Rock Formation. Of several dated ca 1800 Ma granites that intrude the Lander Rock Formation, the 1806 ± 4 Ma Boothby Orthogneiss (Worden et al. 2008) is apparently the oldest. Regional geophysical interpretation suggests that the (generally poorly outcropping) Lander Rock Formation probably includes correlatives of, for example, the Junalki Formation and rocks of the Ooradidgee Group in the Tennant Region. Age constraints on the Ooradidgee Group include an igneous crystallisation age of 1840 ± 4 Ma, and an igneous crystallisation age of 1814 ± 3/6 Ma for the Epenarra and Treasure volcanics, respectively (Claoué-Long 2005, Claoué-Long et al. 2008b), corroborating previous data of Blake and Page (1988). It is possible on this basis that the Lander Rock Formation may include sediments that were deposited over a significant time interval. Available detrital zircon geochronological data for the Lander Rock Formation are consistent with at least a partial chronostratigraphic correlation between it and the Ooradidgee Group. Compston’s (1995) original SHRIMP geochronological data for TENNANT CREEK are consistent with this spectrum of ages, eg Compston’s igneous crystallisation ages of 1840 ± 8 Ma and 1845 ± 4 Ma for samples of ignimbrites.
from the Bernborough Formation. Similarly, an $1849 \pm 5$ Ma igneous crystallisation age for a dacitic ignimbrite from the lower Yungkulungu Volcanics (Smith 2001) is within error of the age of the Epenarra Volcanics. Felsic volcanic rocks from the Junalki Formation have an igneous crystallisation age of $1862 \pm 5$ Ma (Smith 2001). The conservative view (see above) of the maximum depositional age of sedimentation of the Lander Rock Formation (Claué-Long et al. 2008a) allows the possibility of temporal equivalence between parts of the Lander Rock Formation and the Junalki Formation. However, detrital zircon data from the Lander Rock Formation is remarkably consistent with that from the Killi Killi Formation in the Tanami Region (Cross and Crispe 2007), which overlies a tuff dated at $1838 \pm 5$ Ma (Cross and Crispe 2007).

The Lander Rock Formation is intruded by the $1789 \pm 6$ Ma (Cross et al. 2005) Esther and $1793 \pm 3$ Ma (Worden et al. 2006) Koonoonyeri granites in MOUNT PEAKE, and by the $1798 \pm 4$ Ma Yapingidjara Orthogneiss and the $1799 \pm 3$ Ma Harverson Granite (Worden et al. 2008) in NAPPERBY. These last two named granites have complex zircon systematics; previous age determinations were $1806 \pm 6$ Ma (Vry et al. 1996) for the Yapingidjara Orthogneiss and $1818 \pm 8$ Ma (Collins and Williams 1995) for the Harverson Granite.

**Correlatives**

The Lander Rock Formation is the most widespread metasedimentary unit of the Aileron Province. Partial lateral correlatives include the Mount Dunkin and Mount Freeing schists and the Nolans Dam Metamorphics in NAPPERBY (Stewart et al. 1980a). The Wickstead Creek Beds were correlated with most of the Lander Rock Formation succession in NAPPERBY (Stewart et al. 1984), but are now considered more likely to belong to the Reynolds Range Group (Dirks 1990). The Lander Rock Formation is also correlated with the Woolla Gneiss in ALCOOTA.

Correlation of the Lander Rock Formation, in part, with the Ooradidgee Group and the Bullion Schist is compatible with the geological continuity under cover between the Aileron Province and Tennant Region recognised by Donnellan and Johnstone (2004). These authors also suggested a partial correlation with the Warramunga and Junalki formations and the Woodenjerrie beds. One implication of this is that there may be an unconformity within the Lander Rock Formation that has not yet been mapped.

The Lander Rock Formation is interpreted to be a direct correlative of the Killi Killi Formation of the Tanami Group in the Tanami Region, on the basis of strong lithological similarities, apparent geological continuity across the interpreted Tanami–Arunta boundary, and very similar detrital zircon populations (Cross and Crispe 2007, Crispe et al. 2007, Claué-Long et al. 2008a, Vandenberg et al in prep).

**Provenance**

D detrital zircons indicate that, throughout a wide area (in MOUNT PEAKE, NAPPERBY, MOUNT DOREEN and by correlation MOUNT SOLITAIRE), the Lander Rock Formation is characterised by a provenance spectrum which is dominated by ca $1880–1840$ Ma zircons and subordinate zircons scattering to a maximum age of about $2700$ Ma (Claué-Long et al. 2008a). This is consistent with derivation from a North Australian Craton provenance, together with an admixed component derived from earliest Palaeoproterozoic and Neoarchean rocks. The following discussion is directed towards elucidating possible contributions from a volcanic versus granitic source (within the NAC).

Stewart et al. (1980a) inferred that the Lander Rock Formation had a granitic provenance. However, quartzofeldspathic metasedimentary rocks have a restricted distribution within the outcropping extent of the Lander Rock Formation. Stewart et al. (1980a) described biotite-bearing, quartzofeldspathic schistose gneiss in the Lander Rock Formation in TEA TREE (NAPPERBY). They also recognised small amounts of feldspathic metasedimentary rocks in MOUNT PEAKE, but otherwise, feldspar is apparently largely restricted to metapelitic granofels.

The Lander Rock Formation does not generally have any of the classic indications of a pyroclastic provenance, eg bipyramidal, often embayed quartz with or without associated devitrified glass, euhedral typically oscillatory-zoned feldspar, fractured quartz and feldspar grains, and low quartz contents and high feldspar/quartz ratios. However, oscillatory-zoned plagioclase is found in the vicinity of $314480$mE $7632546$mN.

The schistose Anningie Member contains more biotite than the interbedded metasedimentary and slate of the Walabanba Member. Differences in fabric may reflect differences in both metamorphic grade and the original sediment composition. The Anningie Member may thus have had a more iron- (and magnesian-) rich composition than the Walabanba Member. Chlorite is likely to react to form biotite in more potassic rocks. This would be consistent with the protolith of the Anningie Member being a feldspathic- or lithic-wacke, possibly with a potassic, felsic volcanic provenance (rhyolite or dacite). Geochemically, this would be indistinguishable from a granitic or granodioritic provenance. Variable ferromagnesian content probably reflects a grain size fractionation of fine-grained detritus (‘matrix’), derived from the weathering of ferromagnesian minerals (biotite or hornblende) in the source rocks. The mineralogy is consistent with the metamorphism of quartz- and feldspar-bearing, fine-grained, illitic and chloritic sedimentary rocks.

A probable potassic, felsic volcanic provenance raises the possibility that interbedded, poorly outcropping, magnetic horizons within the Lander Rock Formation could include contemporaneous felsic volcanic rocks or porphyry, comparable with those seen in the Bullion Schist, or Ooradidgee Group in the Tennant Region. However, such rocks have not been recognised in outcrop or in drill core. Where they do outcrop, these magnetic units are dolerite, gabbro or amphibolite.

Mica indicates potassic and aluminous original sediment compositions. Andalusite also indicates aluminous sediment compositions. It is probable that these metasedimentary rocks represent redeposited felsic volcaniclastic/pyroclastic material. Such detritus would typically become wackes on burial, and primary or diagenetic matrix could have been metamorphosed to mica. Not only the relative proportions of...
potassic to sodic feldspar, but also the muscovite/sericite to biotite/chlorite ratios may help resolve provenance, ie arkosic, versus feldspathic/lithic wacke. It is noted in passing that the interval of Lander Rock Formation with a significantly younger (ca 1805 Ma) maximum age of sedimentation comprises quartz-rich wackes. This more lithologically mature succession could reflect a discrete provenance, and postdate a significant time break (and interval of weathering) within the Lander Rock Formation succession, or simply result from winnowing in a proximal shoreline environment.

Geochemical data for Lander Rock Formation metasedimentary rocks from the Clarke Mine area in MOUNT DOREEN raise some additional provenance considerations, in particular the relative significance of metasomatism versus source rock weathering, which may be reflected in final rock compositions. Figure 9a indicates derivation from a rhyolitic (or alternatively a granitic) provenance, with weathering resulting in variable degrees of kaolinite of feldspars together with subsequent (diagenetic or hydrothermal) potassic metasomatism. Figure 9b suggests that the source rocks had a restricted range of ferromagnesian mineral contents. Ti/Zr ratios for the Lander Rock Formation demonstrate that the parental rocks could include both I- and S-type felsic rocks.

Figure 9. Fields for 31 samples of Lander Rock Formation from Clarkes Mine area in MOUNT DOREEN. CIA = chemical index of alteration. CaO content corrected for apatite, but not for any (minor) carbonate content. Total iron as FeO.
(a) Data plotted as molar proportions of $\text{Al}_2\text{O}_3 - (\text{CaO} + \text{Na}_2\text{O}) - K_2\text{O}$ ($A$-$CN$-$K$), illustrating a weathered felsic igneous (granitic or rhyolitic) provenance and potassium metasomatism (see Fedo et al 1995). Average rock, mineral compositions and weathering trends (arrows) from Nesbitt and Young (2004: figure 5.10-2a).
(b) Data plotted as molar proportions of $\text{Al}_2\text{O}_3 - (\text{CaO} + \text{Na}_2\text{O} + K_2\text{O}) - \text{FeO} + \text{MgO}$ ($A$-$CNK$-$FM$). Average rock, mineral compositions, and weathering trends (arrows) from Nesbitt and Young (2004: figure 5.10-2b).
The Lander Rock Formation in the Clarkes Mine area of MOUNT DOREEN and the Amningie Member in MOUNT PEAKE are considered to have had a similar provenance. However, the Walabanha Member may represent more compositionally mature material, possibly deposited as interlayered winnowed quartzitic sandstone and siltstone/mudstone in a more proximal environment.

Ooradidgee Group

Rocks of the Ooradidgee Group do not outcrop in LANDER RIVER and MOUNT PEAKE. However, rocks of this group have been extrapolated into the subsurface from the adjacent Tennant Region using geophysical data, and are interpreted over a wide area of LANDER RIVER, where they underlie either surficial cover or Phanerozoic strata. The lithology of individual stratigraphic units within the Ooradidgee Group is inferred from outcrop in the adjacent mapsheets. Accordingly, the Kurinelli Sandstone is interpreted to represent the majority of the Ooradidgee Group in LANDER RIVER. This is consistent with the lateral equivalence between the Kurinelli Sandstone and many of the other mapped lithostratigraphic units of the Ooradidgee Group that outcrop in the northern Davenport, and Warramunga provinces (see Blake et al 1987). The Treasure Volcanics are a distinctive highly magnetic interval at the top of the Ooradidgee Group and are recognised in LANDER RIVER. The geophysical data are consistent with a general correlation between the Ooradidgee Group and the Lander Rock Formation; the latter probably represent a more distal facies variant of the Ooradidgee Group succession. The transition from Lander Rock Formation to Ooradidgee Group stratigraphy is arbitrarily shown as being approximately coincident with the southern margin of the Lander Trough.

The Ooradidgee Group outcrops extensively in the Warramunga Province of the Tennant Region. It also outcrops in the cores of anticlines in the Davenport Province, and as scattered outcrops in northwestern BARROW CREEK and southwestern BONNEY WELL, adjacent to northeastern MOUNT PEAKE and southeastern LANDER RIVER, respectively. The group name was derived from OORADIDGEE in BONNEY WELL. The unit was originally defined as a subgroup of the Hatches Creek Group by Blake et al (1985), and was upgraded to a group when it was combined with the correlative Flynn Subgroup by Donnellan et al (2001; further details are given under Hatches Creek Group). The Ooradidgee Group is a volcano-sedimentary succession consisting of predominantly felsic volcanic rocks, including pyroclastic rocks and lava, and immature clastic sedimentary rocks; together with subordinate basaltic volcanic rocks, in particular, the Edmirringee Volcanics. The sedimentary rocks include deep and shallow-water, including littoral, marine and fluviatile deposits. Four local successions have been mapped and the group is characterised by lateral facies variations around a number of volcanic centres, apparently with two major felsic volcanic episodes at ca 1850–1840 and ca 1810 Ma. The first of these is contemporaneous with syn-to immediately post-tectonic granite emplacement associated with the ca 1850 Ma Tennant Event. Volcanic rocks of this age include those of the Yungkulungu Formation (1849 ± 5 Ma; Smith 2000), Bernborough Formation (1845 ± 4 Ma and 1840 ± 8 Ma; Compston 1995), and the Epenarra Volcanics (1840 ± 4 Ma; Claoué-Long et al 2008a). Volcanic rocks of the Monument and Wundirgi formations, and the Warrego Volcanics are undated, but can be broadly correlated with those of the Yungkulungu and Bernborough formations. The younger volcanic interval is represented by the Treasure Volcanics (1814 ±3/-6 Ma; Claoué-Long et al 2008a), and by the correlated, although undated Mia Mia Volcanics. The latter is restricted in outcrop to the Mia Mia Dome in the southwestern HATCHES CREEK REGION (Blake et al 1984). Sedimentary rocks of the Kurinelli and Taragan sandstones, and the Brumbreau Formation may at least in part postdate the Epenarra Volcanics and partially fill the time interval (ca 1840–1810 Ma) between the first and second volcanic episodes.

The non-outcropping Ooradidgee Group rocks in LANDER RIVER are probably more distal with respect to their source than those exposed in the Tennant Region. The succession is therefore likely to be dominated by elastic sedimentary rocks (eg Kurinelli Sandstone or Rooneys Formation), rather than by volcanic rocks.

The Ooradidgee Group has an estimated maximum thickness of about 6000 m. In the Tennant Region, it unconformably overlies the Warramunga Formation and the Woodenjerrie beds, and is locally conformably, disconformably or unconformably overlain by the Hatches Creek Group.

Hatches Creek Group

There is minor outcrop of probable Hatches Creek Group rocks (specifically the Unimbra Sandstone) in LANDER RIVER. No rocks of this group have been identified in outcrop in MOUNT PEAKE. However, sandstone outcropping at 312500mE 7622750mN and mapped as undivided Lander Rock Formation could belong to the Hatches Creek Group, or more specifically to the Coulters Sandstone, given that minor intensely silicified rock immediately overlying this sandstone may represent stromatolitic carbonate rocks of the Frew River Formation. Hatches Creek Group rocks have been interpreted from geophysical data over a wide area of LANDER RIVER, underlying either surficial cover or Phanerozoic strata. Rocks of the Hatches Creek Group, specifically the Unimbra Sandstone and Newlands Volcanics (or stratigraphic equivalents thereof, ie Gwynne Sandstone and Strzeleckie Volcanics) are also interpreted in the extreme northeastern corner of MOUNT PEAKE, where they can be extrapolated from outcrop in the adjacent mapsheet (BARROW CREEK). Similarly, marker magnetic volcanic units of the Hatches Creek Group (in particular the Kudunga Basalt and Newlands Volcanics) can be extrapolated from BONNEY WELL into LANDER RIVER, and facilitate interpretation of Hatches Creek Group (and also the Ooradidgee Group) stratigraphy in the latter mapsheet. In the absence of outcrop, these intervals of stratigraphy are inferred from their geophysical expression and, in particular, from airborne magnetic data. Interpretations are aided by the layer-cake character, and extensive outcrop of the Hatches Creek Group lithostratigraphy in the Tennant Region.

The Hatches Creek Group was originally named by Sullivan (1953), replacing the Hatches Creek Series of
Hossfeld (1941). Smith et al (1961) recognised that rocks of the 'Bottom Series' of Hossfeld (1954), which were previously thought to unconformably underlie the Hatches Creek Group, were in fact conformable with the group and redefined the group name to include these rocks. Ryan (1961) and Blake et al (1985) used the name Hatches Creek Group in this revised sense, and the latter authors divided the Hatches Creek Group into three subgroups (Ooradidgee, Wauchope and Hanlon). Donnellan et al (2001) redefined the Ooradidgee Subgroup as a group, after combining it with the correlative Flynn Subgroup in TENNANT CREEK. Rocks formerly included in the Flynn Subgroup by Donnellan et al (1995) were originally included in the Warramunga Group of Ivanac (1954), but were recognised to be unconformable with respect to the older units of that group (which were called the Warramunga and Junalki formations, and Woodenjerrie beds) by Donnellan et al (1991). The name Ooradidgee was kept in accordance with precedence, and group status reflects a distinction between the lateral facies variations that characterise Ooradidgee Group rocks, in contrast with the layer cake stratigraphy of the Wauchope and Hanlon subgroups of the Hatches Creek Group.

The Hatches Creek Group is largely confined in outcrop to the Murchison, Davenport, Crawford and Taylor ranges, but minor outcrop of equivocal Unimbra sandstone occurs in LANDER RIVER and it is possible that the Coulters Sandstone and Frew River Formation outcrop in MOUNT PEAKE (see above). It is interpreted from geophysical evidence that the Hatches Creek Group extends under cover into northern MOUNT PEAKE and is widespread in LANDER RIVER. The group is also interpreted to extend over a much larger area, both towards the Birrindudu Basin to the west and under the Georgina Basin to the east.

In ascending stratigraphic order, the Wauchope Subgroup comprises the Unimbra Sandstone, Yeeradgi (and correlative Tinfish) sandstones and laterally equivalent Newlands, Arabulja and Strzeleckie volcanics, Coulters (and correlative Gwynnie) sandstones, Frew River Formation and Kudenga Basalt. The Hanlon Subgroup comprises the Errolola and Alinjabon sandstones, Lennee Creek Formation, Canulgerra Sandstone, Vaddingilla Formation and Yaddanilla Sandstone. The succession comprises ridge-forming quartz-rich sandstone (Unimbra, Coulters and Errolola sandstones), and recessive feldspathic and lithic sandstone and volcanic rocks. The volcanic rocks are predominantly felsic ignimbrite and lava; however, the Kudenga Basalt is a widespread (continental flood) basalt succession, varying between 50 and 770 m in thickness, and is locally pillowed. The sandstones are mainly shallow marine and fluvialite, whereas the felsic volcanics are subaerial. Carbonate and evaporite rocks are subordinate to minor components of the succession.

The Hatches Creek Group succession varies in thickness up to about 8000 m (Blake and Page 1988). Its maximum age is constrained by the immediately underlying ca 1814 Ma Treasure Volcanics, and by 1814 ± 3 Ma and 1805 ±6/3 Ma igneous crystallisation ages for the Arabulja and Strzeleckie volcanics, respectively, from near the base of the group (Claoué-Long et al 2008b). A minimum age constraint is provided only by intrusive magmatism of the Devils Suite at ca 1710 Ma.

Reynolds Range Group

The Reynolds Range Group and its constituent units (Mount Thomas Quartzite, Pine Hill Formation) were first defined in NAPPERBY by Stewart et al (1980a). The Reynolds Range Group also outcrops in the Giles Range in southwestern MOUNT PEAKE (GILES). A well documented progression in metamorphic grade occurs between greenschist-facies conditions in the Giles Range (in MOUNT PEAKE) and upper amphibolite- and granulite-facies conditions in the southeastern Reynolds Range (in NAPPERBY; Stewart et al 1980a, Dirks et al 1991, Hand and Buick 2001). The Reynolds Range Group also outcrops in MOUNT DOREEN, particularly in the Wabudali Range in northern VAUGHAN, and locally in adjacent MOUNT THEO and HIGHLAND ROCKS.

In the Giles Range in MOUNT PEAKE, only the Mount Thomas Quartzite and Pine Hill Formation of the Reynolds Range Group are represented. There is a sharp concordant (eg at 229636mE 756772mN) to sheared, faulted contact between the Mount Thomas Quartzite and the Redhackle Granite in this area. It is locally difficult to distinguish sheared granite from sheared quartzofeldspathic biotite- and tourmaline-bearing Mount Thomas Quartzite. At 229059mE 756807mN, the Mount Thomas Quartzite is a thinly bedded and flaggy fine-grained quartzite with scattered tourmaline and pink clayey partings. Beds are up to 10 cm thick and bed sets up to about 50 cm. Individual beds are of laminated grey and blue-grey quartzite, or pink clay-bearing sandstone, the colour reflecting variable haematitisation, fine-grained detrital tourmaline and probable original (now degraded) feldspar content. The sandstones are variably planar to very low-angle cross-bedded, and planar units have sinuous-crested, interference and truncated ripple marks. Lithologically, the quartzite in the Giles Range is correlated with the dominant fine-grained orthoquartzite unit (Prt₃) of the type section, about 4 km southeast of Mount Thomas in NAPPERBY (REYNOLDS RANGE). Sedimentary structures suggest a shallow-marine to intertidal environment of deposition, consistent with the shallow-marine to shore face interpretation of Stewart et al (1980a) for this unit. Further sedimentological details of the Reynolds Range Group in the eponymous ranges were presented by Dirks (1990) and Dirks and Norman (1992); the palaeoenvironmental interpretations given by these authors are in general agreement with those originally proposed by Stewart et al (1980a). However, Dirks and Norman (1992) also recognised stromatolitic bioherms in the carbonate lithofacies of the Reynolds Range Group and they further reported a general lack of tidal deposits (although they noted their occurrence in their 'quartz-arenite facies association'), from which they concluded that the palaeo-marine shelf experienced a small tidal range. In this context, it should be noted that intertidal facies are probably represented locally in the Mount Thomas Quartzite in the Giles Range.

The Pine Hill Formation is very poorly outcropping in MOUNT PEAKE, where it comprises biotite-muscovite schist and variably muscovite-, haematite- and feldspar-bearing quartz arenite. In NAPPERBY, the Pine Hill Formation conformably overlies the Mount Thomas
Quartzite or forms a meta-pelitic lens within it; it has been interpreted to represent deeper-water, offshore sedimentation by comparison with the Mount Thomas Quartzite (Stewart et al. 1980a).

Stewart et al. (1980a) recorded that small amounts of mafic rocks are interlayered with Pine Hill Formation metapelites in the Reynolds Range. Mafic rocks are also represented in this formation in MOUNT DOREEN (Young et al. 1995a). In the Reynolds Range, mafic rocks are interlayered with metapelite and have an assemblage of hypersthene-clinopyroxene-labradorite-microcline (Stewart et al. 1980a), consistent with the high metamorphic grade of the enclosing metapelite. In the Wabudali Range in MOUNT DOREEN, metabasalt comprises albite, elongate hornblende, fine-grained quartz, and minor epidote, chlorite and Fe-Ti oxides, suggesting retrogression to epidote-amphibolite facies. This is consistent with the low metamorphic grade of the associated metasedimentary rocks. Despite metamorphism and deformation, the mafic rocks in the Wabudali Range are amygdaloidal and are interpreted to represent one, or probably several lava flows. Basaltic detritus is present in the overlying sedimentary rocks (Young et al. 1995a).

The age of the Reynolds Range Group is poorly constrained. The Coniston Schist, interpreted to be an S-type quartz-feldspar porphyry intruding the unconformity at the base of the Mount Thomas Quartzite, has a 1780 ± 10 Ma SHRIMP U-Pb age (Smith 2000, 2001) although Claoué-Long et al. (2008a) suggested that the zircons may be inherited. The Napperby Gneiss, which intrudes the Reynolds Range Group in the Reynolds Range, also has an interpreted SHRIMP U-Pb age of 1780 ± 10 Ma (Collins and Williams 1995). In the western Aileron Province, in central LAKE MACKAY, a sample of Mount Thomas Quartzite has a maximum deposition age of 1779 ± 14 Ma, and is interpreted to be intruded by granite with a SHRIMP U-Pb zircon age of 1773 ± 2 Ma (Worden et al. 2006).

A sample of Mount Thomas Quartzite from Cordertite Creek in the southeastern Reynolds Range and a sample from the type section in the central Reynolds Range have maximum deposition ages of 1799 ± 8 Ma and 1798 ± 12 Ma, both based on SHRIMP U-Pb data on the youngest coherent detrital zircon population (Claoué-Long et al. 2008a). Rubatto et al. (2001) reported two spot ages of 1792 ± 9 Ma and 1771 ± 10 Ma (1σ) from a detrital zircon core in the Reynolds Range Group. Claoué-Long et al. (2008a) reported that sandstones in the previously mapped as Lander Rock Formation, immediately underlying the Mount Thomas Quartzite in the northwestern Reynolds Range, have an 1820–1800 Ma population of detrital zircons. Thus, according to Claoué-Long et al. (2008a), it is possible that there is an unconformity (not yet mapped) within the Lander Rock Formation (corresponding to the Stafford Event), and that the unconformity at the base of the Reynolds Range Group could therefore represent a younger event. However, it is noted herein that the 1820–1800 Ma detrital zircons in the uppermost Lander Rock Formation could reflect derivation from a volcanic provenance and sedimentation immediately prior to, or penecontemporaneous with the Stafford Event. This alternative is favoured until an unconformity is mapped within the Lander Rock Formation.

Previously the Reynolds Range Group has been correlated with the Hatches Creek Group (Blake et al. 1987, Stewart et al. 1984) and with the Pargee Sandstone (as well as the Supplejack Downs Sandstone and Mount Winnecke Formation) of the Tanami Region (Blake et al. 1979). Claoué-Long et al. (2008a) have suggested a correlation between the Reynolds Range Group and the Birrindudu Group. However, the Reynolds Range Group succession closely compares lithologically with the succession of sandstone, stromatolitic carbonate and basalt of the Coulters Sandstone, Frew River Formation and Kudinga Basalt in the upper Wauchope Subgroup of the Hatches Creek Group, lending support to the correlation originally proposed by Blake et al. (1987). A best estimate for the age of this interval of Hatches Creek Group stratigraphy is ca 1810 Ma, based on an igneous crystallisation age of 1811 ± 5 Ma reported for an intrusive dolerite sill in the Kurinelli goldfield of the Davenport Ranges by Maidment et al. (2006). Claoué-Long et al. (2008b), following Blake et al. (1987), considered these dolerite sills to be contemporaneous with the Kudinga Basalt; alternatively, the Kudinga Basalt could be related to mafic magmatism during the Attutra Event of Hoatson et al. (2007). If the time equivalence of the Kudinga Basalt and the Kurinelli dolerite is correct, then this would suggest that the sandstone at the top of Lander Rock Formation, immediately underlying the Mount Thomas Quartzite, may in fact be conformable with the Reynolds Range Group. If this was the case, then the Reynolds Range Group may represent a progressive rather than transgressive succession.

INTRUSIVE ROCKS

A summary of granites from LANDER RIVER and MOUNT PEAKE is presented in Table 2.

Early granite

In these notes, 'early' refers to granites with igneous crystallisation ages in the range 1820–1770 Ma, with most falling in the range ca 1805–1790 Ma. These granites are classified here as peraluminous, biotite granites. Three textural variants of early granites are recognised in MOUNT PEAKE. These are consistent with the range of textural types seen in classical rapakivi associations: (a) rapakivi-textured (cf wiborgitic) granite; (b) coarse grey porphyritic K-feldspar granite; and (c) equigranular/seriate porphyritic granite. These textural characteristics are typically associated with high-level intrusions and extensional, ensialic tectonic settings (cf Anderson and Bender 1989, Anderson and Morrison 1992). The rapakivi-textured type tends to be locally to regionally gneissic and is confined in outcrop to southwestern MOUNT PEAKE (eg Anmatjira Orthogneiss). This granite type is proximal to widely distributed, similar rapakivi-textured orthogneisses (eg Mount Airy Orthogneiss) in the Reynolds and Anmatjira ranges in NAPPERBY and belongs to the same suite. Penecontemporaneous with these rapakivi-textured orthogneisses is an associated group of granites lacking rapakivi textures, and also submagmatic and gneissic fabrics. These granites include the Koonoonyeri Granite in MOUNT PEAKE, and the Harveson Granite in NAPPERBY. Localised, gneissic and phyllicitic fabrics in
<table>
<thead>
<tr>
<th>Unit, map symbol</th>
<th>Mineralogy and texture</th>
<th>Structures</th>
<th>Contacts</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed dolerite, Pd</td>
<td>Dolerite dykes</td>
<td></td>
<td>Interpreted to intrude Amesbury Quartzite</td>
<td>Neoproterozoic, age equivalent to unnamed basalt Pe b</td>
</tr>
<tr>
<td>Unnamed porphyry, Pp</td>
<td>Quartz-feldspar porphyry</td>
<td></td>
<td>Phase of Eg5</td>
<td></td>
</tr>
<tr>
<td>Unnamed granite, Eg5</td>
<td>Grey, biotite-granite with either hypidiomorphic granular or K-feldspar megacrystic texture; late aplite phase</td>
<td>Elongate megacrysts define a 1pfc-texture; localised mylonitic or gneissic texture</td>
<td>Not exposed, interpreted to intrude Etr and Egk</td>
<td>Probable phase of the 1622 Ma Ennugan Mountain granite</td>
</tr>
<tr>
<td>Windajong Granite, Egw</td>
<td>Biotite-muscovite granite; equigranular/seriate porphyritic; rutiled quartz</td>
<td>Weakly foliated to massive in outcrop; deformational microstructures</td>
<td>1730 ± 3 Ma</td>
<td></td>
</tr>
<tr>
<td>Unnamed granite, Eg4</td>
<td>Poorly-outcropping granite forming discrete subcircular, non-magnetic gravity lows</td>
<td></td>
<td>Interpreted to be age equivalent to Pgw</td>
<td></td>
</tr>
<tr>
<td>Unnamed granite, Eg3</td>
<td>Only one probable outcrop in the Bau Range</td>
<td></td>
<td>Interpreted to be age equivalent to Pgr</td>
<td></td>
</tr>
<tr>
<td>Redhackle Granite, Pgr</td>
<td>Biotite-granite/gneiss; equigranular/seriate porphyritic and K-feldspar megacrystic phases; dark blue, opalescent quartz; local rapakivi texture; tourmaline-bearing; aplite, pegmatite</td>
<td>Gneissic foliation; dynamic and static recrystallisation microstructures</td>
<td>Intrudes Etr, and Ert?</td>
<td>1772 ± 3 Ma</td>
</tr>
<tr>
<td>Koonoonyeri Granite, Egk, Egk1</td>
<td>Grey, biotite-granite with equant K-feldspar megacrysts; blue quartz; discrete low magnetic, high-U phase, Egk</td>
<td>Discrete phylloitic and mylonitic zones, deformational microstructures</td>
<td>Intrudes Etr and Etr</td>
<td>1793 ± 3 Ma</td>
</tr>
<tr>
<td>Unnamed granite, Egu</td>
<td>Non-outcropping, inferred K-feldspar megacrystic granite and minor granitic gneiss</td>
<td></td>
<td>Interpreted to intrude Ooradigeed and Hatches Creek group rocks, Eot, Eha, Ehs</td>
<td>Interpreted to be a ca 1810–1800 Ma Treasure Suite granite</td>
</tr>
<tr>
<td>Unnamed granite, Eg2, Eg2m</td>
<td>Biotite-granite; K-feldspar mega-crystic; tourmaline-bearing; locally greisenous; aplite; pegmatite; more magnetic phase is designated Eg2m</td>
<td>Weakly defined sub-magmatic foliation defined by aligned feldspar megacrysts</td>
<td>Intrudes Etr, Etr</td>
<td>1879 ± 6 Ma</td>
</tr>
<tr>
<td>Esther Granite, Ege, Ege1, Ege2</td>
<td>Biotite-granite, K-feldspar megacrystic or equigranular/seriate porphyritic; different textural phases designated Ege1 and Ege2; aplite, pegmatite</td>
<td>Well-developed sub-magmatic foliations defined by elongate K-feldspar megacrysts and biotite</td>
<td>Intrudes Etr, Etr, Etr</td>
<td>1814 ± 6 Ma</td>
</tr>
<tr>
<td>Unnamed Granite, Eg1, Eg1m</td>
<td>Biotite-granite/granodiorite; equigranular/seriate porphyritic, or K-feldspar megacrystic; magnetic phase is designated Eg1m</td>
<td>Foliated</td>
<td>Intrudes Etr (various members) and Eld</td>
<td>Granitic phase 1795 ± 4 Ma Orthogneiss 1798 ± 3 Ma</td>
</tr>
<tr>
<td>Anmatjira Orthogneiss, Ega</td>
<td>Biotite-granite and orthogneiss, with mantled K-feldspar megacrysts rapakivi texture); rutiled quartz; tourmaline-bearing</td>
<td>Gneissic foliations, locally more granitic but with overprinting extensional shear zones; microstructures</td>
<td>Intrudes Etr, with which it forms hybrid diatexite locally</td>
<td></td>
</tr>
<tr>
<td>Unnamed mafic rocks, Eld</td>
<td>Mafic igneous and meta-igneous rocks including gabbro, olivine-gabbro, hornblende-gabbro, dolerite and amphibolite</td>
<td>Forms stratiform units and local subcircular intrusions</td>
<td>Intrudes Etr, Etr, Etr, Etr</td>
<td>Syn- to post-1860 Ma max, pre-1800 Ma min</td>
</tr>
<tr>
<td>Unnamed mafic rocks, Elg</td>
<td>Mafic igneous and meta-igneous rocks including gabbro, olivine-gabbro, uralitised gabbro, dolerite, and amphibolite</td>
<td>Generally stratiform, folded within Etr</td>
<td>Intrudes Etr</td>
<td>Syn- to post-1860 Ma max, pre-1800 Ma min</td>
</tr>
</tbody>
</table>

Table 2. Magmatic rock units of MOUNT PEAKE and LANDER RIVER. 1pfc indicates pre-full-crystallisation or submagmatic fabric/foliation. 2 1730 ± 3 Ma, ages quoted with errors are single crystal zircon SHRIMP U-Pb ages and are interpreted as igneous crystallisation ages.
these granites are probably a consequence of non-magmatic deformation. This group of granites is herein included in the same suite as the orthogneisses.

The Esther Granite in southeastern MOUNT PEAKE typifies the K-feldspar porphyritic granites. These granites have distinct fabrics defined by the alignment of inequidimensional feldspar megacrysts and biotite. There is currently debate regarding the origin of these so-called 'flow' fabrics. Blenkinsop (2000) recommended that the term 'flow' with its attendant genetic connotations should be avoided, and advocated calling these fabrics magmatic or submagmatic/pre-full-crystallisation. Blenkinsop concluded that there must be no associated indications of tectonism (eg undulose extinction in quartz) for such fabrics to be (solely) magmatic. This criterion is not met by MOUNT PEAKE granites and at least a component of tectonism is recorded in the magmatic/pre-full crystallisation fabric(s) in these rocks.

Fabrics are more difficult to recognise in the field in the equigranular (to seriate porphyritic) granites. However, they are apparent in thin section. This third textural type tends to be associated with discrete phases within the early K-feldspar megacrystic granites, or as separate (younger) plutons (eg the 1730 Ma Windajong Granite).

Although there are three main textural types, the 1805–1790 Ma granites described above are all considered to belong to the same suite, as they are compositionally and mineralogically similar. However, although the Redhackle Granite in southwestern MOUNT PEAKE is similar to the rapakivi-textured orthogneisses in MOUNT PEAKE and NAPPERBY, it is younger (ca 1772 Ma) than these orthogneisses and is consequently not a member of the same suite. Conversely, there is a poorly outcropping, but widespread K-feldspar megacrystic biotite granite in LANDER RIVER and MOUNT PEAKE, which is older (ca 1814 Ma) than the 1805–1790 Ma suite. This older granite is mapped as unnamed granite Pg2.

The early granites are typically tourmaline bearing. Offe (1978) also reported fluorite in the granite phase of the Anmatjira Orthogneiss in the Yundurbulu Range, and in granite on the eastern side of the Nanga Range (here mapped as the Koonoonyeri Granite). Furthermore, Offe (1978) recorded a fluorite-bearing quartz vein approximately 2 km south-southwest of Old Mount Esther homestead, which cuts granite (here mapped as Esther Granite) and is truncated by the basal Central Mount Stuart Formation.

**Esther Granite**

The Esther Granite (new name; see Appendix 1) is named after Mount Esther in southwestern ANNINGIE. It outcrops sporadically over ca 650 km² in southern ANNINGIE from around Mount Esther to Central Mount, Amesbury Bore and the Walabanba Hills (Figures 10, 11a–b). The Esther Granite is a grey, biotite granite and typically has a K-feldspar megacrystic texture.

A number of textural variants have been identified and mapped. These include: extremely coarsely megacrystic K-feldspar granite with elongate, inequidimensional feldspars up to approximately 15 cm; coarsely K-feldspar megacrystic granite with inequidimensional feldspars to about 1.5–2 cm; granite with equidimensional, porphyritic K-feldspar up to approximately 5 cm; and coarse or very coarse, equigranular ('classically granitic'-textured) granite. Examples of these textural types can be seen in the vicinity of Old Yards Well (312370mE 7595441mN and 308489mE 7594550mN), around Central Mount (318377mE 7574082mN), to the north of Mount Esther (329378mE 7574917mN) and near Amesbury Bore (314467mE 7596937mN), respectively.

Different textural varieties are intimately inter-associated in, for example, the area north of Mount Esther and in outcrops to the southeast of Salt Bore. On the mapface, the generalised distribution of the first three textural varieties of the Esther Granite are shown. This broad textural zoning may reflect multiphase emplacement, and a greater or less degree of intermingling. Typical K-feldspar megacrystic Esther Granite is illustrated in Figure 11a–e.

Quartz from the Esther Granite shows a variety of fabrics variably consistent with deformation by intracrystalline plasticity, cataclasis and solid state diffusive mass transfer. These fabrics include undulose extinction and prismatic subgrain development, sutured grains, inter- and intra-granular microcracks, and polygonised grains. K-feldspar megacrysts in the Esther Granite are markedly sericitised, variably exolved, show string perthite, and tend to (ordered) tartan-twinned maximum microcline. Significant ordering of alkali feldspar is confirmed by the extinction angle on 001. Deformational microstructures in alkali feldspars include bent (tapering microcline) exsolution lamellae, undulose extinction, subgrain development at crystal margins, and melt-filled microveins. These microfabrics in quartz and feldspar (as well as undulose extinction in biotite and bent biotite grains), together with the mesoscale foliations seen in outcrop, are interpreted to record a history of (magmatic/submagmatic and non-magmatic deformation in the Esther Granite.

Extensively sericitised myrmekite is often present where microcline is in contact with plagioclase. K-feldspar megacrysts show zoning and have biotite inclusions parallel to internal growth zones. Recessive halos around magmatic crystalline feldspars are attributed to the preferential weathering out of biotite. Rims of biotite around K-feldspar megacrysts are a common feature in the granites in MOUNT PEAKE and LANDER RIVER, and biotite inclusions (locally paralleling internal growth zones within K-feldspar megacrysts) form continuous zones in some cases. K-feldspar megacrysts have therefore grown in situ (and in some instances, probably in stages) and moved earlier-formed biotite flakes aside to accumulate at their rims (cf Mehnert 1971). This is consistent with Vernon's (1986) interpretation that K-feldspar megacrysts in granites are phenocrysts, not porphyroblasts. Occasional crystals of biotite attached to growth zones within the K-feldspar megacrysts (and possibly internal, more continuous zones of biotite) are attributed to mixing of basic magma with the crystallising granite (cf Hibbard 1991). Magma mixing may also result in rapakivi textures. However, rapakivi texture can also develop by subsolvus exsolution and segregation of albite from alkali-feldspar. This is apparently, at least locally, the case in the ca 1800 Ma rapakivi granite suite in MOUNT PEAKE and NAPPERBY.

In the Mount Airy Orthogneiss in NAPPERBY, for example, there is physical continuity (which can be seen in the field)
between exsolved albite within the K-feldspar megacrysts and their rapakivi rims. Syenitus (cf Shelley 1992) is locally (eg 330613mE 7576018mN) evident at outcrop scale. This suggests that feldspar has been mobile in the presence of a significant melt component. Thus, K-feldspars that have come together in favourable crystallographic orientations are mutually overgrown by zoned rims. This process is considered to be quite distinct from that associated with the submagmatic foliations defined by K-feldspar megacrysts.

Plagioclase is typically interstitial and relatively unaltered, although it is locally sericitised and/or saussuritised. Biotite shows straw-yellow to red-brown pleochroism and alteration to green chlorite together with rutile and magnetite, or locally epidote. Rutile in this paragenetic association suggests that the biotite is titanium-rich, which is consistent with its red-brown colour. Tourmaline is an accessory mineral, particularly in late-stage pegmatitic phases. Locally (eg 316677mE 7580658mN), multiple phases of pegmatite are evident. Tourmalinisation of country rock is also locally well developed (eg Figure 12a, 303291mE 7600238mN).

Stewart et al (1980a) described rafts of tourmalinised country rock within the granite. Offe (1978) recorded that lithium-bearing mica, tourmaline and pyroxene (ie lepidolite, elbaite and spodumene, respectively) were identified by Pontifex (1965) in pegmatite about 4 km northeast of the Anningie tin field.

Contacts are generally not exposed. However, contact effects are evident; for example, coarse porphyroblastic andalusite growth in the Lander Rock Formation is well exposed in the Walabanba Hills (304277mE 7600390mN; Figure 12b). Extremely coarse 5–6 cm muscovite and large biotite books are seen in Lander Rock Formation metasediments at 316370mE 7633023mN and these are attributed to the contact effects of the Esther Granite. Elongated andalusite porphyroblasts are retrogressed, but are not apparently crenulated. This suggests they grew subsequent to, or contemporaneously with deformation in the Lander Rock Formation. Locally, eg at 303115mE 7600318mN, andalusite is elongated within the plane perpendicular to the intersection lineation of S1 and S2, but plunges in the opposite direction to the intersection lineation. The Esther Granite crosscuts mafic
rocks in the Walabanba Hills. Localised igneous layering in the granite is folded. Biotitised xenoliths and the magnetic signature of the Esther Granite in airborne geophysical data are consistent with it intruding the Lander Rock Formation.

Enclaves in the Esther Granite are predominantly surmiceous (ie mica rich; see Didier and Barbarin 1991) and are probably biotitised xenoliths of country rock, as distinct from either restite or accidental inclusions of country rock, ie they are inclusions of rock derived from the level of emplacement of the granite rather than of rocks encountered by the granite en route through the crust to its level of emplacement. Biotitisation of in situ country rocks is also seen locally (eg 30410mE 7623161mN). In southwestern Anningie, near the old Mount Esther Homestead, the Esther Granite is locally markedly altered, with haematitisation and saussauritisation of feldspar.

The Esther Granite has an igneous crystallisation age of 1789 ± 6 Ma (Cross et al 2005). Inherited zircons, occurring either as cores or distinguished by their rounded, equant shapes, have yielded ages in the range ca 1840–2535 Ma. These zircons suggest that there has been recycling of older crustal material, possibly through a (meta-) sedimentary source of approximately Lander Rock Formation age.

The Esther Granite has multiple pre-full-crystallisation fabrics, defined by the orientation of inequidimensional K-feldspar megacrysts and biotite. These include linear and platy flow fabrics, and locally, a herringbone fabric (see Marre 1986) which suggests a probable component of shear. These submagmatic fabrics are interpreted to be a consequence of granite emplacement syntectonic with respect to deformation in the Lander Rock Formation. Locally, the orientation of andalusite porphyroblasts suggests peak contact

Figure 11. Esther Granite. (a) Ege, ‘transitional’ textured granite, with mixture of inequidimensional elongate, and more equidimensional microcline crystals (330613mE 7576018mN). Pencil parallels foliation (S) defined by elongated K-feldspar megacrysts. Zoning can be seen in some crystals, [eg (1), where two crystals also show synneusis]. Other crystals are fractured, (2) and fractures are filled with (now crystallised) melt indicating another, later foliation (S2) running top-right to bottom-left which also predates full crystallisation. (b) Ege, small elongate K-feldspar megacrysts characterise this granite phase from vicinity of Central Mount (319377mE 7574082mN). Feldspar long dimensions define multiple pre-full crystallisation fabrics. (e) Ege, coarsely megacyrstic K-feldspar biotite granite at 309012mE 7595066mN. Tabular feldspars to 10 cm x 2 cm. Dominant alignment of feldspars is to northwest. Although not evident in this figure, note that tourmaline occurs both poikilitically enclosed in other minerals and with radiating habit, suggesting growth during both magmatic crystallisation and subsequent late-stage deuteric alteration, respectively. (d) Synneusis of zoned, equant K-feldspar megacrysts (1) in Ege (330612mE 7576017mN). (e) Typical granite (Ege), with well developed pre-full crystallisation texture, defined by inequidimensional K-feldspar megacrysts, immediately south of Walabanba Hills (309111mE 7595066mN).
metamorphic effects penecontemporaneous with the final stage of deformation, and tourmaline forms mantled sigma porphyroclasts in metasomatised country rock, suggesting granite-related metasomatism contemporaneous with deformation. Alternatively, if the preferred interpretation of the fabrics in the Esther Granite is that they relate to magmatic flow, then the crystallisation age of the granite provides a lower age constraint on deformation in the Lander Rock Formation of ca 1795–1790 Ma. Foliations in the Esther Granite and the other outcropping ‘early’ granites in LANDER RIVER and MOUNT PEAKE are discussed further below.

It is possible that the first phase of deformation and associated $S_1$ foliation in the Lander Rock Formation predates the Esther Granite, and that the dominant fabric in this granite, which is generally subparallel to $S_1$ in the country rocks, was inherited during emplacement (see below). Additional fabrics ($S_2$ and $S_3$) recognised in the Esther Granite are attributed to its syntectonic emplacement with respect to the later stages of Stafford Event. In this context, it is noted that multiple fabrics, and three phases of folding, have however been attributed to a single deformation and metamorphic episode (Stafford Event) in the Mount Stafford Member of the Lander Rock Formation by Vernon et al (1990). These fabrics are recognised throughout the Lander Rock Formation in LANDER RIVER and MOUNT PEAKE in the mapping reported herein.

Localised phyllonite zones (eg 313386mE 7596318mN) are attributed to probable Chewings or Alice Springs orogeny-aged shear zones or reactivation. A Rb-Sr whole-rock and mineral separate isochron for the Esther Granite gives a model 2 age of 1535 $\pm$ 53 Ma, and an initial ratio of 0.72514 (G Luther, La Trobe University, pers comm 2004). This isochron is tentatively interpreted as a Chewings, or post-Chewings, cooling age, and it is close to the ca 1535 Ma Rb-Sr ages reported by Buick et al (1999) from shear zones in the Anmatjira Orthogneiss in the Yundurbulu Range. It suggests that any effects of the Alice Springs Orogeny in southeastern MOUNT PEAKE are probably confined to localised shear zones. No such zones were present where the granite was sampled for geochronology. However, recrystallised regions of zircons within the Esther Granite

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**Figure 12.** Thermal and metasomatic effects of Esther Granite. (a) Tourmalinised Walabanba Member (303292mE 7600238mN). (b) Coarse porphyroblastic andalusite (now retrogressed to quartz-sericite) in contact aureole in Walabanba Hills (303500mE 7601000mN).
have a non-zero discordia trend and suggest incomplete U-Pb isotopic resetting of an indeterminate age (A Cross, Geoscience Australia, pers comm 2002). Palaeozoic-aged shear zones have been recognised in the Reynolds Range (Cartwright et al 1999) and Anmatjira Range (Collins and Teyssier 1989).

In a more regional context with respect to granites of Stafford Event-age, it is noted that deformation in the 1793 ± 3 Ma Koonoonyeri Granite in south-central MOUNT PEAKE is largely confined to phyllonitic zones that probably reflect shearing during the Alice Springs Orogeny. Collins and Teyssier (1989) and Vernon et al (1990) attributed discrete mylonitic zones in the nearby Anmatjira Orthogneiss to mid-Palaeozoic deformation. Shear zones in the 1795 ± 4 Ma Anmatjira Orthogneiss (age equivalent of the Koonoonyeri Granite) are, at least in part, extensional crenulation cleavages, or have been overprinted by them. Greenfield et al (1998) have inferred that peak metamorphism and migmatitisation at Mount Stafford were contemporaneous with localised extension in conjugate shear zones (attributed by Vernon et al 1990 to discrete compressional events). If the Anmatjira Orthogneiss was emplaced syn- to immediately post-peak metamorphism, ongoing extension may have facilitated granite emplacement and produced the extensional shear zones in the granite noted above. Thus, these structures may be (at least in part) Palaeoproterozoic. The Koonoonyeri Granite is interpreted to extend over an area of approximately 500 km² and the high-U phase occupies an area of about 70 km².

Quartz in the Koonoonyeri Granite shows a variety of microstructural characteristics, including undulatory extinction and sutured grain boundaries. These microstructures are consequent on intracrystalline plasticity and grain boundary migration, and are consistent with non-magmatic, dynamic recrystallisation. Both prismatic and chessboard subgrains are also developed in quartz. Mylonitic Koonoonyeri Granite at 252259mE 7583536mN has blue quartz cores overgrown by clear rims. Where the margins of K-feldspar megacrysts are in contact with biotite they show muscovitisation; however, the feldspar does not show pervasive sericitisation. It is typically exsolved and shows fine string perthite development and undulose extinction.

Feldspar textural characteristics in the Esther Granite are consistent with slow cooling and deuteric alteration. Ordering of feldspars suggests that late-stage fluids were not peraluminous although the granite compositions themselves are peraluminous (Figure 13).

### Koonoonyeri Granite

The Koonoonyeri Granite (new name; see Appendix 1) is named after Koonoonyeri Bore (258904mE 7592370mN). It is a grey biotite granite with equant K-feldspar megacrysts. The Koonoonyeri Granite outcrops to the north of the Anzac Dam Fault Zone in southern-central MOUNT PEAKE, particularly peripheral to the Nanga Range, where it is overlain with apparent unconformity by the Vaughan Springs Quartzite. A subcircular gravity low with no magnetic character but a high radiometric response is interpreted to constitute a discrete, late high-U phase of the granite. This phase outcrops immediately to the east of the Nanga Range. The Koonoonyeri Granite is interpreted from geophysical data to extend over an area of approximately 1500 km² and the high-U phase occupies an area of about 70 km².

Quartz in the Koonoonyeri Granite shows a variety of microstructural characteristics, including undulatory extinction and sutured grain boundaries. These microstructures are consequent on intracrystalline plasticity and grain boundary migration, and are consistent with non-magmatic, dynamic recrystallisation. Both prismatic and chessboard subgrains are also developed in quartz. Mylonitic Koonoonyeri Granite at 252259mE 7583536mN has blue quartz cores overgrown by clear rims. Where the margins of K-feldspar megacrysts are in contact with biotite they show muscovitisation; however, the feldspar does not show pervasive sericitisation. It is typically exsolved and shows fine string perthite development and undulose extinction.

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**Figure 13.** Molar CaO − Na₂O + K₂O − Al₂O₃ plot (after Bonin 1986) for granites from MOUNT PEAKE, showing that these granites are peraluminous. CaO is corrected for normative apatite.

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### Graph

- Hyperalkaline (>1% normative aegirine (acmite))
- Metaluminous (ie<1% normative aegirine and <1% corundum)
- Peraluminous (>1% normative corundum)

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**Appendix 1.**

- Esters Granite
- Koonoonyeri Granite
- Anmatjira Orthogneiss
Microcline microperthite is also present and indicates that ordering is essentially complete in a proportion of the potassium feldspar. Myrmekite is locally well developed at grain boundaries where potassium feldspar is in contact with plagioclase. Plagioclase is very turbid and is typically largely sericitised and saussuritised. Epidotised euhedral plagioclase is commonly mantled by clear, albic overgrowths, some of which are zoned. Superficially, these crystals give the appearance of euhedral rapakivi feldspars in the field. The rims are often very pale green. The lack of a rapakivi texture is one field criterion for distinguishing the Koonoonyeri Granite from the Anmatjira Orthogneiss. Polysynthetic twinning is rarely preserved in plagioclase; however, where preserved, typically proximal to grain boundaries, twin lamellae are deformed, indicating intracrystalline plasticity. Blenkinsop (2000) noted that deformed twin lamellae by themselves are not conclusive evidence that intracrystalline plasticity was necessarily in the presence of melt. Plagioclase with clear overgrowths on intensely altered cores indicate disequilibrium, with early cores representing restitic or cumulate material entrained within the granite. Euhedral, plagioclase of this type (i.e., with altered cores and clear rims) also occurs, poikilotically enclosed in alkali-feldspar megacrysts. The genetic implications of these composite (pseudo-antirapakivi) feldspars are uncertain. Biotite is pleochroic from straw yellow to red-brown and contains inclinations of zircon and rutile. Some biotite crystals are clearly deformed. The red-brown colour suggests that biotite is titanium-rich and this is probably consistent with the occurrence of rutile needles within biotite. Apatite is an additional accessory phase. On a semi-regional scale, deformation is apparently confined to discrete, wide zones that are characterised either by the development of phyllonite, or by mylonitisation. Zones of phyllonite result from the muscovitisation of feldspar and alteration of the granite over a few tens of metres to quartz-mica rock. One example of phyllonite is developed parallel to the Anzac Dam Fault Zone at 263415mE 7574880mN. Phyllonite is also well developed in the vicinity of 257228mE 758352mN, where it is apparently axial planar with respect to folding in the overlying Vaughan Springs Quartzite. This latter example of phyllonite development therefore apparently postdates the Palaeoproterozoic and could possibly relate to the Alice Springs Orogeny. However, foliation development in the Warimbi and Coniston schists in the Reynolds Range in NAPPERBY was interpreted by Stewart et al. (1980a) to be contemporaneous with, or to predate the Chews Orogeny. These authors recognised that this event was in part an open system, in that the breakdown of plagioclase to mica (and quartz) is not associated with the crystallisation of a sodium- or calcium-bearing phase. The same can be said of the phyllonite zones in the Koonoonyeri Granite. It should also be noted that phyllonite can develop contemporaneously with granite emplacement. This is particularly plausible where granite plutons have a sheet-like form and may have been emplaced along shear zones. The Koonoonyeri Granite lacks elongate, K-feldspar megacrysts and any obvious submagmatic (or flow) fabric defined by oriented K-feldspar and biotite. In this regard, it contrasts with many of the other early granites in MOUNT PEAKE. The microstructures described above are consistent with post-full crystallisation, i.e., non-magmatic deformation. Furthermore, subgrain development that defines a chessboard pattern in quartz in the Koonoonyeri Granite is evidence of recrystallisation at high temperatures, according to Blenkinsop (2000). The α-β inversion temperature in quartz is 573°C (at atmospheric pressure) (Deer et al. 1970). The chessboard fabric in quartz therefore suggests that dynamic recrystallisation occurred in the absence of melt, but nonetheless under high-temperature conditions relatively early in the cooling history of the granite. The Koonoonyeri Granite has an igneous crystallisation age of 1793 ± 3 Ma (Worden et al. 2006). It is interpreted to be immediately pre- to syntectonic with respect to the Stafford Event. The slightly younger Esther Granite has well-developed submagmatic fabrics and is considered to have intruded contemporaneously with the Stafford Event. Discrete zones of phyllonite and mylonite are interpreted to probably reflect subsequent deformation associated with thrusting and most likely developed penecontemporaneously with folding in the Vaughan Springs Quartzite.

**Redhackle Granite**

The Redhackle Granite (new name; see Appendix 1) outcrops sparsely in southwestern MOUNT PEAKE, in the vicinity of Giles Range and Western Creek Yard. Minor granite outcrops in extreme southwestern MOUNT PEAKE, west-southwest and southwest of Woodalla Bore, are also included in the Redhackle Granite. Geophysical data and company drilling indicate that the granite probably extends over an area of about 1000 km² in MOUNT PEAKE. However, the magnetic character in about one third of this area indicates that rafts of Lander Rock Formation rocks are widely distributed within the granite. Outcrops of the Redhackle Granite extend locally into NAPPERBY.

The Redhackle Granite is a grey, K-feldspar megacrystic biotite granite. It is generally gneissic, often with 'augen' of feldspar or quartz, with K-feldspar eyes up to 5 cm (Figures 14a and 14b, 225447mE 7569329mN) Gneissosity (dominantly S₁) results in a generally tabular outcrop morphology (e.g., 222970mE 7565370mN; Figure 14e). Where gneissosity has been transposed, it runs obliquely to the strike of the outcrop. Rhythmic mineralogical layering in the granite is apparently parallel to gneissic layering, for example at 228844mE 7567329mN. The granite has a locally well developed lineation defined by the intersection of foliations or by mineral elongation. Deformation of the Redhackle Granite (Figures 14d and 14e) proximal to the Giles Range Fault may be contemporaneous with the Alice Springs Orogeny, but this has not yet been confirmed by geochronology. A number of textural subtypes of the Redhackle Granite are recognisable, principally on the basis of feldspar morphology. These include aligned tabular, coarse equant, and minor rapakivi feldspar-bearing (eg 222212mE 7564910mN) variants. A variety of K-feldspar morphologies may be closely inter-associated, for example at 228454mE 7566692mN, where megacrystic tabular, subrounded and equant feldspars coexist. Equant feldspars are locally subrounded (eg 226549mE 7567935mN), and rapakivi feldspars tend to be euhedral rather than classically...
rounded, although the granite at 214505mE 7569205mN is more classically wiborgitic (cf Rämö and Haapala 1995). It is possible that confusion may arise between genuine augen gneiss, and gneissic pyterlitic (ie ovoidal, but non-rapakivi alkali feldspar), or wiborgitic granite. However, where present in the Redhackle Granite feldspar augen are readily identified. They are generally of variable size and may have tails, form ribbons, be smeared in a pervasive fabric, or the rock may be an equigranular mylonite with progressively increasing intensity of deformation. The granite is also locally phyllonitic or schistose.

'Rotten stone' at 220883mE 7566189mN is in fact associated with pyterlitic, as distinct from wiborgitic textures in the Redhackle Granite. The weathering characteristics of this granite therefore reflect the ovoidal character of the feldspars rather than the presence of sodic-plagiooclase rims. Very thin rapakivi rims are seen in feldspars at 222212mE 7564910mN. More or less equant (2 x 3 cm), incipiently rounded K-feldspar megacrysts at 220883mE 7566189mN have plagioclase rims and are loosely referred to as rapakivi (ie sensu lato). Other K-feldspar megacrysts are mantled by biotite and some of these biotite rims are subsequently

Figure 14. Redhackle Granite. (a) Deformed granite; top of pen points approximately west (225447mE 7569329mN). (b) K-feldspar megacrystic granite (228844mE 7569329mN). (c) Gneissic granite forming tabular outcrop (222970mE 7565370mN). (d–e) Deformed and markedly crenulated Redhackle Granite in Giles Range (225446.627mE 7569329mN). These structures may be contemporaneous with Alice Springs Orogeny.
marked saussauritisation (e.g. albitioned. muscovitisation of feldspar. include zircon and apatite. Muscovite is widespread, but is of its crystallisation and deuteric history. Accessory minerals include zircon and apatite. The widespread occurrence, and presence of several generations of tourmaline indicate that the granite was boron rich throughout a significant interval. The widespread occurrence of tourmaline, and probably occurs in several generations; one of which is poikilocrystically intergrown with potassium feldspar. The widespread occurrence, and presence of several generations of tourmaline indicate that the granite was boron rich throughout a significant interval of its crystallisation and deuteric history. Accessory minerals include zircon and apatite. Muscovite is widespread, but is probably largely secondary, resulting from sericitisation/muscovitisation of feldspar.

Late-stage phases of the Redhackle Granite include pegmatite and aplite. Biotitisation and tourmalinisation occurs in the granite at the margins of pegmatite dykes. Quartz-tourmaline forms rounded clots up to 15 cm diameter. Where weathered out, these can be confirmed to be essentially spherical. At 228844mE 7567329mN, they are seen to predate the dominant gneissic fabric in the granite. At this locality, the clots are atypical in that they do not have marked leucocratic rims. A variety of clots are recognised on the basis of their mineral content, which includes: (a) tourmaline-quartz with minor K-feldspar; (b) tourmaline-rich with minor quartz; (c) tourmaline-K-feldspar with minor quartz; and (d) very tourmaline-rich. Variants a to c all have leucocratic quartz-K-feldspar ('bleached') rims, whereas type d lacks a markedly leucocratic rim. These structures lack a preferred internal growth orientation. Their origin is unknown, but presumably involves localised concentration of a boron-rich late-magmatic phase and may involve variable degrees of autometasomatism. These tourmaline-rich clots are analogous to the tourmaline 'cocardes' described from Himalayan leucogranites (see Le Fort 1991). Cocardes are tourmaline- and quartz-rich spheres surrounded by bleached, tourmaline- and biotite-free granite; they are attributed to late-stage metasomatism, and are crosscut by aplite dykes in the Himalayan examples (Le Fort 1991). The morphology of tourmaline in cocardes contrasts with magmatic, prismatic tourmaline also found in the Himalayan granites. Le Fort (1991) attributed bleaching around the cocardes to liberation of Fe and Mg from biotite in the adjacent granite and their migration to the cocardes, and he observed that, in some instances, chloritic remnants of biotite remain. The compositional variants described above from the Redhackle Granite may reflect variable degrees of metasomatic replacement. However, the very tourmaline-rich clots would be anticipated to have the most marked leucocratic halos in this scenario. Probable cocardes are also found in the Anmatjira Orthogneiss in the Bilba Hills, and examples from there are illustrated in Figures 15a and 15b.

The Redhackle Granite has an igneous crystallisation age of 1772 ± 3 Ma (Worden et al. 2004). Relict cores of only two zircon grains were also analysed. They have a mean age of ca 1840 Ma and record inheritance. Post-crystallisation metamorphic rims are generally too thin to analyse; however, two such rims give an average age of 1579 ± 7 Ma. These rims have low Th/U ratios (0.01) and probably indicate upper amphibolite- or granulite-facies metamorphism during the Chewings Orogeny. This event is considered to have been largely thermal and to have resulted in static recrystallisation and a granoblastic texture.

The Redhackle Granite is interpreted to intrude the Lander Rock Formation. The contact is apparently not exposed, although spotted hornfels is locally preserved in the Lander Rock Formation in extreme southwestern MOUNT PEAKE (eg 214550mE 7569147mN and 201756mE 7572590mN) to the west-southwest of Woodalla Bore. Andalusite in the Lander Rock Formation at 201756mE 7572590mN plunges 70° to the north within the S3 foliation. This andalusite growth is interpreted to postdate the S3 foliation in the Lander Rock Formation, which is crenulated by S1. At 214550mE 7569147mN, aggregates of quartz and muscovite are interpreted to be
retrogressed andalusite. These relationships indicate that contact metamorphism associated with the emplacement of the Redhackle Granite may be contemporaneous, at least locally, with S1 in the Lander Rock Formation. Granitic orthogneiss at 201296mE 7568301mN, interpreted to be deformed Redhackle Granite, is conformable with the S1 foliation in the Lander Rock Formation. These relationships are difficult to reconcile with those in the Yundurbulu Range and the Walabanba Hills. They suggest that deformation of the Lander Rock Formation is, at least in part, of a different age (ca 1772 Ma) in the vicinity of the Redhackle Granite in southwestern MOUNT PEAKE, in comparison to that (ca 1790 Ma) in the vicinity of the Esther Granite in southeastern MOUNT PEAKE. Deformation in extreme southwestern MOUNT PEAKE could therefore be, at least in part, of Yambah / Strangways event age (ca 1770 Ma). These considerations raise the question as to whether Stafford Event foliations have been overprinted by Yambah / Strangways event foliations, or whether the Woodalla Member (in part at least) represents a discrete succession from the Lander Rock Formation generally. In the latter case, this interval of stratigraphy could equate with that identified at the top of the Lander Rock Formation near Mount Thomas by Claué-Long et al (2008a). However, no evidence for a ca 1805 Ma population of zircons was found in geochemical studies of the Woodalla Member from the vicinity of Tin Bore reported by Claué-Long et al (2008a).

The Redhackle Granite is in sheared and faulted contact with the Mount Thomas Quartzite in the Giles Range. There is scattered tourmaline in the Mount Thomas Quartzite, and sheared quartz-feldspar-biotite rock can be followed laterally into silicified quartz arenite. Offe (1978) reported that the Mount Thomas Quartzite has an apparent concordant or faulted contact with the granite in MOUNT PEAKE. Stewart et al (1980a) recognised a similar concordant relationship between the Mount Airy Orthogneiss and the Mount Thomas Quartzite in NAPPERBY, but concluded that the protolith to the gneiss intruded to the base of the quartzite, where it induced local "spruce-tree" folding. These relationships are difficult to reconcile with those in the Yundurbulu Range and the Walabanba Hills. They suggest that deformation of the Lander Rock Formation is, at least in part, of a different age (ca 1772 Ma) in the vicinity of the Redhackle Granite in southwestern MOUNT PEAKE, in comparison to that (ca 1790 Ma) in the vicinity of the Esther Granite in southeastern MOUNT PEAKE. Deformation in extreme southwestern MOUNT PEAKE could therefore be, at least in part, of Yambah / Strangways event age (ca 1770 Ma). These considerations raise the question as to whether Stafford Event foliations have been overprinted by Yambah / Strangways event foliations, or whether the Woodalla Member (in part at least) represents a discrete succession from the Lander Rock Formation generally. In the latter case, this interval of stratigraphy could equate with that identified at the top of the Lander Rock Formation near Mount Thomas by Claué-Long et al (2008a). However, no evidence for a ca 1805 Ma population of zircons was found in geochemical studies of the Woodalla Member from the vicinity of Tin Bore reported by Claué-Long et al (2008a).

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Locally, tabular xenoliths of quartz sandstone occur in the granite, and scattered surnicaceous enclaves are present. At some localities, these enclaves are flattened in a mylonitic fabric in the granite.

Several generations of pegmatite are present in association with the Redhackle Granite. Pegmatite occurs parallel to, and also at a shallow angle to the S1 gneissic fabric in the granite. This is interpreted as evidence that S1 predates the full crystallisation of late-stage granitic melt. Pegmatite also occurs parallel to S2. At one locality, a 20 cm-wide pegmatite dyke trends northeast, crosscuts the S1 mylonitic fabric and is itself crosscut by northwest-trending biotitic selvedges. Quartz veins are variably parallel to or crosscut pegmatite, and also crosscut the dominant gneissic foliation in the granite. A narrow, 0.5 cm-wide quartz vein with biotitic selvedges parallels the local S1 (north-striking) foliation. It is locally reoriented northwest, suggesting probable reactivation of S1, and is overprinted by S2. At 201220mE 7566510mN, pegmatite parallels a shear zone striking west-southwest that overprints an earlier, locally intense foliation striking northwest. Similarly, at 214407mE 7570367mN, pegmatite striking west-southwest is parallel to S1 and has sheared margins. This pegmatite crosscuts both the west-northwesterly S1 gneissic fabric in the granite and a quartz vein striking northwest parallel to S2, but also swings into a strongly sheared pegmatite which is parallel to S2.

The range of textural variation in the Redhackle Granite is typical of the outcropping granites in MOUNT PEAKE. Although generally gneissic, where more intensely deformed locally, the granite is phyllonitic or mylonitic. Minor quartz-biotite schist, rather than the more typical quartz-muscovite schist or phyllonite, is also interpreted to be deformed granite. Locally, the granite is largely recrystallised and granoblastic, and associated polygonal textures suggest static recrystallisation, or at least that recrystallisation continued after the cessation of any deformation. Recrystallised quartz and microcline show no evidence of deformation in the granoblastic textural variant, eg they lack undulose extinction and subgrain development. A foliation is preserved in this granoblastic granite and is defined by biotite and muscovite. Only one variety of biotite (with green pleochroism) is evident in the granoblastic granite. Biotite growth may have been associated with deformation early in an event that subsequently resulted in predominantly static recrystallisation and granoblastic texture. Zircon growth, interpreted to be associated with this episode of deformation/recrystallisation, suggests a Chewings Orogeny age (1579 ± 7 Ma, Worden et al 2004).

On the northern boundary of NAPPERBY, an easterly-trending foliation (S1) is defined by the orientation of K-feldspar and biotite, and a second north-northwest-trending fabric is defined by oriented biotite, very comparable with the definition of foliations in the Esther Granite. In this area, clots and veins of pegmatite are oriented within a third north-northwest-trending fabric (S2).

The Redhackle Granite is minerallogically and texturally very similar to the Anmatjira Orthogneiss in the Bilba Hills. However, the latter has an igneous crystallisation age of 1795 ± 3 Ma (Worden et al 2006).

Discussion

The Redhackle Granite is mineralogically and texturally very comparable with other feldspar megacrystic, tourmaline-bearing granites and granitic orthogneisses in southwestern MOUNT PEAKE and adjacent areas of NAPPERBY in the Yundurbulu, Anmatjira and Reynolds ranges. Structural characteristics outlined above indicate that the dominant S1 gneissosity in the granite is probably penecontemporaneous with emplacement and is therefore constrained by the 1772 Ma igneous crystallisation age of the granite. This gneissosity in the Redhackle Granite is subparallel to an igneous layering that is only locally apparent (eg at 221959mE 7565225mN). In contrast with the Redhackle Granite, the orthogneisses in the Reynolds and Anmatjira ranges apparently lack any prior layering (Stewart et al 1980a).

The S1 gneissosity is generally east–west. However, in some areas, for example at 224339mE 7565210mN, it strikes northeast and is overprinted by an S2 differentiated layering/
that sheared pegmatite is locally aligned in S3 and crosscuts age of S2 and S3 is not constrained. However, it is noted further along strike in the Giles Range Fault Zone at 225279mE retrogression during the Alice Springs Orogeny.

Quartzite in the Nanga Range area. Thus it is postulated in accord with the coplanarity of phyllonitic zones in the Granite is probably of Alice Springs Orogeny age. This is deformation. Phyllonite development in the Koonoonyeri layers, but are poorly-developed in the quartzofeldspathic layers.

The S1 foliation is attributed to the Yambah Event. The age of S2 and S3 is not constrained. However, it is noted that sheared pegmatite is locally aligned in S1 and crosscuts the S1 foliation in the granite. These relationships may be consistent with S1 to S3 being related to a single progressive deformation. Phyllonite development in the Koonoonyeri Granite is probably of Alice Springs Orogeny age. This is in accord with the coplanarity of phyllonitic zones in the granite and folding in the Neoproterozoic Vaughan Springs Quartzite in the Nanga Range area. Thus it is postulated that phyllonite development in the Redhackle Granite may similarly be a consequence of coaxial deformation and local retrogression during the Alice Springs Orogeny.

Sinistral movement is recognised, associated with S1 at 225279mE 7569032mN, and north-over-south movement further along strike in the Giles Range Fault Zone at 225447mE 7569329mN. At 221000mE 7566000mN, quartz tails on rounded potassium feldspar augen indicate pure shear associated with a northwest-trending gneissosity.

In summary, it is postulated that the 1772 ± 3 Ma Redhackle Granite is syntectonic with respect to the Yambah Event. Its igneous crystallisation age is within error of that of the Napperby Gneiss (1778 ± 8 Ma), as reported by Collins and Williams (1995), which is also interpreted to be syntectonic with respect to the Yambah Event. Collins and Williams (1995) also reported a SHRIMP U-Pb zircon age for the Possum Creek Charnockite in the Anmatjira Range in NAPPERBY of 1774 ± 6 Ma, which they interpreted to be both the igneous crystallisation and essentially simultaneous metamorphic age of this granite.

All of these granites (Redhackle Granite, Napperby Gneiss and Possum Creek Charnockite) have low Th/U zircon overgrowths with ages of ca 1580 Ma, 1587 ± 6 Ma and 1588 ± 5 Ma, respectively (the latter two ages were reported by Collins and Williams 1995). The 1580 Ma overgrowths in the Redhackle Granite are attributed to static recrystallisation during the Chewings Orogeny. Collins and Williams (1995) suggested the Chewings Orogeny ages in the Possum Creek Charnockite and the Napperby Gneiss may result from recrystallisation associated with hydrothermal activity, partial melting and pegmatite generation, as distinct from high-grade metamorphism. The Redhackle Granite was probably finally reactivated in discrete, coaxial Alice Springs Orogeny-aged shear zones.

**Anmatjira Orthogneiss**

The Anmatjira Orthogneiss (Stewart et al 1980b, Figure 15) is named after the Anmatjira Range in northern REYNOLDS RANGE. This grey, coarse-grained, megacrystic, granitic augen gneiss outcrops (Figure 15c) along the entire length of the Anmatjira Range in NAPPERBY (TEA TREE and REYNOLDS RANGE). The texturally appropriate name 'Anmatjira granite' had been used by Offe (1978) for granite outcropping to the northeast of the Yundurbulu Range and in the Bilba Hills in MOUNT PEAKE. However, the Anmatjira Orthogneiss was defined by Stewart et al (1980b), and includes the rocks Offe (1978) had informally called the Anmatjira granite. The names Mount Stafford granite (Collins and Williams 1995) and the northern, and eastern granite (Greenfield et al 1996, 1998) have also been used informally for granite and granitic gneiss along the flanks of Yundurbulu Range in northern REYNOLDS RANGE, and in MOUNT PEAKE. In accordance with the dictates of stratigraphic nomenclature, these rocks are all referred to the Anmatjira Orthogneiss.

SHRIMP U-Pb dating of the Anmatjira Orthogneiss at Mount Stafford by Rubatto et al (2006) yielded zircon and monazite ages of 1805 ± 3 Ma and 1802 ± 3 Ma, respectively, which supersedes an earlier U-Pb SHRIMP zircon age of 1818 ± 15 Ma for granite from the same area by Collins and Williams (1995). These samples were collected from the area called the eastern granite by Greenfield et al (1996). Recent SHRIMP U-Pb zircon geochronological data confirms that the orthogneiss (1798 ± 3 Ma; Worden et al 2008) in REYNOLDS RANGE and the granite (1795 ± 4 Ma) in MOUNT PEAKE are variably deformed phases of the same granite.

Outcropping granite in the Bilba Hills was in part assigned to the Anmatjira granite and in part to unnamed and undifferentiated porphyritic granite (Offe 1978). Ding et al (1998) similarly made a distinction between two granites in the Bilba Hills, namely the Anmatjira granite and the Bilba Hill orthogneiss. In the absence of any outcropping intrusive relationships or compositional differences, it is interpreted here that the distinction is between different textural phases of the same granite, i.e the Anmatjira Orthogneiss. However, Stewart et al (1980a) suggested, on the basis of their alumina saturation index (ASI), that the granitic variant of the Anmatjira Orthogneiss was derived from an igneous source, whereas the gneissic variant had a mixed igneous and sedimentary source.

The Anmatjira Orthogneiss is a classical rapakivi granite/orthogneiss (Figure 15d and 15e) with ovoidal microcline mantled by sodic feldspar. It weathers to a characteristic ‘rotten stone’ at the northern extremity of the Yundurbulu Range. Alkali feldspar (or K-feldspar megacrystals) show exsolution textures, with common string to bead perthite development and subordinate microcline microperthite. Rapakivi feldspars have perthitic alkali feldspar mantled by plagioclase, which may show combined albite and pericline
twinning. Plagioclase tends to be euhedral and includes phenocrysts with irregular, intensely altered (sericitised and epidotised) cores. These indicate disequilibrium. Coarse-grained quartz typically shows undulose extinction and is commonly rutile-filled; finer-grained aggregates of quartz have sutured to polygonal mutual boundaries. Biotite is red-brown, and is commonly associated with an opaque oxide mineral, probably magnetite. Scattered, more coarsely grained epidote is locally present, as is chlorite. Collins and Williams (1995) reported rare euhedral cordierite in the Anmatjira Orthogneiss (Mount Stafford granite), pseudomorphed by muscovite and green biotite (pinite).

In MOUNT PEAKE, the Anmatjira Orthogneiss intrudes the Mount Stafford Member of the Lander Rock Formation. Greenfield et al. (1996, 1998) have described leucosome derived from migmatitisation of the Mount Stafford Member intermingled with Anmatjira Orthogneiss to form a hybrid diatexite near 260129mE 7565170mN in MOUNT PEAKE and in the immediately adjacent area of NAPPERBY. The granite is intruded by dolerite, now metamorphosed to amphibolite. In the northwestern Yundurulu Range, the Anmatjira Orthogneiss crosscuts the metamorphic isograds in the Mount Stafford Member. Foliations associated with each of three phases of folding are delineated by metamorphic mineral assemblages in the metasediments, leading Vernon et al. (1990) to conclude that all three phases of folding were contemporaneous with prograde metamorphism. Thus, the Anmatjira Orthogneiss puts a lower age constraint on folding and metamorphism (Stafford Event) in the Mount Stafford Member, whereas the development of diatexite further suggests that granite emplacement was contemporaneous with the peak of metamorphism. Stewart et al. (1980a) had previously similarly concluded that the Anmatjira Orthogneiss was syntectonic and was emplaced during deformation and high-grade metamorphism of the surrounding country rocks.

Figure 15. Anmatjira Orthogneiss. (a–b) Probable cocardes in granitic phase (Bilba Hills, 248516mE 7572388mN). (c) General view of granitic phase looking approximately west, with Mount Stafford in background (260481mE 7567545mN). (d) Rapakivi texture (1) in granitic phase (towards southeastern end of Yundurulu Range, 7567047mE 7566877mN). (e) Pyroclitic texture. Rounded K-feldspar megacrysts are surrounded by recessive mantles of biotite indicating in situ growth of K-feldspar (phenocrysts). Some K-feldspar megacrysts have internal zones of biotite, indicating incremental growth of feldspar phenocrysts (1). Although this outcrop is part of more granitic phase of Anmatjira Orthogneiss, a fabric is apparent, striking ca 025° parallel to pen. Also, note broken feldspar porphyroblasts with fractures infilled by crystallised melt (2), indicating syntectonic emplacement and crystallisation of orthogneiss (261528mE 7567002mN).
Hand and Buick (2001) reported that granitic orthogneisses on the high metamorphic-grade side of the migmatite-in isograd in the central and southeastern Anmatjira Range, including the Anmatjira Orthogneiss, have Chewings Orogeny-aged metamorphic zircon growth. These authors were inclined to the view that the Anmatjira Orthogneiss may be of Yambah Event age, and therefore younger than the granitic phase of the Anmatjira Orthogneiss along the northeastern flank of the Yundurbulu Range. However, it is herein confirmed that the gneissic phase of the Anmatjira Orthogneiss is contemporaneous with the granitic phase and is syn to late tectonic with respect to the ca 1805–1790 Ma Stafford Event.

It is noted above that the Anmatjira Orthogneiss is locally less deformed and, in these areas, has been referred to as the granitic phase of the Anmatjira Orthogneiss. The granitic phase has a Stafford Event crystallisation age comparable with that of the orthogneissic phase. A number of foliations, including extensional shear zones, have been recognised locally in the granite during the mapping reported here. These shear zones are probably of Mesoproterozoic age, given the Rb-Sr ages of ca 535 Ma reported by Buick et al (1999) from sheared granite within the Anmatjira Orthogneiss in the Yundurbulu Range. However, Vernon et al (1990) reported that mylonitic shear zones in the granitic phase of the Anmatjira Orthogneiss to the north of Mount Stafford are of mid-Palaeozoic age, according to Collins and Teyssier (1989).

In NAPPERBY, the granite/orthogneiss intrudes the Mount Stafford Member, undivided Lander Rock Formation, Weldon Metamorphics and probably also the Possum Creek Charnockite. It is intruded by the Aloolya Gneiss in the southwestern Anmatjira Range.

Currently available geochronological data (see Hand and Buick 2001) indicate that evidence for a Chewings Orogeny age overprint on gneisses and metasedimentary rocks is dependent on metamorphic grade which increases to the southeast along the Anmatjira and Yundurbulu ranges. Metamorphic grade presumably increases again further to the northwest in GILES, where the Redhackle Granite has broadly Chewings Orogeny-aged metamorphic overgrowths on ca 1772 Ma igneous zircons.

Late granite

‘Late’ granite is an informal term used primarily to distinguish granites with igneous crystallisation ages that postdate the ca 1770 Ma Yambah Event from ‘early’ ca 1820–1770 Ma granites (ie granites associated with the Stafford and/or Yambah events). The late granites form a much less coherent group, and include granites attributable to both the ca 1740–1690 Ma Strangways Event (eg ca 1730 Ma Windajong Granite), and possibly also the ca 1640–1630 Ma Liebig Orogeny (eg unnamed granite Eg 5 in the northern Ennugan Mountains).

Windajong Granite

The Windajong Granite is named after Mount Windajong (Figure 16) in northern WILLOWRA, where it is exposed in a few scattered outcrops over an area of about 40 km². The association of some of the outcrops with a subcircular, non-magnetic gravity low in the geophysical data indicates that the granite probably extends over an area of about 160 km² and into the very southermost margin of LANDER RIVER. A few scattered granite outcrops to the east of Mount Windajong are interpreted to be related to the Windajong Granite, although these are not encompassed by the gravity low.

The Windajong Granite is an equigranular two-mica granite. K-feldspar morphologies include elongate, inequidimensional crystals and some with simple twinning. Perthitic exsolution textures in feldspar include those indicative of ordered maximum microcline, and string perthite is also common. Plagioclase is proportionally relatively minor and is more intensely altered and locally sericitised than the K-feldspar. The plagioclase is quite sodic and may show weak oscillatory zoning. A more calcic plagioclase occurs in cores that are overgrown by microcline. Biotite is generally pleochroic from pale straw-yellow to red-brown. A second variety of biotite is pleochroic from pale yellow to green and may show anomalous birefringence. It forms small grains, is sometimes a marginal phase of the red biotite and is associated with opaque minerals. It is inferred that

Figure 16. Windajong Granite at Mount Windajong. Photograph by Alison Dean (formerly NTGS), 292561mE 7666834mN).
the green biotite is iron-rich, whereas the red biotite is both iron- and titanium-bearing. The red biotite is characterised by abundant pleochroic halos, whereas the green biotite is not. This probably reflects the different timing of their growth. Muscovite forms small elongate flakes and may overgrow, but is typically intimately inter-associated with biotite. Muscovite also forms large plates, some of which appear to have completely replaced plagioclase as shown by relict simple and polysynthetic twinning. Quartz is often rutileated. Probable monazite is an accessory mineral and there is apparently no apatite.

In the field, the granite is typically massive although weak foliations are recognisable. In thin section, quartz is dynamically recrystallised and is intimately intergrown with elongate K-feldspar. Plagioclase shows deformed, bent twin lamellae and K-feldspar has deformation lamellae. Biotite and muscovite are intimately intergrown in probable pre-full-crystallisation fabrics in two orientations.

The Windajong Granite has an igneous crystallisation age of 1730 ± 3 Ma (Cross et al 2005). It is interpreted to be associated with the Devils Suite granites in the Davenport Province. These are similar two-mica granites forming discrete subcircular, non-magnetic gravity lows. Dated members of the Devils Suite are apparently a little younger than the Windajong Granite. The Devils Marble Granite has a crystallisation age of 1711 ± 11 Ma, and the Elkedra Granite 1720 ± 6 Ma (Geoscience Australia OZCHRON database). The Elkedra Granite has inherited xenocrysts with ages of ca 2260, 1820 and 1785 Ma. The Kaidwalla granite (informal name) in the southern Davenport Province has an igneous crystallisation age of 1707 ± 4 Ma (Maidment et al 2006) and is also considered a member of this suite.

**Unnamed granite (in northern Ennugan Mountains)** $Eg_5$

Granite that outcrops in the northern Ennugan Mountains and extends south into NAPPERBY has been designated $Eg_5$ on the mapface. It is a grey biotite granite and, where it has a hypidiomorphic granular texture, it is very homogeneous and massive, well jointed, and bouldery to castellated in outcrop (Figures 17a, b). A second phase of the granite is porphyritic, with elongated K-feldspar megacrysts. These feldspar megacrysts locally define a strong preferred orientation. This more or less trachytic, northwest-trending, pre-full-crystallisation fabric is strongly overprinted by an east-trending mylonitic fabric at 285025mE and 7568917mN. Rapakivi textures (eg 285446mE 7568787mN) and biotite mantles on feldspar are rare.

Mylonitic and gneissic fabrics are well developed in localised zones in the granite, and a rodding lineation is apparently defined by the intersection of mylonitic and gneissic fabrics at, for example, 0285010mE 7568788mN (Figure 17c). Rare tails on feldspar megacrysts suggest north-over-south movement on the east-trending mylonitic zone at this locality. The deformed granite typically has a tabular or ‘bedded’ outcrop morphology, in contrast with the boudery outcrop characteristics of undeformed granite. Biotite granite apparently grades into a predominantly quartzose rock in an east-trending mylonitic shear zone at 285446mE and 7568787mN.

**Figure 17.** Unnamed granite in northern Ennugan Mountains. (a) View looking south from approximately 287580mE 7568095mN. (b) Outcrop from same locality, showing blocky as opposed to bouldery character or granite. (c) Steeply dipping (ca 80º south) gneissic/mylonitic easterly-striking shear zone (285139mE 7568958mN). Pen parallels plunge of rodding lineation apparently at intersection of gneissic and mylonitic fabrics. North-over-south sense of shear is poorly preserved in - mylonitic fabric and further obscured by later, easterly-striking, steeply (ca 75º) north-northwest dipping foliation that overprints (crenulates) mylonitic fabric.
A more or less aplitic phase has an irregular intrusive contact with the granite and is subparallel to, but unaffected by a northwest-trending mylonitic fabric in the granite at 285117mE 7568255mN. A later east-trending fabric, defined by rodded quartz and biotite, crosscuts the mylonite, and both the granite and aplite. A grey quartz-feldspar porphyry is seen to crosscut the granite at several localities, for example, at 287938mE 7568120mN. K-feldspar crystals in this porphyry are typically elongated and slightly to markedly rounded, and some show classical rapakivi texture. Rare feldspar phenocrysts have been completely biotitised. An early generation of biotite is seen as square-shaped inclusions in some K-feldspar megacrysts. Quartz is clear and glassy and there is none of the blue opalescent quartz that characterises many of the granites in the area. A rock texturally transitional between porphyry and granite occurs at 287425mE 7566517mN. This rock is undeformed and could represent a late/marginal phase of the granite.

Haematitisation of feldspar and biotite imparts a red colour to the more deformed areas of the granite. Some feldspar crystals have markedly square cross-sections and have cream-white, probable albite cores mantled by clear grey K-feldspar; other feldspar crystals are exclusively albite.

The equigranular to hypidiomorphic homogeneous phase of the granite is magnetic, but with a lower magnetic susceptibility than the porphyritic phase. The magnetic character of the unnamed granite in the northern Ennugan Mountains is in marked contrast with the adjacent/contiguous granite in NAPPERBY. The latter granite has been informally referred to as the Ennugan Mountain granite by Smith (2000, 2001) who determined it had a 1622 ± 7 Ma igneous crystallisation age. The Ennugan Mountain granite is U, Th, Nb and Ta enriched. Traces of uranium mineralisation, which is associated with xenotime in biotite-rich shear zones, were reported by Kojan (1980). The Ennugan Mountains granite has 10–15% biotite, 3–5% hornblende and about 0.5% allanite (KJ Hussey, Arafura Resources Ltd., pers comm 2005), in contrast with the unnamed granite described above, which lacks hornblende and allanite. The latter granite is provisionally interpreted to represent two additional discrete textural and mineralogical phases of the Ennugan Mountains granite. Tin mineralisation in the Ennugan Mountains granite is probably associated with a greisenous roof zone and alluvials shed from it; the greisen veins carry chrysoberyl, topaz and fluorite (Kojan 1980). Kojan (1983) reported that the Ennugan Mountains granite is largely undeformed, in contrast with the granite in the vicinity of the Anzac Dam uranium prospect (herein called the Koonoonyeri Granite), indicating that the former postdates, and the latter predates the major regional deformation. High U and Th contents (up to 320 and 740 ppm, respectively) were reported by Kojan (1983) from rock chips in the Ennugan Mountains granite, and this author also considered that secondary carnitite at the Anzac Dam U prospect was derived from a biotite-rich shear zone.

Relationships between discrete mylonitised and gneissic fabrics in the unnamed granite and aplite and porphyritic phases described above suggest that the granite is pre- to syntectonic with respect to the Chewings Orogeny and may be crosscut by mid-Palaeozoic shear zones.

**Poorly or non-outcropping unnamed granites**

All the unnamed granites described below except P Lg are interpreted to be early granites, ie they predate or are contemporaneous with the ca 1770 Ma Yambah Event.

P Lg

P Lg is an equigranular (to seriate porphyritic) biotite granite/granodiorite with equant to tabular K-feldspar megacrysts. It constitutes a number of small weathered outcrops, extending over about 18 km² from 296250mE 7634000mN to 290250mE 7651250mN in MOUNT PEAKE. The granite also outcrops in LANDER RIVER over an area of about 10 km² in the vicinity of 249000mE 7681250mN, where it intrudes the Lander Rock Formation, and at 273000mE 7677500mN. There are further minor outcrops of this granite in LANDER RIVER at 277500mE 7689000mN, 276750mE 7688500mN, 280250mE 7677500mN, 280500mE 7679500mN, 281250mE 7679250mN and 281250mE 767850mN. Granodiorite intruding gabbroic rocks in the vicinity of Waldhills Hill (239000mE 7710500mN) has an igneous crystallisation age of 1814 ± 6 Ma. This places a lower age constraint on these mafic intrusive rocks.

Granite P Lg is interpreted from geophysical data to extend under cover over an area of about 3000 km² in northern MOUNT PEAKE and southern LANDER RIVER. It is non-magnetic with a moderate gravity response. A further approximately 500–600 km² in MOUNT PEAKE and a similar area in LANDER RIVER are interpreted to be a more magnetic variant of this granite. This more magnetic granite is not exposed. The change in magnetic character is probably a reflection of the variable magnetic character of the Lander Rock Formation, into which the granite has intruded, and which is preserved as pendants or screens within the granite. The non-magnetic variant of the granite is designated P Lg and the magnetic variant P Lgm.

A westerly-striking shear zone approximately 10 km west-northwest of Conical Hill and exposed, for example, at 298197mE 7632524mN, is associated with dark grey-green mylonitised biotite granite, in which K-feldspar megacrysts have survived as variably equant and slightly rounded, to markedly elongated and incipiently boudinaged megacrysts (Figure 18). The elongated K-feldspar megacrysts are up to 12 cm long and 2 cm wide. More equant megacrysts show only slight dextral rotation in the horizontal plane. The mylonitic fabric is S, and dips 80° to the south. The grey-green colour of the mylonitised granite matrix may reflect saussuritisation, whereas the K-feldspar megacrysts are pink-red.

North of this shear zone, as noted above, there are eight spatially separated small outcrops of generally deeply weathered (lateritised) granite, scattered over 18 km² in a north-northwesterly direction in MOUNT PEAKE. At 0294087mE 7633852mN, this granite comprises more or less equigranular biotite granite with minor, scattered muscovite apparently forming a fine film on the surface of K-feldspar grains. Muscovite is similarly developed on the surface of K-feldspar in local pegmatitic segregations. Where less

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1 Formerly NTGS.
Conically hill LANDER RIVER has an igneous crystallisation age of 1814 ± 6 Ma indicating that it is older than the 1799 ± 3 Ma Anmatjira Orthogneiss. However, granite mapped as gneissic, and is interpreted to be a probable time-equivalent mylonitised shear zone (29897mE 7632524mN).

This granite is tourmaline-bearing, is locally foliated or gneissic, and is interpreted to be a probable time-equivalent of the Anmatjira Orthogneiss. However, granite mapped as Pg, in LANDER RIVER has an igneous crystallisation age of about 6 cm. The granite is locally much finer grained, darker coloured and mylonitic. The mylonitic fabric dips steeply to the south and is interpreted to be S2. It is overprinted by two later foliations dipping south-southeast and northwest. These scattered granite outcrops are mapped as Pg1.

Figure 18. Residual 'enclave' of less deformed (Pg1) granite in mylonitised shear zone (298197mE 7632524mN).

\[ P_{g2m} \]

\[ P_{g2m} \] is a poorly outcropping granite that is probably contiguous and penecontemporaneous with the Esther Granite. Like the Esther Granite, this generally poorly outcropping granite is characterised by discrete, markedly magnetic zones in the geophysical data. It is interpreted from geophysical data to extend over a substantial area to the north and northwest of the Walabanba Hills, to near the Lander River (247500mE 7646000mN), about 5 km south of Willowra. Spatially discrete, but geophysically analogous granite is interpreted over an area of about 600 km² in central CONICAL HILL, where it outcrops fairly well (Figure 19a).

\[ P_{g2m} \] and over about 100 km² in the vicinity of the Mulyugaridji and Wini hills in central-western STUDHOLME. However, there is no outcrop in these latter two areas. A non-magnetic granite, further characterised by a low-gravity response, outcrops in an area immediately north of Conical Hill (302100mE 7623500mN) and east and northeast of Mount Rennie (293850mE 7626200mN). It is interpreted to be a discrete (late) phase of the unnamed granite \[ P_{g2m} \] and is designated \[ P_{g2} \]. Comparable unnamed granite \[ P_{g2} \] outcrops poorly over an area of 375 km² in eastern MOUNT PEAKE, and over 800 km² in northeastern MOUNT PEAKE and southeastern LANDER RIVER, in the vicinity of the Jarrah Jarrah Range. \[ P_{g2m} \] that outcrops immediately to the east of Conical Hill (302100mE 7623500mN) is a biotite-granite. Texturally, this granite is characterised by K-feldspar megacrysts (Figures 19a, b), including discrete, markedly tabular, elongated megacrysts (locally showing syenussis or glomeroporphyritic character, eg at 305515mE 7624517mN), and more equant megacrysts comparable with phases \[ P_{g1} \] and \[ P_{g2} \] of the Esther Granite (described above). This unnamed magnetic granite is (in common with the Esther Granite) syntectonic with submagmatic fabric(s) defined by the alignment of elongate K-feldspar megacrysts and biotite.

Local compositional variants of the granite in this area include a dark, biotite-rich granite with distinctive pink K-feldspar megacrysts, associated with a correspondingly leucocratic (biotite-poor) compositional phase. The pink K-feldspar granite is saussuritised, and is comparable with a distinctive pink and green phase of the Esther Granite outcropping very locally to the west of Mount Esther in southeastern ANNINGIE. Outcropping \[ P_{g2m} \] in the vicinity of 313821mE 7632516mN has a low SiO₂ content of ca 62 wt%.

A discrete textural variant of the unnamed granite is a coarse, to very coarse, more equigranular (to seriate porphyritic), muscovite-bearing biotite granite. This is comparable with the Esther Granite outcropping in the vicinity of Amesbury Bore (314468mE 7596937mN). This granite is fairly massive, but does have weakly defined fabrics, again consistent with syn- to late-tectonic emplacement.

The depth of emplacement of the unnamed granite \[ P_{g2m} \] is epizonal (to mesozonal?); contacts with the Lander Rock Formation are exposed locally. An alignment of feldspar megacrysts immediately adjacent to some of these contacts probably reflects local magmatic flow (Figure 19e). Variably biotitised schlieren and xenoliths of the Lander Rock Formation are exposed near contact zones of the granite (eg Figures 19c–e). The prevalence of xenoliths near, for example, 304100mE 7623160mN suggests emplacement, at least in part, by stoping.

\[ P_{g2m} \] outcrops in an area immediately north of Conical Hill (302100mE 7623500mN) and east and northeast of Mount Rennie (293850mE 7626200mN), and is a K-feldspar megacrystic granite. It is biotite bearing but is, at least locally, partially greisenised, with biotite content subordinate to that of muscovite. The granite is also tourmaline bearing. Spherical clots of essentially pure tourmaline rock, with individual constituent grains up to about 4 cm in diameter comprise mainly black tourmaline (probably schorl), although locally, a green-grey colour suggests the occurrence of significant
ferrous iron, and possibly Li-bearing tourmaline in the schorl-elbaite series. There are also patches, up to 10 cm in diameter, showing incipient tourmalinisation. However, these patches are texturally dissimilar to those occurring in classical luxullianite, in which clusters acicular tourmaline crystals are radially arranged and enclosed by phenocrysts of orthoclase and quartz in a matrix of quartz, tourmaline, alkali feldspar (see Hatch et al 1981). Luxullianite in the Hercynian granites of southwest England is a consequence of the progressive pneumatolytic replacement of firstly biotite and subsequently of (brick-red) feldspar by tourmaline. Early-formed brownish tourmaline forms centrally located corroded relics which are mantled by acicular, radiating black tourmaline; red-feldspar relics are preserved, but are partially replaced by secondary quartz (Hatch et al 1981). Even where pneumatolysis has progressed to the stage of producing tourmaline-quartz rock, feldspar crystal outlines are preserved. The earlier- and later-formed tourmalines that replace firstly biotite and then feldspar are described as yellowish and blue or blue-green, respectively, by Deer et al (1970). These colours are still consistent with the pneumatolytic tourmalines being compositionally schorl and schorl-elbaite. The tourmaline clots in the unnamed granite Pg2 are analogous with those described above in the Koonoonyeri and Redhackle granites, and the Anmatjira Orthogneiss and are similarly interpreted to be cocardes.

Figure 19. (a–b) ‘Classically’-textured biotite granite (Pg2), with rare, scattered K-feldspar phenocrysts (photographs by Alison Dean, formerly NTGS, 303959mE 7625533mN). (c–d) Xenoliths of Lander Rock Formation in porphyritic biotite granite (Pge; near Conical Hill at 304162mE 7423234mN and 303956mE 7825530mN, respectively. Figure 19c photograph by Alison Dean, formerly NTGS. (e) Alignment of K-feldspars proximal to screen of Lander Rock Formation in roof zone of granite Pg2 may locally reflect magmatic flow, as distinct from pre-full crystallisation, submagmatic, tectonic foliation (304101mE 7623161mN).
Although texturally distinct cocardes are, in common with luxullianite, interpreted to be metasomatic in origin (Le Fort 1991).

Also present in Pg2 are: (a) irregular aplite dykes up to about 30 cm wide, with pegmatitic margins crosscutting coarse-grained granite, (b) equigranular granite; similar aplite dykes with pegmatitic margins crosscutting tourmalinised leucogranite; and (c) pegmatite veins with tourmaline growth perpendicular to vein margins (ie originally into open space?), adjacent to the granitic wall-rock. The margins of these latter pegmatite veins are also more feldspathic and their centres are predominantly quartz-tourmaline rock. Surmicaceous enclaves to 4–5 cm diameter comprise quartz-biotite-muscovite rock.

Pg3 in the vicinity of Conical Hill and Mount Peake tends to be weathered, in contrast with the sparsely outcropping but fresh Pg2m, and has weakly defined north-northeast- and south-southeast-trending fabrics, defined predominantly by oriented tabular feldspar. The latter fabric is well developed in the central area of the granite pluton. Local north–south-trending shear zones are also present in this granite.

An area of about 375 km² in eastern MOUNT PEAKE is also designated Pg3 on the interpreted geology map. Outcrop in this area is poor, largely scree covered and restricted to the flanks of ridges defined by the Amesbury Quartzite, eg, in the vicinity of, 335500mE 7605000mN and 327000mE 7605700mN. Granite, outcropping in gullies at 335200mE 7600200mN. Granite, outcropping at 335200mE 7605869mN, is a two-mica equigranular granite containing two varieties of feldspar. One is a pink K-feldspar and the second is typically kaolinised. The latter may constitute a second generation of K-feldspar or could be relict plagioclase. The granite has two well developed foliations and a third weak one, all of which are defined by mineral alignment.

Two small outcrops of granite on LANDER RIVER, at 315124mE 7682750mN and 314500mE 7681000mN in the Jarrah Jarrah Range, have been designated Pg3 and are interpreted to be part of a granite body extending over about 800 km² in northeastern MOUNT PEAKE and southeastern LANDER RIVER.

Unnamed granite Pg4

Unnamed granite Pg4 does not outcrop. It is interpreted to intrude rocks of the Ooradidgee and lowermost Hatches Creek groups and to be a member of the ca 1820–1800 Ma Treasure Suite of the Tennant Range. From the geophysical data, it appears to intrude the Newlands Volcanics and Unimbra Sandstone, so is considered to be towards the younger end of this age range, and possibly analogous to the 1809 ± 5 Ma Ooralingie Granite and 1803 ± 6 Ma Bean Tree Granite in BARROW CREEK.

Pg5

Pg5 is essentially non-outcropping. One small outcrop at 239375mE 7612750mN is interpreted on geophysical evidence to be Pg5 although this isolated exposure near the Bau Range was not visited in the current mapping program. Pg5 is interpreted to extend over an area of about 550–600m², from near Bau Range in the central-west of MOUNT PEAKE in a northwesterly direction towards the Mulyugaridji Hills. The granite is interpreted to be a more magnetic equivalent of the Redhackle Granite, and on the basis of its magnetic character probably includes abundant surmicaceous enclaves, and xenoliths and pendants of Lander Rock Formation country rocks.

Pg6

Pg6 is used for poorly or non-outcropping (late) granite in both MOUNT PEAKE and LANDER RIVER. This granite forms discrete, subcircular gravity lows and is non-magnetic. The plutons are considered to be equivalent to the two-mica, equigranular Windajong Granite. Granite outcropping in the Wanabanda Hills is interpreted on geophysical evidence to be one of these 'late' granites and is designated Pg6, although this area could not be visited during the mapping reported here. Note that Pg5 is not mapped or interpreted in LANDER RIVER; however, Pg6 is used to refer to the same granite on both MOUNT PEAKE and LANDER RIVER to maintain consistency between the maps.

The unnamed granites described in this section typically extend over large areas or occupy discrete, spatially separate areas. A common designation on the map (eg Pg2m) is not intended to imply these are necessarily single granite bodies. It is probable that they comprise a number of penecontemporaneous and broadly consanguineous plutons.

Mafic intrusive rocks

Poorly outcropping mafic intrusive rocks are scattered throughout MOUNT PEAKE and southern LANDER RIVER, and include variably metamorphosed gabбро, olivine gabbro, hornblende gabbro and dolerite, forming both stratiform and sub-circular intrusive bodies.

Hoatson et al (2005) investigated the dolerites intruding the Mount Stafford Member in NAPPERBY and extreme south-central MOUNT PEAKE as part of a regional study of mafic and ultramafic intrusions of the Arunta Region. These 'dolerites' also include doleritic gabbro, gabbro and gabbronorite and are interpreted to be sills and dykes that predate folding and metamorphism (in the ca 1805–1790 Ma Stafford Event); Hoatson and Stewart 2001). Although granulite-facies mineral assemblages have been described in the surrounding Mount Stafford Member, the mafic rocks are only weakly recrystallised and preserve primary igneous textures, including subophitic and intergranular textures (Hoatson and Stewart 2001).

Mafic intrusive rocks at Waldrons Hill (in LANDER RIVER) are hornblende gabbro with primary igneous textures well preserved. Southwest of Waldrons Hill at 257879mE 7704701mN, olivine gabbro has a well preserved subophitic interstitial texture. Olivine in this rock is fresh and shows local reaction to clinopyroxene-magnetite symplectite, and there is minor development of hornblende rims on primary ferromagnesian minerals (both these reactions are probably metamorphic).

A number of the other outcropping mafic (intrusive) rocks preserve igneous textures. Subophitic-textured dolerites are folded within the Walabanba Member in the Walabanba Hills in MOUNT PEAKE (eg dolerite sills at 304000mE 7600250mN). Although poorly outcropping, the mafic units are interpreted from the geophysical data to be a widespread stratiform component of the Lander...
Rock Formation in MOUNT PEAKE and LANDER RIVER. It is inferred that relationships are similar to those seen in outcrop in the Yandrubulu Range and Walabanba Hills, ie the mafic rocks were emplaced prior to folding and metamorphism of the Lander Rock Formation in the ca 1805–1790 Ma Stafford Event. However, geophysical interpretation indicates that highly magnetic stratiform units occur at various stratigraphic levels within the Lander Rock Formation and it is possible they represent a number of discrete episodes of mafic magmatism, postdating Lander Rock Formation (ca 1860 Ma max) and prior to the Stafford Event (ca 1805–1790 Ma). Claoué-Long and Hoatson (2005) have interpreted the mafic rocks in the Yandrubulu Range in NAPPERBY and MOUNT PEAKE to have been part of a regionally widespread mafic event immediately prior to, or during the Stafford Event. For example, Claoué-Long and Hoatson (2005) reported magmatic crystallisation ages of 1811 ± 3 Ma and 1803 ± 5 Ma for metagabbros of the Enbra Granulite (ALICE SPRINGS) and Mount Hay Granulite (HERMANNsburg), respectively, and 1805 ± 4 Ma for the Johannsen Metagabbro (ALICE SPRINGS). Dolerite intruding Ooradidgee Group rocks in the Kurinelli area of the Tennant Region have an igneous crystallisation age of 1811 ± 5 Ma (Maidment et al 2006) and it is possible that the Kudinga Basalt is contemporaneous with these intrusive dolerites and gabbros (Claoué-Long et al 2008b). However, airborne magnetic data suggests that the mafic rocks in the Kurinelli area may have been folded prior to deposition of the Hatches Creek Group or are, in common with Ooradidge Group rocks, folded disharmonically with respect to the overlying Hatches Creek Group.

Geochemical data were presented for the dolerites intruding the Mount Stafford Member by Hoatson et al (2005). These authors concluded that, despite widespread crustal contamination of the tholeiitic mafic rocks of the Stafford Event, these mafic rocks are probably consistent with subduction-related or back-arc tectonic settings. However, the contemporaneity of these mafic rocks and rapakivi-association granitic magmatism during the Stafford Event is considered to be more consistent with a generally extensional continental (margin) context.

Metamorphism of the mafic intrusive rocks in LANDER RIVER and MOUNT PEAKE is described under Structure and metamorphism. However, it is noted here that the more typically amphibolitic lithologies may represent metamorphosed volcanic, as distinct from stratiform intrusive rocks. Hoatson and Stewart (2001) interpreted the absence of chilled margins around mafic intrusive rocks in the Mount Stafford Member to indicate that they were intruded essentially contemporaneously with metamorphism, which Vernon et al (1990) concluded peaked immediately prior to the emplacement of the (1795 ± 4 Ma) granitic phase of the Anmatjira Orthogneiss. Upper amphibolite-facies mineral assemblages in Lander Rock Formation metasedimentary rocks proximal to some mafic intrusive rocks in LANDER RIVER and MOUNT PEAKE suggest that these mafic rocks may have been a local source of additional heat during regional prograde metamorphism. This suggests that these mafic rocks were emplaced contemporaneously with regional metamorphism of the country rocks.

Geochemistry and petrogenesis of early granite in MOUNT PEAKE and LANDER RIVER

Geochemical data for 19 representative samples of granite from MOUNT PEAKE and a further 6 samples from LANDER RIVER are presented in Table 3. Prior to discussing the petrogenetic implications of the geochemistry of these granites, a number of mineralogical observations relevant to granite petrogenesis in MOUNT PEAKE and LANDER RIVER need to be considered:

1. Corroded cores in plagioclase are probably restitic and are consistent with low-P melting of hornblende and/or biotite bearing sources, eg tonalite (cf Patiño Douce 1997). However, Pitcher (1993) recognised that calcic cores in plagioclase may also result from the mixing of two compositionally discrete magmas.

2. Opalescent blue quartz is restitic/xenocrystic and reflects a granulite-facies source component. Chappell et al (1987) suggested that restitic quartz is probably common in granites, and that it is universal in S-type granites. Dempster et al (1991) suggested derivation from Ketilidian Orogen granulites as a possible source of blue quartz in the rapakivi granites of south Greenland.

3. Inherited zircons are consistent with (at least in part) a crustal protolith for LANDER RIVER and MOUNT PEAKE granites.

4. Potassium-rich feldspar megacrysts are (at least largely) phenocrysts. This is consistent with the inclusion of biotite and plagioclase crystals in growth zones within the megacrysts (see Pitcher 1993), and with biotite mantles around the megacrysts (cf Mehnert 1971). Included biotite (and plagioclase) could represent restitic material (cf Augustithis 1973), although Pitcher (1993) suggested that restitic biotite would probably form small clots. It is therefore most likely that these biotite and plagioclase inclusions in feldspar megacrysts reflect changing phase equilibria during crystallisation.

5. Pitcher (1993) considered that oscillatory zoned plagioclase probably reflects localised conditions, whereas truncated zoning reflects processes affecting the magma as a whole, most probably recharge and magma mixing. This author similarly favoured a process involving the mixing of magmas undergoing decompression as the most likely cause of rapakivi texture.

6. The probable mesozonal level of emplacement of the MOUNT PEAKE granites is consistent with relatively dry melts, which is similarly consistent with the apparent late crystallisation of biotite. Thus, in the granites in southwestern MOUNT PEAKE, biotite is commonly seen to mantle K-feldspar megacrysts, the latter often being rounded (pyterlitic texture), suggesting prior corrosion that reflects changed phase equilibria.

7. A number of textural characteristics of these granites are consistent with late-stage metamatism, possibly enhanced by deformation. These include microcrinatisations of feldspar megacrysts, and myrmekite development at plagioclase/K-feldspar grain contacts. Late-stage fluid saturation of the magma is seen in the development of pegmatite like that associated with the Esther Granite in the Walabanba Hills.
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Table 3. Major and minor oxide contents for granites from MOUNT PEAKE and LANDER RIVER. Samples with numbers prefixed by 7211 or 7411 are from Stewart et al (1980a). All other samples were analysed by Amdel Laboratories with the exception of MP02ND108 which was analysed at Geoscience Australia. Full data including trace elements are presented in Appendix 2.
8. Coarse, upward-tapering and vertically oriented feldspar crystals to ca 35 cm are seen in granite in LANDER RIVER at 279488mE 7676973mN. The granite is in contact with the Lander Rock Formation, and these crystals are interpreted to be growing downwards from the roof zone of the granite. In this outcrop (and also in outcrops in MOUNT PEAKE), aplite shows rhythmic layering. Rhythmic layering of this type is common in both F- and B-bearing aplite systems; examples include the topaz-bearing Gibson Gully aplites in North Queensland and tourmaline-bearing aplites of the Calamity Peak pluton in South Dakota (USA), respectively. In the latter example, Rockhold et al (1987) have described layering that reflects the relative proportions of light- (i.e., feldspar and quartz) to dark-coloured (i.e., tourmaline, and subordinate biotite and garnet) minerals. These authors attributed the repetitive layering to: (1) a progressive build-up in B and ferromagnesian mineral components in the melt during the crystallisation of quartz and feldspar; leading to (2) tourmaline crystallisation with both the removal of B from the melt and decreased solubility of water in the melt; resulting in (3) the generation of a B-rich vapour phase and a correspondingly B-depleted melt. Radiating tourmaline suns are developed in granite at 238552mE 7710886mN.

The granites are potassic (Figure 20), a characteristic which is consistent with their K-feldspar megacrystic modal mineralogy, and with internal differentiation of the continental crust. A plot of molar proportions of CaO, Na₂O + K₂O, and Al₂O₃ (Figure 13) shows that the granites have peraluminous compositions, which is corroborated by their ASI index.

Fluid-absent or dehydration melting of tonalite containing fluorine-rich biotite produces fluorine-rich granitic melt (with A-type chemistry) and an orthopyroxene-plagioclase-quartz residuum above 6 kbar (Skjerlie and Johnston 1993). More recently, Patiño Douce (1997) reported that, whereas dehydration melting of hornblende- and/or biotite-bearing granitic rocks yields granitic melts with an A-type chemistry at P ≤ 4 kbar and a calcic-plagioclase and orthopyroxene residuum, melting at higher pressures (P ≥ 8 kbar) results in a clinopyroxene-dominated residuum and the A-type chemistry of the melt is largely lost. High-temperature melting of water-poor tonalitic source rocks therefore adequately explains the generation of A-type melts without necessitating either granulite facies, or F-rich source rocks.

Fluorite is absent or rare in MOUNT PEAKE granites. However, accessory fluorite occurs in the Anmatjira Orthogneiss and Koonoonyeri Granite (Offe 1978), and a fluorite-quartz vein crosscuts the Esther Granite southwest of the old Mount Esther Homestead (Offe 1978, Stewart et al 1980a).

Fluorite is a typical late magmatic phase in many anorogenic granites. However, Anderson and Bender (1989) noted that it is usually absent from biotite ± muscovite granites. Tourmaline is widespread in MOUNT PEAKE granites and suggests they were B- rather than F-rich, a feature that may be more consistent with a metasedimentary protolith. Boron-enriched granites are typically siliceous and peraluminous and, at least during the Phanerozoic, are associated with late- to post-tectonic melting in continent–continent collision zones (London et al 2002).

The metamorphic grade of country rocks into which the LANDER RIVER and MOUNT PEAKE granites are emplaced is indicative of mesozonal to epizonal intrusion. The early granites also show many of the characteristics

![Figure 20](image-url). Classification diagram for MOUNT PEAKE granites based on K₂O versus SiO₂ (after Middlemost 1985).
Hughes (1982) attributed to mesozonal granite. These include, for example, subsolvus feldspar mineralogy, forceful emplacement, submagmatic foliations, schistose aureoles (or narrow zones of contact migmatites) and roof pendants.

Granulite-facies rocks of the Mount Stafford Member in southern MOUNT PEAKE are high temperature but low pressure. Anderson and Bender (1989) suggested that one method of estimating pressure and therefore the depth of melting is a comparison between granite compositions and the water-saturated minima in the granite system. The high-level emplacement of MOUNT PEAKE granites is consistent with them being water-undersaturated melts. However, Anderson and Bender (1989) considered that the effect of this on estimations of the pressure of melting are minimised, because granite minimum melt compositions change along a trend that is subparallel to the isobars in the system. Their approach to estimating pressure is illustrated for LANDER RIVER and MOUNT PEAKE granites in Figure 21. The plot suggests that these granites are middle crustal melts, and that the rapakivi granites and orthogneisses of southwestern MOUNT PEAKE reflect shallower crustal melting than those in southeastern and northern MOUNT PEAKE and LANDER RIVER. This implies steeper geothermal gradients in the vicinity of the Anmatjira and Nanga ranges. Fluorine has a significant effect on minimum melt compositions in the granite system, displacing these towards albite in the haplogranitic system according to Pichavant and Manning (1984). These authors further reported that boron and fluorine are similarly effective in fluxing granitic melts, but unlike fluorine, boron does not have a significant effect on minimum melt compositions in the granite system. Consequently, it is considered that pressure estimates based on Figure 21 are reasonable, although Clarke (1992) indicated that the sensitivity of the minimum to 'bulk composition and fluid conditions' significantly impacts on estimating pressure from water-saturated minima. Furthermore, Brown et al. (1992) considered it unlikely that water-deficient granite magmas are minimum melts, and attributed a wide range of alkali feldspar morphologies (very analogous with those described here in the MOUNT PEAKE granites) in the rapakivi granites of south Greenland to cumulate processes. Mixing between mafic and felsic magmas (particularly plausible in the context of the rapakivi association) may also affect granite compositions, with an adverse impact on the above-mentioned pressure estimates.

Normative albite-anorthite-orthoclase (Ab-An-Or) and orthoclase-quartz-albite+anorthite (Or-Q-Ab+An) classificatory plots, presented in Figures 22a and 22b, also distinguish between the Esther, Anmatjira, Koonoonyeri and Windajong granites. Wyborn (1988) pointed out that normative classificatory plots for granitoids can potentially bias biotite-bearing variants to more potassic (ie granitic, sensu stricto) compositions than are reflected in their modes. This is because the potassium content of biotite is represented as orthoclase in the normative plots. Modal analysis of rapakivi and K-feldspar megacrystic granites is difficult (see for example Brown et al 1992). However, modal analyses were undertaken on a small number of granites from MOUNT PEAKE and indicated consistency between normative and modal granitic compositions.

Possible crustal source rocks for the granites in LANDER RIVER and MOUNT PEAKE could include rocks of quartz-dioritic, granodioritic, tonalitic or basaltic compositions, together with admixed metasedimentary rocks. Although tonalites can yield granitic melts, they are generally infertile for substantial melt production. However, when interlayered with pelitic rocks, they are more fertile and melt production from the inherently more fertile pelite is similarly also enhanced (Skjerlie et al. 1993). Dehydration melting of

![Figure 21](A08.187.ai)

**Figure 21.** Normative quartz−albite−orthoclase compositions of MOUNT PEAKE granites compared to H2O-saturated minimum melt compositions summarised by Anderson and Cullers (1978; after Anderson and Bender 1989). Normative compositions normalised to 100% (ie water-free) and projected from H2O NaAlSi3O8-KalSi3O8-SiO2 tetrahedron. Field is for Proterozoic anorogenic plutons from southwestern USA which were studied by Anderson and Bender (1989: figure 9). Isobars designated 2 kbar etc refer to $P_{\text{total}}$ and An/An+Ab ratios are indicated by 0.11, 0.16 etc, with average ratio for MOUNT PEAKE granites being 0.23.
basaltic rocks will only yield granite at small percentages of partial melting with greater proportions of melting producing trondhjemite or tonalite. Basalt alone is not considered a substantial source rock component for granite generation in LANDER RIVER and MOUNT PEAKE. However, it is likely that intercalated biotite-sillimanite-quartz or biotite-quartz-cordierite metapelitic rocks, and basaltic rocks (amphibolite) are a potentially fertile source of peraluminous K-feldspar megacrystic granitic melts in MOUNT PEAKE. Less aluminous metapelite may favour garnet growth and result in slightly HREE-depleted melt compositions. It is similarly plausible that intercalated mafic
rocks could result in a degree of HREE-depletion. In this context, it is noted that the Esther Granite shows slightly HREE-depleted chondrite-normalised patterns (Figure 23), in contrast with the flat HREE patterns of the Anmatjira Orthogneiss. Note also the similarity of the REE patterns for the Anmatjira Orthogneiss and the Koonoonyeri Granite. These data suggest a difference in source rock compositions between the Esther Granite, and the Anmatjira Orthogneiss / Koonoonyeri Granite (ie less aluminous and/or with a greater mafic component in the case of the former).

A supracrustal protolith is the preferred source for LANDER RIVER and MOUNT PEAKE, peraluminous biotite granites. The fertility of this source may be enhanced by intercalated amphibolite. It is plausible that heat could be provided by mafic underplating, and a number of textural characteristics of these granites (eg rapakivi textures, corroded calcic feldspar cores and truncated zoning in plagioclase) are consistent with magma mixing. Magma mixing is a likely scenario in the rapakivi-association granites, where mafic underplating of newly formed continental crust that is undergoing extension is a plausible petrogenetic model.

**STRUCTURE AND METAMORPHISM**

**STRUCTURAL GEOLOGY**

Geophysical data indicate a predominantly northwest-trending fabric in MOUNT PEAKE and southern LANDER RIVER. This fabric is defined by both magnetic and gravity data, and is interpreted to reflect the broad distribution of the Lander Rock Formation succession and granite. This regional fabric is paralleled by northwest-striking faults that can be readily interpreted as extending across the mapsheet. Outcropping geology (eg in the Walabanba Hills) suggests that the regionally pervasive fabric seen in the geophysical data can probably be equated with the axial trend of F₂ (northwest-trending) upright folds in the Lander Rock Formation. Shorter-wavelength F₁ folds are not readily identified in the available airborne magnetic data. However, they can be mapped locally. Although a D₃ crenulation is widespread, F₃ folds are not generally recognisable in outcrop and can only be inferred locally in the magnetic data in southeastern MOUNT PEAKE. Thus, domains of northwest-striking, folded Lander Rock Formation alternate with similarly striking granite-dominated domains. The boundaries between domains are partially obscured by a close inter-association of metasedimentary rocks and granite, consistent with intrusion of the granites into the Lander Rock Formation. On the other hand, the boundaries between these domains are reinforced by a broad coincidence with interpreted northwest-trending faults, which are described in more detail below.

The significance of fabrics in granites

Pitcher (1993) concluded that most granites are associated with tectonism, although this is not necessarily expressed at the level of granite emplacement. Nonetheless, Hughes (1982) pointed out that most mesozonal granites are foliated. The fabrics of particular interest in the notes are those that are associated with melt-present deformation rather than those developed in the absence of melt. The latter may reflect either deformation late in the emplacement history (ie post-full crystallisation) of syntectonic granites, or deformation imposed during some subsequent tectonic event. In the absence of suitable mineralogies that can be used for the direct dating of foliations in the Lander Rock Formation in MOUNT PEAKE and LANDER RIVER, the interpretation

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Figure 23. Chondrite normalised REE plot for MOUNT PEAKE granites; normalising values of Sun and McDonough (1989).
of granites in these mapsheets as syntectonic with respect to deformation in this formation is of particular importance. It is in this context that the nature and interpretation of fabrics in granites is briefly reviewed below.

The porphyritic granites of LANDER RIVER and MOUNT PEAKE have elongated K-feldspar crystals; these phenocrysts commonly define combined platy (ie parallelism of crystal faces) and linear fabrics (ie parallelism of, or cozenal arrangement of crystal long dimensions so as to define a linear foliation; cf Marre (1986)). The preferred orientation of the dominant generation of the mafic mineral biotite typically reinforces the definition of these structures. Tabular to slightly rounded surfaces of some outcropping whalebacks show megamicroclines with their (010) crystal faces preferentially oriented upwards and with the (manebach) twin plane running the length of this crystal face. Some surfaces show rare well-developed herringbone structures developed in localised zones, or more commonly there are multiple (typically three) preferred linear orientations defined by the megacrysts within a given platy structure. Predominantly the same aspect ratios are represented in the elongate K-feldspar megacrysts that define these multiple foliations. However in some outcrops, the feldspars that define the different linear foliations tend to have different aspect ratios. In these cases, they probably reflect the presence of two (or more) planar (ie platy) fabrics. The absence of any preferred orientation associated with the platy structure is rare, although locally, megacrysts define apparent swirling patterns as was previously recognised by Stewart et al (1980a). Marre (1986) interpreted that combined linear and platy fabrics result from deformation, whereas herringbone structures reflect locally arrested deformation during flow. Melt-present deformation results from magmatic or sub-magmatic flow involving displacement of melt and crystal rotation, and in the case of sub-magmatic flow crystal deformation (Blenkisop 2000). Sub-magmatic fabrics, and the pre-full crystallisation of fabrics of Hutton (1998) are synonymous according to Blenkisop (2000). Marre (1986) took the view that ‘flow’ fabrics can be used to investigate the intrusive history of plutons. This view was previously espoused by Balk (1937), when investigating megascopic structures evident in igneous rocks and apparent in the field. Pitcher (1993) considered that foliations in granite generally reflect a history of incremental strain rather than free flow, and suggested that it is incumbent on those who use such fabrics to unravel intrusive history to demonstrate that any original flow fabrics have not later been reoriented in the prevailing stress field. Heicht and Vigneresse (1999), although making references to ‘magmatic flow fabrics’, recognised that these fabrics reflect the control (and imprint) of deformation on granite during emplacement. Vernon (1991) considered that the use of ‘flow’ terminology in relation to fabrics in granites (eg, Balk 1937, Marre 1986) is misleadingly genetic in its connotations. Patterson et al (1998) concluded that the fabrics preserved in magmatic rocks are those that formed near the solidus and accordingly reflect post-emplacement, syn- to post-tectonic stress conditions. They also suggested that they should be described using the non-genetic term ‘magmatic fabric’ as opposed to ‘primary flow fabric’. These authors further concluded that large plutons, a greater depth of emplacement and high geothermal gradients are all factors that bear on the elapsed time between low-viscosity Newtonian melts and high-viscosity, largely crystalline Bingham plutons. The latter consideration may be a limiting factor in the use of igneous crystallisation ages to constrain the age of deformation and fabric development in the surrounding country rock.

The (apparently) large volume of Early granite in the Aileron Province, its mesozonal (to epizonal) character and the consideration that there is a space requirement for the emplacement of such large volumes of magma may make igneous crystallisation ages equivocal constraints on the absolute timing of regional deformation. For example, at some indeterminate time following zircon crystallisation, incompletely crystallised granite may have been remobilised to higher crustal levels, or dilation zones. Pitcher (1993) made the point more generally, ie the apparent timing of a granite with respect to deformation is applicable only at the crustal level at which the relationships are observed, and further reflects only an instant of geological time. However, a close mechanical coupling between tectonic fabrics in the country rock and magmatic fabrics in the associated plutons is apparent regionally in the Aileron Province. The intensity, pervasiveness and timing of fabric development in the granites from southwestern to southeastern and central-eastern MOUNT PEAKE vary. It is suggested that these considerations may reflect the relative timing of tectonism and granite emplacement, with the magmatism related to the Stafford Event representing: (a) plutons emplaced throughout a finite period of similar prevailing stress conditions; (b) extended cooling histories; and (c) the variable intensity of that prevailing stress field. It is thus hypothesised that evidence for magmatism ranging in age from ca 1805–1790 Ma and apparently associated with a consistently oriented stress field is evidence for the temporal extent and possible diachronous nature of the Stafford Event, rather than the regional imposion of two discrete tectono-thermal events (ie Stafford and Yambah).

When evaluating the significance of fabrics, it is relevant to note that Patterson et al (1998) reported that magmatic fabrics recorded by crystal preferred orientations are not necessarily very intense and a statistically significant number of crystals may have their long axes at a high angle to the fabric. This observation also has a bearing on the interpretation of multiple fabrics, as defined by crystal preferred orientations. However, Patterson et al (1998) have noted that multiple magmatic fabrics are increasingly being recognised. They offer a number of possible explanations for the development of multiple fabrics. For example, crystals with different shapes or axial ratios will rotate differently in non-coaxial strain, or orthogonal fabrics may be formed where crystals with different aspect ratios align parallel to unequal elongation directions during coaxial flow. Patterson et al (1998) also recorded that orthogonal linear fabrics may be preserved metastably in circumstances of combined pure and simple shear.

It is significant that the magmatic fabrics recognised in the MOUNT PEAKE granites are predominantly defined by the preferred orientation of elongated K-feldspar megacrysts. Generally flat outcrop surfaces typically allow only the strike and not the dip of these fabrics to be measured. The feldspars generally have similar aspect ratios, irrespective of
their preferred orientation in one of three fabrics (although as noted previously, there are exceptions). This may be most readily attributed to metastable preservation of orthogonal linear fabrics during conditions of simple and pure shear (see above). It is important to note that the strike of these multiple magmatic fabrics parallel schistosity, cleavage and overprinting crenulation cleavages in the surrounding Lander Rock Formation country rocks, and similarly, parallel unequivocal tectonic fabrics, gneissosity, crenulations and mylonite (ie melt-absent or non-magmatic foliations) in granites in southwestern and central-southwestern MOUNT PEAKE.

Depending on temperature, percentage melt, the amount of deviatoric stress and the strain rate, the only indications of accommodated strain may be a ‘magmatic-looking’ fabric; ie, throughgoing shear zones, pervasive fracturing or other evidence of focused deformation may be absent. Thus, although different types of fabric are developed in granites in southeastern and central MOUNT PEAKE (ie mesoscopic magmatic or sub-magmatic fabrics) and central-southwestern MOUNT PEAKE (microscopic sub-magmatic and mesoscopic non-magmatic fabrics), they probably reflect increasing crustal depths and associated thermal gradients, strain rates and deviatoric stress southward.

Structure of the Lander Rock Formation and granites

The Lander Rock Formation is polydeformed. Typically, three well-developed foliations are recognised in these rocks: S₁–S₃. These are a differentiated, or domainal schistosity and two overprinting crenulation cleavages. Schistosity is defined by biotite- and muscovite-rich domains that typically alternate with more quartz- and/or lithic clast-rich microlithons. Quartz is generally fractured, indicating brittle deformation within these domains, by contrast with the ductile deformation in the micaceous domains. In more slaty rocks, the S₁ fabric is a more closely spaced cleavage rather than a schistosity, but is similarly overprinted by two crenulations.

The S₁ foliation is developed contemporaneously with peak regional metamorphic conditions. Crenulation cleavage development locally appears to involve new mica growth, which in the absence of the retrogression of mica grown in S₁, suggests probable progressive deformation. In some instances, in higher-grade assemblages, sillimanite has grown in two distinct foliations. This again suggests multiple fabric development during a single tectono-metamorphic event. Coarse porphyroblastic andalusite, now retrogressed to sericite, is attributed to overprinting contact metamorphic effects, as andalusite (and sillimanite) are typically found proximal to granite (and mafic rocks). Locally, andalusite grows at the intersection of two foliations (S₁ and S₂), but plunges in the opposite direction to the intersection lineation. Finally, proximal to mafic bodies, quartz-feldspathic domains within differentiated pelitic to psammo-pelitic rocks have polygonal textures, indicating that metamorphic recrystallisation locally overlaid deformation.

The structure of the Mount Stafford Member has been investigated in detail by a number of previous authors. Outcrop of the Mount Stafford Member defines a series of open northwest-trending folds that are particularly well delineated by folded mafic sills. These open folds were attributed by Vernon et al (1990) to the second (F₁₂) of three generations of folding (F₁₋₃), associated with a single prograde metamorphic episode. The first generation of folding is represented by mesoscale intrafolial folds that are best recognised in high-grade rocks. The third episode of folding produced north-northeast-trending macroscale folds. The structural history of the Mount Stafford Member is therefore comparable with that described above for the rest of the Lander Rock Formation in MOUNT PEAKE (and also in MOUNT DOREEN; see Young et al 1995a). Recent geochronological constraints are consistent with the interpretation presented here that these three phases of deformation throughout the Lander Rock Formation (including the Mount Stafford Member) are of ca 1805–1790 Ma Stafford Event age (Rubatto et al 2006, Worden et al 2008).

Vernon et al (1990) concluded that metamorphism in the Mount Stafford Member coincided with the first two fold episodes in low-grade rocks, but that the metamorphic peak was not reached until the third fold episode in high-grade rocks, although all three phases of folding are part of a single prograde tectono-thermal event (ie Stafford Event). Metamorphic isograds crosscut bedding and fold axes, and folds and metamorphic isograds are, in turn, both crosscut by the granitic phase of the Anmatjira Orthogneiss. Greenfield et al (1996) recognised that the granite commingled with migmatic leucosome to produce hybrid diatexite in the vicinity of 260250mE 7566000mN, indicating that granite emplacement was penecontemporaneous with the peak of prograde metamorphism. These authors concluded that peak metamorphism coincided with D₁a and was related to granite emplacement. Melt, generated contemporaneously with D₁a extension, is folded in F₁ₑ.

Dirks et al (1990) suggested that an axial planar foliation (S₁), which is associated with early chevron folding in the Lander Rock Formation in the northwestern Reynolds Range, probably correlated with a slaty cleavage or schistosity (S₃), which is associated with F₁ₑ upright, open to isoclinal folds in the Mount Stafford Member that were reported by Vernon et al (1990). Collins et al (1991) reported that two, prior, recumbent fold generations (F₁₋₂ and F₁₃) are recorded in the granulite-facies Mount Stafford Member. However, these authors further commented that the structures are largely confined to high-grade rocks, despite the absence of any major structural break between the high- and low-grade rocks. However, it is apparent from recent geochronology [eg, 1802 ± 3 Ma metamorphism and ca 1805–1795 Ma magmatism (Rubatto et al 2006, Worden et al 2008)] that the three phases of folding in the Mount Stafford Member are essentially contemporaneous with those mapped in the Lander Rock Formation throughout MOUNT PEAKE and southern LANDER RIVER.

Dirks and Wilson (1990) suggested that folding in the Lander Rock Formation, immediately unconformably underlyiing the Reynolds Range Group in the vicinity of Mount Thomas in NAPPERBY, correlated with the third episode of folding in the Mount Stafford Member. Claoué-Long et al (2008a) reported a maximum depositional age of 1813 Ma for this uppermost interval of the Lander Rock Formation, and interpreted that, in contrast with the Lander
Rock Formation in general (including the Mount Stafford Member), these rocks postdate the ca 1805–1790 Ma Stafford Event (ie they contain detrital zircon derived from that event). The regional extent of this stratigraphic interval has yet to be established, and no unconformity within the Lander Rock Formation has yet been mapped. It is possible that the Lander Rock Formation is a conformable succession in the vicinity of Mount Thomas, but that sedimentation was in part contemporaneous with the onset of (early) Stafford Event magmatism(?). The Boothby Orthogneiss, for example, outcropping at the southeastern end of the Reynolds Range, has an igneous crystallisation age of 1807 ± 6 Ma (Worden et al 2008). Pending further mapping, this issue is unresolved.

Regionally widespread granite intruding the Lander Rock Formation, particularly in southeastern MOUNT PEAKE, has multiple fabrics defined by the alignment of inequidimensional K-feldspar megacrysts and biotite. These fabrics are interpreted to be pre-full-crystallisation or submagmatic fabrics. The fabrics tend to be subparallel to the multiple foliations in surrounding, schistose, Lander Rock Formation metasedimentary rocks. The fabrics in the granites are interpreted to indicate emplacement of these granites penecontemporaneously with deformation and metamorphism of the country rocks. Multiple fabrics defined by feldspar alignment in the granites suggest shear. It is further concluded that granite emplacement was mainly by stoping and 'assimilation', rather than by forceful emplacement. However, the latter is probably manifested in a steeply dipping andalusite lineation, and in intersection lineations associated with crenulation cleavage development in penecontemporaneously deforming country rock.

Vernon et al (1990) suggested that the granitic phase of the Anmatjira Orthogneiss (the Mount Stafford Granite of Vernon et al 1990) may define a sheet. In southwestern MOUNT PEAKE, in particular, granite bodies are apparently bounded by northwest-trending structures that variably show simple shear with reverse movement (north over south, and with some strike-slip component), or apparently pure shear. Some of these structures in the southwest may have been (re-) activated during the Alice Springs Orogeny. In areas of minimal or no outcrop, geophysical interpretation suggests that northwest-trending faults (showing reverse movement, with or without a strike-slip component) are probably widespread throughout MOUNT PEAKE and border zones dominated by either granite or Lander Rock Formation.

Field relationships and contact metamorphic effects of the Esther Granite indicate that it was emplaced penecontemporaneously with deformation (at least with respect to S2 and S3) in the Lander Rock Formation. The 1789 ± 6 Ma igneous crystallisation age for this granite is considered to be a minimum age constraint on deformation in the Lander Rock Formation in southeastern MOUNT PEAKE. Three pre-full-crystallisation fabrics in the Esther Granite suggest that the three regional deformations recorded in the Lander Rock Formation are probably part of a single tectonic event. Xenoliths of (biotitised) country rock provide evidence for stoping and passive emplacement, whereas a component of forceful emplacement is indicated by parallelism between a fabric in the granite and (S3) foliation in the surrounding country rocks; ie the earliest foliation in the country rocks may predate the granite and may have been subsequently inherited by the granite during emplacement. Thus, it is argued that S2 and S3 are constrained by the granite crystallisation age, but S1 could potentially significantly predate the granite. It is possible that the tectono-thermal Stafford Event continued over a time interval of ca 1805–1790 Ma.

The Redhackle Granite (1772 Ma) shows evidence of recrystallisation and zircon growth associated with the Chewings Orogeny. Any expression of this predominantly thermal event in the Lander Rock Formation (Woodalla Member) surrounding this granite has not yet been identified.

In summary, it is interpreted that the three foliations in the Lander Rock Formation, as well as two generations of macro-scale folding, are the expression of a progressive deformation and associated prograde metamorphism. Regional metamorphism probably peaked slightly earlier than contact metamorphism that is associated with granite emplacement (and possibly locally also with mafic intrusions) and which was late to immediately post-tectonic. This structural and metamorphic history is comparable with that presented for the Mount Stafford Member by Vernon et al (1990). The timing of this event (ie Stafford Event) in southwestern MOUNT PEAKE is well constrained by the recently determined igneous crystallisation ages for the Anmatjira Orthogneiss, and metamorphic ages from Mount Stafford, which both fall in the range 1805–1795 Ma (Rubatto et al 2006, Worden et al 2008). This data suggests that the Anmatjira Orthogneiss is penecontemporaneous with peak metamorphism and, in turn, with progressive deformation in the Mount Stafford Member, as described by Vernon et al (1990) and Greenfield et al (1996, 1998). On field evidence, the Stafford Event apparently largely predates the 1793 ± 3 Ma Koonoonyeri Granite, and is correlated with the ca 1803 Ma Murchison Event in BARROW CREEK (and the Tennant Region). Deformation penecontemporaneous with the 1789 ± 6 Ma Esther Granite in southeastern MOUNT PEAKE is here also included in the Stafford Event, suggesting some slight possible diachronicity in this event within MOUNT PEAKE.

Regional-scale faulting

Regional-scale northwest-trending faults are a distinctive feature in geophysical data over MOUNT PEAKE and LANDER RIVER. A number of these faults can be identified as reverse faults or thrusts in southwestern MOUNT PEAKE, and these have southwesterly vergence. These reverse faults may have been initiated as normal extensional faults associated with (apparently ensialic) rifting and sedimentation, and in part, may have created space for granite emplacement. Most of these major structures are interpreted to have been active during the mid-Palaeozoic Alice Springs Orogeny. Collins and Teyssier (1989) interpreted a probable pop-up structure, based on their structural transect in the AnmatjiraRanges in NAPPERBY, which they related to deformation associated with the Alice Springs Orogeny. This corresponds to the transition from south or southwest-vergent faults to the south, and north to northeast-vergent faults to the north. A similar
pop-up structure could be related to the distribution of the Mount Stafford Member along strike in north-central NAPPERBY and adjacent MOUNT PEAKE. Regional data (Collins and Teyssier 1989, Scrimgeour and Raith 2001) suggests that throughout most of MOUNT PEAKE and LANDER RIVER, with the exception of southwestern MOUNT PEAKE, Palaeozoic faults are likely to be steeply south to southwest-dipping, with a south-side-up sense of movement.

East- and northeast-trending muscovite-quartz shear zones crosscut foliations associated with D_{1-2} in the Mount Stafford Member. Collins and Teyssier (1989) suggested that these structures were formed during the Alice Springs Orogeny, whereas Greenfield et al. (1996) considered that they were probably older structures that were reactivated during the Alice Springs Orogeny. Cartwright et al. (1999) have determined Alice Springs Orogeny ages (330–320 Ma) for (late) east- and southeast-trending shear zones in the Annmatjira and Reynolds ranges, and Collins and Teyssier (1989) have interpreted a transpressional tectonic setting with a component of sinistral strike-slip movement. The metamorphic grade of these shear zones apparently increases from greenschist to amphibolite facies southeastward along these ranges (Hand and Buick 2001). Greenschist-facies assemblages in phyllonitic, east- to southeast-oriented shear zones in the Koonoonyeri Granite in southern MOUNT PEAKE are probably similarly related to (or at least were reactivated during) the Alice Springs Orogeny. Similar phyllonitic shear zones are evident in the Esther Granite in ANNINGIE, and east-trending shear zones in unnamed granites north of Conical Hill (eg 298197mE 7632524mN, 294113mE 7638318mN and 298596mE 7632206mN) may also relate to the Alice Springs Orogeny. However, a Rb-Sr whole-rock and mineral separate isochron for the Esther Granite suggests a post-Chewings Orogeny cooling age, not subsequently reset during the Alice Springs Orogeny. This suggests that the effects of the Alice Springs Orogeny may not extend beyond southwestern MOUNT PEAKE.

Locally, it can be identified that individual faults have been active a number of times during the geological history of the area. The total (vertical) displacement on many of the faults is constrained by the fact that, in no instance, is basement to the Lande Rock Formation (including the Mount Stafford Member) exposed. Furthermore, vertical displacement is constrained by the fact that there are not any marked changes in metamorphic grade of the Lande Rock Formation across any of these faults in MOUNT PEAKE or southern LANDER RIVER. Similarly, the change of metamorphic grade between the Woodalla and Mount Stafford members to the south of the Yundurbulu Range is a smooth progression, and does not indicate any substantial discontinuity that necessitates major vertical displacement. There is also no evidence for a substantial strike-slip component of movement on faults in LANDER RIVER and MOUNT PEAKE.

Exposed Neoproterozoic and Palaeozoic rocks in MOUNT PEAKE are generally only gently tilted and faulted. These units, as well as the surficial geology of this mapsheet provide evidence that the latest movement on some of the faults occurred during the Cenozoic. The deformation of these rocks is not discussed further herein, except to mention that the Vaughan Springs Quartzite is folded and that this phase of folding probably occurred during the Alice Springs Orogeny.

**Metamorphism**

The Lander Rock Formation in LANDER RIVER and MOUNT PEAKE is typically regionally metamorphosed to greenschist facies. Regional amphibolite-facies metamorphism may possibly have been more widespread than is currently recognised. This may be recorded in the distribution of epidote-amphibolite-, and locally amphibolite-facies parageneses in mafic rocks. However, many mafic rocks now have greenschist-facies assemblages. Andalusite in metasedimentary rocks is attributed to contact metamorphic effects around granite intrusions, and is now generally retrogressed to sericite or mica. Locally, mid to upper amphibolite-facies assemblages are developed syntectonically in the Lander Rock Formation and are proximal, and apparently consequent on localised heat sources associated with the emplacement of mafic intrusive rocks. A regional, low-pressure, high-temperature contact aureole including granulite-facies parageneses is associated with the Mount Stafford Member.

**Metamorphism of the Lander Rock Formation**

Metamorphism of the Lander Rock Formation in LANDER RIVER and MOUNT PEAKE is regional, in the sense of its areal extent and association with deformation. However, at a somewhat more local scale, the distinction between regional and contact metamorphic effects is less clear. This is considered to reflect widespread syntectonic (bimodal) magmatism and probable local perturbations of a generally elevated regional geothermal gradient.

One example of this ambiguity which has been of particular interest to previous researchers is the metamorphism of the Mount Stafford Member in the Yundurbulu Range in central-southern MOUNT PEAKE. Stewart et al. (1980a) interpreted this as a regional-scale hornblende and pyroxene hornfels, implying a contact metamorphic response. Nonetheless, there is an association between metamorphism, deformation and intrusive magmatism and probable local perturbations of a generally elevated regional geothermal gradient.

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Similarly, there is a spotty distribution of andalusite in regional greenschist-facies slates of the Walabanba Member proximal to the Esther Granite in the Anningie tin field. The widespread distribution of syntectonic granite penecontemporaneous with Stafford Event deformation and metamorphism blurs the distinction between regional and more localised, contemporaneous, syn-deformational contact metamorphic effects in many areas.

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Localised, mid to upper amphibolite-facies metamorphic effects, which are proximal to some mafic intrusive bodies that preserve primary igneous textures (eg southwest of Waldrons Hill), suggest that these metamorphic assemblages are similarly a consequence of the local imposition of a steeper-thermal gradient, contemporaneous with deformation, regional metamorphism and intrusion of gabbro and olivine gabbro. Conversely, many typically stratiform mafic bodies have amphibolite- and epidote-amphibolite-facies peak metamorphic assemblages. These metamorphic effects are more easily reconciled with the intrusion of these stratiform bodies prior to regional metamorphism and deformation.

These complex associations are interpreted here as the natural consequence of widespread, bimodal intrusive magmatism, contemporaneous with the deformation and metamorphism of sedimentary and stratiform mafic rocks of the Lander Rock Formation during the 1805–1790 Ma Stafford Event. Thus, it is considered that the distinction between regional and contact metamorphic effects is somewhat arbitrary and the terrane is best considered one of regional metamorphism with a widespread elevated geothermal gradient contemporaneous with deformation, but with more localised thermal anomalies superimposed on the regional gradient.

Lander Rock Formation sedimentary rocks in MOUNT PEAKE and LANDER RIVER are variably metamorphosed from greenschist to granulite facies. Greenschist- to transitional amphibolite-facies assemblages (with muscovite-biotite-quartz and quartz-muscovite-biotite + epidote ± K-feldspar ± magnetite ± minor apatite ± rutile ± calcite?) predominate in metapelitic slate and schist, and (locally) in probable metapsammitic gneissic rocks in MOUNT PEAKE. Many rocks have a matrix of fine-grained quartz and sericite that locally includes fractured euhedral quartz grains; this matrix is interpreted to be lithic detritus rather than degraded and metamorphosed K-feldspar. Stewart et al (1980a) recognised muscovite-biotite-sillimanite schist in the Anningie Member in the vicinity of Central Mount, indicating mid amphibolite facies, and this is corroborated here. Sillimanite is also found in the Walabanba Member in LANDER RIVER (eg 238552mE 7710886mN, Waldrons Hill), where it is associated with microcline, indicating upper amphibolite-facies metamorphic conditions. The mineral assemblage includes quartz-microcline-plagioclase-biotite-sillimanite-garnet-green spinel; at Waldrons Hill, biotite and sillimanite are proportionally subequal and greater than feldspar; elsewhere, garnet is abundant.

Stewart et al (1980a) described hornfels, containing cordierite, sillimanite, andalusite and garnet, proximal to mafic intrusive rocks and granite in LANDER RIVER, at both 238552mE 7710886mN (see Waldrons Hill above) and 257879mE 7704701mN. It is noted here that the garnet- and sillimanite-bearing rocks at Waldrons Hill are well foliated and schistose. The country rock in these areas is poorly exposed, but is interpreted to be probable Anningie Member. The mineral assemblage indicates a higher metamorphic grade than that of the Anningie Member in ANNINGIE. They are compositionally comparable with the Anningie Member further south, and probably more iron- and manganese-rich than the Walabanba Member metasedimentary rocks. Mafic rocks adjacent to the microcline-sillimanite-bearing assemblages at Waldrons Hill were probably originally dolerite, but are now largely retrogressed to amphibolite. Mafic rocks adjacent to the occurrences of cordierite-bearing country rocks are olivine gabbro with primary igneous (ophitic and interstitial) textures.

In MOUNT PEAKE, sillimanite also occurs locally in the Lander Rock Formation to the northeast of Conical Hill (eg 314480mE 7632546mN), where it is associated with muscovite (muscovite-biotite-plagioclase-quartz-sillimanite), indicating that metamorphic conditions were below the breakdown temperature of muscovite and were not therefore as high grade as in the vicinity of Waldrons Hill. At the Conical Hill locality (and elsewhere) sillimanite is seen to have grown in two discrete foliations. Stewart et al (1980a) described the small, scattered outcrops of Lander Rock Formation in northeastern MOUNT PEAKE as a sillimanite- and andalusite-bearing micaceous hornfels. Most identified occurrences of sillimanite in MOUNT PEAKE and LANDER RIVER are near to mafic bodies. However, sillimanite could easily be overlooked in the Lander Rock Formation, as it is commonly retrogressed to chlorite and is not generally obvious in outcrop. Consequently, sillimanite could be more widespread in MOUNT PEAKE and LANDER RIVER than is currently recognised. At Central Mount Stuart in ANNINGIE, Stewart et al (1980a) have described pods of sericite-corundum-tourmaline-biotite-muscovite composition in sillimanite-bearing schist, and their description suggests that sillimanite-biotite-muscovite schist is quite abundant in this same area.

The assemblages: (a) muscovite-biotite, (b) muscovite-biotite-sillimanite and (c) biotite-microcline-sillimanite, represent similar prograde assemblages to those seen progressively to the southeast along the Reynolds Range in NAPPERBY. Stewart et al (1980a) also recognised orthoclase-biotite-sillimanite-cordierite-garnet assemblages, both in the southeastern Reynolds Range and locally in LANDER RIVER.

Andalusite formed coarse porphyroblasts locally in the Walabanba and Anningie members, and is attributed to contact metamorphism associated with granite emplacement. It is now pseudomorphed by sericite (and quartz). In the Walabanba Hills, retrogressed porphyroblastic andalusite has grown at the intersection of S₃ and S₂, and this is interpreted to indicate that the peak of hornblende hornfels-facies contact metamorphism (and granite emplacement) was probably contemporaneous with D₂ and D₁. The occurrence of (relict) andalusite at the intersection of two fabrics and its association with granite emplacement, and the growth of sillimanite in two fabrics proximal to mafic rocks suggest that an episode of that both granitic and mafic magmatism was coincident with regional deformation.

In a more regional context, Stewart et al (1980a) mapped ten informal units in the Lander Rock Formation in NAPPERBY and Young et al (1995a) subdivided the succession into six mapped informal units in MOUNT DOREEN. These units predominantly reflect variable textural characteristics and mineralogical compositions associated with the metamorphic grade.

There is a progressive increase in metamorphic grade from lowermost greenschist facies in the northwestern Reynolds Range in NAPPERBY (and extending into
southwestern MOUNT PEAKE) to upper amphibolite/lower granulite facies in the southeast in the vicinity of Mount Airy. Transitional granulite-facies rocks that outcrop extensively in YUENDEMU in MOUNT DOREEN were also assigned to the Lander Rock Formation by Young et al. (1995a). The Lander Rock Formation in MOUNT DOREEN also includes greenschist- and lower amphibolite-facies schist and quartzite, a cordierite-bearing granofels similar to those in the Mount Stafford Member, and transitional granulite-facies rocks, including migmatites. High-grade metamorphism of the undivided Lander Rock Formation in northwestern NAPPERBY, and the Mount Stafford Member in NAPPERBY and MOUNT PEAKE was at ca 1800 Ma (Rubatto et al 2006, Claoué-Long et al 2008b). In contrast, granulite-facies metamorphism of the Lander Rock Formation in the southwestern Reynolds Range is of Chews Wonders Orogeny age, as is shown by 1583 ± 2 Ma monazite and 1579 ± 7 Ma zircon growth in metasedimentary rocks (Vry et al 1996).

Stewart et al. (1980a) considered metamorphism of the Lander Rock Formation in MOUNT PEAKE to be of greenschist grade in the centre of the mapsheet, rising to mid amphibolite grade in the southeast, where migmatite has been described locally. Although outcrop of the Lander Rock Formation in northern MOUNT PEAKE and southern LANDER RIVER is very poor, it is now considered that the distribution of metamorphic grade is more irregular than suggested by Stewart et al. (1980a), and probably reflects variability in geothermal gradient proximal to local heat sources around syn-tectonic intrusive rocks. In common with the variability in prograde metamorphism of the pelitic and psammitic Lander Rock Formation, Stewart et al. (1980a) noted that superimposed on initial prograde metamorphism of Lander Rock Formation is subsequent patchy retrogression characterised by sericite after andalusite, chlorite after sillimanite, and correspondingly the formation of actinolite, chlorite and albite in intercalated mafic rocks (see below).

Locally, metamorphic mineral assemblages proximal to granite plutons indicate that contact metamorphic and metasomatic effects in the Lander Rock Formation are superimposed on regional metamorphic ones. For example, aligned, tabular alkali-feldspar phenocrysts define a linear and platy fabric in granite intruding the Lander Rock Formation in southeastern MOUNT PEAKE. This linear fabric parallels the S1 fabric in the surrounding Lander Rock Formation country rocks. However, the igneous crystallisation age of the Esther Granite (1789 ± 6 Ma) suggests that its emplacement postdates the onset of the ca 1805–1790 Ma Stafford Event, ie S3 in the surrounding Lander Rock Formation. These structural relationships, as well as the occurrence of large rafts of Lander Rock Formation in the granite, indicate that granite emplacement was largely by stoping and assimilation. However, a component of forceful emplacement is indicated by steeply plunging andalusite (S1/S2 intersection) lineations, and intersecting crenulation cleavages in the penecontemporaneously deforming country rock.

Surmicaceous enclaves are common in the early granites and may represent biotitised country rock. Biotitisation of in situ country rock is also seen locally at, for example, 304101mE 7623161mN in the Walabanba Hills. Extremely coarse 5–6 cm muscovite and large biotite books are seen in Lander Rock Formation metasedimentary rocks at 316370mE 7633302mN and this is attributed to proximity to the granite, ie to contact metamorphic effects in the intensely crenulated schist. At this locality, schist is associated with minor, interbedded, micaceous quartzo-feldspathic psammitite.

Quartz-tourmaline veins occur locally, proximal to granite contacts. At 303291mE 7600238mN, in the Walabanba Hills, the sedimentary country rocks have been locally metasomatized to a quartz-tourmaline rock that shows marked subsequent shearing. Locally, granite has intruded as veins or dykes parallel to the dominant (S1) foliation in the Lander Rock Formation.

In the northwestern Reynolds Range area in NAPPERBY, contact metamorphic andalusite and cordierite around the Yaningidjara Orthogneiss and Harverson Granite have overprinted an early muscovite-quartz foliation in schistose Lander Rock Formation (Dirks et al. 1991, Vry and Cartwright 1998, Hand and Buick 2001). This foliation is axial planar to chevron folds that make a high angle to folding in the Reynolds Range Group, and is correlated by Dirks and Wilson (1990) and Dirks et al. (1991) with the S3 fabric of Clarke et al. (1990), Vernon et al. (1990) and Collins et al. (1991) in the Mount Stafford Member. Andalusite porphyroblasts in schistose Lander Rock Formation around, for example, the Esther Granite in MOUNT PEAKE are interpreted to have grown penecontemporaneously with the (S1) foliation and in the plane containing the S2/S3 intersection lineation. These andalusite porphyroblasts have been subsequently pseudomorphed during retrogression by sericite (and quartz). Recent geochronological constraints indicate that S1 of Clarke et al. (1990) correlate with S1 of the rest of the Lander Rock Formation in MOUNT PEAKE and LANDER RIVER (see Structure and metamorphism – Discussion). However, in the Woodalla Member, in which Stafford Event foliations may be overprinted, at least locally, by (essentially coaxial?) foliations of Yambah Event age that were contemporaneous with the emplacement of the Redhackle Granite.

**Metamorphism at Mount Stafford**

Metamorphism of the Mount Stafford Member and associated migmatitisation have been studied in detail by Vernon et al. (1990), Greenfield et al. (1996, 1998) and White et al. (2003), but have not been investigated during the mapping reported in these notes. Details resulting from these prior studies are summarised in Tables 4 and 5. Temperature and pressure estimates presented in these studies are also tabulated. The most recent estimates are those of White et al. (2003), based on THERMOCALC. Conditions ranged from ca 2.5 kbar at 625°C for the breakdown of muscovite and quartz (and the first production of cordierite) at the zone 1 / zone 2 isograd to ca 3.2–4 kbar and ca 750–785°C for various reactions at about the zone 3 / zone 4 isograd. Timing of this metamorphism is now established to have occurred in the interval 1805–1795 Ma (Rubatto et al 2006).

Vernon et al. (1990) concluded that the Mount Stafford Member includes unusually low-pressure granulite-facies assemblages as shown by two-pyroxene-bearing mafic granofelses and interlayered andalusite-bearing migmatites. These authors defined four prograde metamorphic zones
<table>
<thead>
<tr>
<th>Lithology Zone</th>
<th>zone 1</th>
<th>zone 2</th>
<th>zone 3</th>
<th>zone 4</th>
<th>zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>lithology</td>
<td>greenschist</td>
<td>Ms zone</td>
<td>amphibolite</td>
<td>And-Crd-Kfs zone</td>
<td>amphibolite</td>
</tr>
<tr>
<td>sandstone/m</td>
<td>Ms+Qtz</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>Opx+Cr+Kfs+Qtz+Bt+Lm+Grt+Pl</td>
<td>Opx-in isograd</td>
</tr>
<tr>
<td>metapsammite</td>
<td>(+ minor Chl-Tur-Ilm)</td>
<td>A. Crd partially or completely pseudomorphed by And+Bl+Qz</td>
<td>(Grt at high-T)</td>
<td>(Spl mostly as inclusions in Crd)</td>
<td></td>
</tr>
<tr>
<td>interbedded</td>
<td>Ms+Bl+Qtz</td>
<td>And+Cr+Kfs+Qtz+Bt+Ilm</td>
<td>And+Cr+Kfs+Qtz+Bt+Ilm</td>
<td>± either Grt or Spl+Taur</td>
<td></td>
</tr>
<tr>
<td>metapelite and</td>
<td>(+ minor Tur-Ilm-Ap)</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>± either Spl+Sil or Qtz=Grt</td>
<td></td>
</tr>
<tr>
<td>metapsammite</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>± either Qtz or Spl+Bl</td>
<td>Crd+Kfs+either (1) Qtz=Bl or Grt; or (2) Spl+Bl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>subaluminous-</td>
<td>Ms+Qtz</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>± either Qtz or Sp+Bl</td>
<td></td>
</tr>
<tr>
<td>metapelitic</td>
<td>(+ minor Chl-Tur-Ilm)</td>
<td>Sil replacing And (locally coaxially)</td>
<td>Crd+Kfs+Sil</td>
<td>± either Qtz or Spl+Bl</td>
<td></td>
</tr>
<tr>
<td>Crd-granofels</td>
<td>Ms+Bl+Qtz+Crd+And</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>Crd+Kfs+either (1) Qtz=Sil or Spl+Sil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms+Bl+Qtz</td>
<td>Crd+Kfs+Bl+Qtz+And/Sil</td>
<td>and/Sil</td>
<td>Crd+Kfs+either (1) Qtz=Sil or Spl+Sil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnostic characteristics</td>
<td>first appearance of And in aluminous assemblages</td>
<td>disappearance of Ms at zone 1/2 boundary</td>
<td>Crd-granofels becomes Als-absent; where Crd still present it is mantled by Spl+Crd symplectite first appearance of Spl (marked decrease in Bt)</td>
<td>zone 3/4 boundary is marked by Opx-in metapasmamite (and rarely in granofels)</td>
<td></td>
</tr>
<tr>
<td>Melt</td>
<td>A. incipient melt</td>
<td>first schlieren migmatite</td>
<td>metapelite has abundant diatexite dominated by hybrid diatexite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B. interconnected</td>
<td>Sil+Bl+Qz = Spl</td>
<td>metasiltstone ('corderite granofels')</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>leucocratic</td>
<td>+Crd+Kfs+Spl</td>
<td>Hbl+Pl+Bt+Ilm</td>
<td>massive to poorly foliated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>symplectes of Qtz+Bl+Kfs</td>
<td>+Liq (ie consumption of Bt); nebulous leucosome commonly centred on Als-segregations</td>
<td>(residual igneous textures; 20–50 m wide Crd-bearing aureoles in metapelitic)</td>
<td>as zone 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Qtz+Kfs+Bl+Crd</td>
<td>Spl+Crd symplectites lack Qtz (Crd mantling Spl+Crd+Kfs+ minor Pl)</td>
<td>extensive partial melting, but bedding preserved; nebulous migmatite</td>
<td>as zone 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. Bedded</td>
<td>and minor Bl</td>
<td></td>
<td>nebulous migmatite</td>
<td></td>
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<td></td>
<td>migmatisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Qtz+Kfs+Cr+And</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>metatexite;</td>
<td></td>
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<tr>
<td></td>
<td>Sil-in</td>
<td></td>
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<tr>
<td></td>
<td>patchy leucosome, strongly</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>peraluminous assemblage</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Qtz+Kfs+Cr+And</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>And minor Bl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mafic</td>
<td>Hbl+Pl+Bl+Ilm</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>(as zone 2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>as zone 2</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 4. Comparative summary table for metamorphic assemblages for Mount Stafford Member of Lander Rock Formation. Data in regular font from Vernon et al. (1990); data in italics from Greenfield et al. (1996, 1998); data in bold from White et al. (2003). Abbreviations after Bucher and Frey (1974).
Greenfield *et al* (1998) have added a fifth zone characterised by biotite-cordierite-plagioclase diatexite; this zone has a gradational contact with the granitic phase of the Anmatjira Orthogneiss (the ‘northern’ granite of Greenfield *et al* 1998). Furthermore, these authors identified three subzones within zone 2.

Specifically, zone 2a is characterised by the subsolidus breakdown of muscovite to andalusite and K-feldspar, the lower limit of zone 2b coincides with the first melt-derived leucosome, and in zone 2c, sillimanite replaces andalusite in migmatite. Rocks in the muscovite zone are greenschist-facies muscovite-biotite-(chlorite)-quartz schists analogous to the widespread Lander Rock Formation in MOUNT PEAKE. Mineral parageneses reflect Na-deficient, K- and Fe-rich aluminous protolith compositions that are comparable to those inferred for the Lander Rock Formation in general.

Greenfield *et al* (1996) concluded: that the compositions of both the metapelitic protolith and its derived-leucosome are remarkably uniform, and that partial melting occurred in an essentially closed system. However, the leucosome does not have a minimum melt composition, and is a product of incongruent melting relationships, resulting in andalusite-, cordierite- and minor biotite-bearing, markedly peraluminous leucosomes in all metamorphic zones (except the muscovite zone). Greenfield *et al* (1996)
described the changes in the character of leucosome from zone 2b to zone 5 as follows. Leucosome formed in zone 2b has a bedded character and forms interconnected segregations entirely within metapelite. In zone 2c, the leucosome forms extensional vein arrays and defines conjugate (extensional) shear zones; it also crosscuts metapsammite. In zone 3, the first schlieren migmatite and a well developed melanosome occur, with both bedded and schlieren migmatite persisting in zone 4. Finally, zone 5 hybrid diatexite is formed from mingling of locally derived leucosome and introduced granitic melt and schollen (ie typically rounded fragments of palaeosome within neosome, see Mehnert 1971: 15) are formed. These progressive changes are interpreted to reflect increasing temperature, although Greenfield et al (1996) concluded that zone 5 does not represent the highest grade of metamorphism, as it contains andalusite rather than sillimanite and does not represent an increase in pressure. Vernon et al (1990) concluded, from the generally random orientation of prismatic sillimanite replacing andalusite and cordierite, that sillimanite growth postdates deformation and reflects an increase in pressure rather than temperature. However, these authors also noted that some sillimanite is oriented in a (late) foliation and interpreted that the peak of metamorphism was reached earlier in the high-grade rocks, by comparison with the low-grade mica schists, where the micas are aligned in the last of three foliations associated with a single, progressive deformation.

Mafic rocks are two-pyroxene granofels (eg 243173mE 7569113mN) in the upper part of zone 2b (and above), and are inter layered with andalusite-bearing migmatite (Greenfield et al 1996). These mafic rocks appear to partially retain primary igneous textures, with orthopyroxene and clinopyroxene poikiloblastically enclosing plagioclase. Pyroxene is partially replaced by brown hornblende, with retrogression being more pervasively expressed in zone 1 greenschist-facies dolerite sills (see White et al 2003), which nonetheless preserve relict igneous textures. Red-brown biotite occurs in the mafic rocks, together with accessory ilmenite. Partial melting of mafic granofels in zone 4 may be represented by rare plagioclase-orthopyroxene-ilmenite-bearing leucosomes. Greenfield et al (1996) argued that metamorphism of the mafic rocks precludes them from being the cause of widespread high T/low P metamorphism at Mount Stafford. The source of the requisite heat remains contentious.

Partial overprinting of the high-temperature/low-pressure metamorphism of the Mount Stafford Member (ca 1805–1790 Ma Stafford Event) was recognised by Clarke et al (1990), and attributed by these authors to the Strangways Orogeny. Buick et al (1999) suggested that this overprinting event could be of Chewsing Orogeny age (ca 1590–1560 Ma). Vernon et al (1990) and Collins et al (1991) recognised that there is little or no expression of Strangways and/or Chewsing orogenies deformation in the Mount Stafford Member. Late shear zones in the Mount Stafford Member could relate to these events, or more probably, to Palaeozoic deformation that is responsible for mylonitic zones in the adjacent granitic phase of the Anmatjira Orthogneiss (Collins and Teyssier 1989, Vernon et al 1990).

**Metamorphism of intrusive and extrusive mafic rocks**

Mafic rocks outcropping within the distribution of the Lander Rock Formation show variable grades of metamorphism. Limited protolith variation within the Lander Rock Formation includes poorly outcropping stratiform/stratabound amphibolites that are considered to represent both extrusive flows and intrusive sills. Discrete gabbro and olivine gabbro bodies preserve igneous (eg subophitic to interstitial) textures; however, clinopyroxene-magnetite symplectites associated with olivine and hornblende rims on ferromagnesian minerals are probably metamorphic rather than magmatic effects. The amphibole coronas may reflect lower temperatures and greater water activities than the symplectites, and are probably associated with progressive cooling during the Stafford Event.

Conceptually, Bucher and Frey (1994) stated that the theoretical starting material for the prograde metamorphism of mafic rocks is an assemblage of secondary minerals (hydrates and carbonates). Robinson and Bevins (1999) and Alt (1999) noted that low-grade (sub-greenschist-facies), regional hydrothermal metamorphism (/alteration) of mafic rocks results in the partial hydration of primary igneous minerals. This contrasts with the progressive dehydration and decarbonatisation reactions that characterise the metamorphism of other rock types, and also with the higher-grade metamorphism of mafic rocks. Thus, mafic rocks in LANDER RIVER and MOUNT PEAKE generally show prograde metamorphism to predominantly epidote-amphibolite-facies, and locally, to amphibolite-facies mineral assemblages. Patchy, partial retrogression of mafic rocks to green schist-facies (actinolite, chlorite and albite bearing) assemblages is also noted. In addition, a number of mafic rocks preserve primary igneous textures. It is interpreted that stratiform, metamorphosed mafic units (within the Lander Rock Formation) represent volcanic rocks or sills. These meta-mafic rocks predate the Stafford Event. In contrast gabbros and olivine gabbros comprise syn-Stafford Event intrusions. These gabbros only show minor metamorphic effects (see above), but have raised the geothermal gradient in nearby Lander Rock Formation sedimentary rocks sufficiently to result in the production of upper amphibolite-facies metamorphic assemblages.

Mafic rock outcropping at, for example, 314480mE 7632546mN has been metamorphosed to epidote-amphibolite facies and shows incipient further retrogression to a green schist-facies assemblage, characterised by actinolite. This mafic rock is interpreted from airborne magnetic data to be intrusive into the Anningie Member. Quartz-zoned plagioclase-muscovite-biotite-sillimanite assemblages in the country rocks indicate a slightly lower grade of amphibolite-facies metamorphism than that at Waldrons Hill, where muscovite is lacking and the assemblage includes microcline together with sillimanite. However, garnet is absent at 314480mE 7632546mN, suggesting locally less iron- and magneserie rich, host sedimentary protolith compositions to the mafic intrusive rocks.

Stewart et al (1980a) similarly reported that metamorphism of basic rocks in MOUNT PEAKE has resulted in variable retrogression. In central MOUNT
PEAKE, they recognised a greenschist-facies assemblage comprising actinolite-chlorite-epidote, whereas elsewhere, metamorphic rocks have hornblende-andesine, mid-amphibolite-facies assemblages. Patchy retrogressive assemblages are superimposed on the prograde assemblages in the metasedimentary rocks and the amphibolite-facies basic assemblages. Thus, sericite pseudomorphs andalusite, chlorite replaces sillimanite, and actinolite-chlorite-albite are found in retrogressed amphibolite-facies basic rocks.

Mafic rocks in MOUNT PEAKE show predominantly epidote-amphibolite- or amphibolite-facies peak metamorphism. Localised occurrences of hornblende- and hornblende-biotite schist are also noted. Metamorphic mineral assemblages in many of the mafic rocks are indicative of partial retrogression from amphibolite to greenschist facies, as is demonstrated by actinolite replacing hornblende, and by chlorite and sericite replacing plagioclase. Mineral assemblages in mafic rocks are reported below.

1. Epidote-quartz-hornblende-(relict) plagioclase-chlorite-actinolite with minor opaque oxide (eg 303291mE 7600238mN); ie, amphibolite facies partially retrogressed to epidote-amphibolite / greenschist facies.
2. Hornblende-epidote-plagioclase-chlorite-quartz (eg 312063mE 7581474mN); ie, epidote-amphibolite facies partially retrogressed to greenschist facies.
4. Plagioclase-hornblende-biotite-epidote-magnetite-quartz-calcite (eg 303731mE 7601185mN). Epidote-magnetite is probably after pyroxene and is rimmed by biotite and hornblende; plagioclase is typically completely sericitised.
5. Hornblende-plagioclase-epidote-biotite-quartz-actinolite(?) (eg 314480mE 7632546mN). Plagioclase is >An20 therefore, the mineral assemblage probably represents amphibolite facies partially retrogressed to greenschist facies.
6. Hornblende-epidote-quartz-chlorite-actinolite with minor relict plagioclase (eg 318064mE 7581911mN); and hornblende schist; ie, amphibolite-, or epidote-amphibolite facies retrogressed to greenschist facies.
7. Plagioclase (including deformed plagioclase)-(relict) clinopyroxene-hornblende-magnetite-biotite-epidote-chlorite with minor orthopyroxene (reacting to clinopyroxene) and (strained) quartz (eg 303823mE 7600572mN). Uralised hypersthene-gabbro with ophitic texture metamorphosed to epidote-amphibolite facies.
8. Olivine-clinopyroxene-plagioclase-magnetite-biotite-minor orthopyroxene (?) as reaction rims on olivine (eg 266305mE 7577728mN); clinopyroxene poikilocrystically encloses olivine and plagioclase; olivine altered to magnetite and rimmed by biotite; magmatic texture preserved; poikilophytic. Probable orthocumulate (although cumulus and poikilitic crystals are apparently unzoned) gabbroic troctolite or troctolitic gabbro. The reaction textures are probably, at least in part, metamorphic.
9. Olivine-clinopyroxene-plagioclase-magnetite (with minor biotite and orthopyroxene) (eg 243172mE 7569113mN); olivine and magnetite with reaction rims of orthopyroxene(?). Interstitial (mesocumulate) gabbroic-troctolite. The reaction textures are probably at least in part metamorphic.
10. Olivine-clinopyroxene-plagioclase-hornblende-magnetite, with clinopyroxene-magnetite symplectites associated with olivine, and hornblende coronas on primary ferromagnesian minerals (eg 257879mE 7704701mN). Subophitic to interstitial, ie igneous, textured olivine gabbro. The symplectite and corona textures probably result from metamorphic reactions with falling temperature and increasing water activities.

Discussion

Stafford Event (1805—1790 Ma)

On the basis of existing evidence, the dominant tectonic and thermal event in LANDER RIVER and MOUNT PEAKE was the Stafford Event, at 1805—1790 Ma. The three phases of folding in the Lander Rock Formation throughout MOUNT PEAKE are correlated with those in the Mount Stafford Member, and they are all attributed to the Stafford Event. Deformation in the Woodalla Member in southwestern MOUNT PEAKE may be a possible exception, in that gneissic fabrics are well developed in the 1772 Ma Redhackle Granite and it is probable that these have also been manifested in the Woodalla Member. However, if this is the case, it is inferred that they represent the reactivation of earlier (Stafford Event) foliations in the country rock. Given that gneissic fabrics in granite typically postdate full-crystallisation, it is possible that deformation of the Redhackle Granite and reactivation of Woodalla Member foliations could relate to the Yambah or Chewings orogenies. However, relationships between foliations and granite-derived pegmatite described above (see Redhackle Granite) are interpreted to indicate that the gneissosity developed more or less contemporaneously with emplacement of the Redhackle Granite.

Regional metamorphism, resulting in a progressive southeasterly increase in metamorphic grade from greenschist to granulite facies in the Reynolds Range in NAPPERBY, postdates the deposition of the Reynolds Range Group. Geochronological data (Vry et al 1996, Williams et al 1996, Rubatto et al 2001) constrain this metamorphic event to the ca 1590—1560 Ma Chewings Orogeny (Hand and Buick 2001). In the northwestern Reynolds Range, earlier deformation and contemporaneous greenschist-facies metamorphism in the Lander Rock Formation has been attributed to the Stafford Event (Dirks and Wilson 1990).

The Anmatjira Orthogoness and Esther Granite are contemporaneous with the Stafford Event. Contact metamorphic effects around the Harverson Granite (NAPPERBY; 1799 ± 3 Ma, Worden et al 2008) have resulted in the growth of andalusite and cordierite, overprinting a prior greenschist-facies biotite-muscovite-quartz foliation (Stafford Event) in the Lander Rock Formation (Hand and Buick 2001).
It is therefore suggested here that the Stafford Event is responsible for regional greenschist-facies foliation in the Lander Rock Formation in the northwestern Reynolds Range and further extending over a large part of MOUNT PEAKE and LANDER RIVER. This foliation and two overprinting crenulations are apparent in the Lander Rock Formation throughout MOUNT PEAKE (and southern LANDER RIVER). These foliations have also been recognised in the greenschist-facies (muscovite zone) former Mount Stafford beds ie Woodalla Member, to the southwest of Mount Stafford in the vicinity of Tin Bore (in NAPPERBY), and are equated with \textit{S}_{p} and \textit{S}_{lc} of Vernon \textit{et al} (1990), in the Mount Stafford Member.

\textbf{Younger events}

Until the mid-1990s, high-grade metamorphism in the southeastern Reynolds and Anmatjira ranges was believed to have occurred during the Yambah Event at around 1780–1770 Ma (Clarke \textit{et al} 1990, Collins and Williams 1995). However, since the recognition that high-grade metamorphism in these regions occurred at 1590–1560 Ma (Vry \textit{et al} 1996, Rubatto \textit{et al} 2001, Hand and Buick 2001), the existence and nature of deformation and metamorphism during the Yambah Event has come under question (Hand and Buick 2001). Hand and Buick (2001) reported that curved inclusion trails in contact metamorphic porphyroblasts in Reynolds Range Group pelitic rocks, around the igneous precursors of the Coniston and Warimbi schists, indicate deformation penecontemporaneous with granite emplacement and contact metamorphism at ca 1780 Ma. This tectono-thermal event has previously been referred to as the early Strangways Orogeny, but is now referred to as the Yambah Event (Scrimgeour 2004). Structural relationships recognised by Dirks and Wilson (1990) in the northwestern Reynolds Range Group demonstrate a tectonic unconformity (at least locally) between the Lander Rock Formation and Reynolds Range Group. These relationships apparently indicate a prior deformation in the Lander Rock Formation in this area, indicating that the Stafford and Yambah events are discrete (regional) tectono-thermal events (or possibly a single, protracted diachronous event). An early foliation in the locally unconformably overlying pelitic rocks of the Reynolds Range Group (again in the northwestern section of the eponymous ranges) is attributed to later deformation. This early foliation in the Reynolds Range Group is overprinted by andalusite and cordierite porphyroblasts, formed during contact metamorphism associated with the emplacement of the Warimbi Schist (1785 ± 22 Ma; Collins and Williams 1995) and Coniston Schist (1780 ± 10 Ma; Smith 2000, 2001), as noted above. Geochronological data presented herein suggest that the Reynolds Range Group postdates the Stafford Event.

Andalusite porphyroblasts, attributed to contact metamorphism associated with late Stafford Event magmatism (eg the Esther Granite), are retrogressed and probably crenulated locally. Similar andalusite blasts in the Bullion Schist in BARROW CREEK are also retrogressed. This is interpreted as a possible expression of either the ca 1780 Ma Yambah Event or the undated Davenport Event.

Collins \textit{et al} (1991) and Hand and Buick (2001) concluded that deformation and metamorphism in the Anmatjira Range is constrained by the crosscutting relationship of the Possum Creek Charnockite (1774 ± 6 Ma; Collins and Williams 1995), with respect to a granulite-grade foliation in the Tyson Creek Metamorphics (1767 ± 17 Ma; Hand \textit{et al} 1995). It could be argued that this corresponds to the Yambah, as distinct from the Stafford Event and similarly, that the gneissic Redhackle Granite (1772 Ma) in MOUNT PEAKE may also constrain the age of the Yambah Event in the Aileron Province.

There is little evidence for Yambah Event (1780–1770 Ma) or Strangways Orogeny (1730–1690 Ma) magmatism, tectonism or metamorphism in MOUNT PEAKE (or LANDER RIVER), except for the 1772 Ma Redhackle Granite in southwestern MOUNT PEAKE. The Redhackle Granite further records the thermal effects of the ca 1580 Ma Chewings Orogeny, but recrystallisation associated with zircon growth at this time was not associated with, or at least outlived deformation. A gneissic foliation in the Redhackle Granite is locally transposed or overprinted by two crenulations. These fabrics in the Redhackle Granite could be an expression of the ca 1780–1770 Ma Yambah Event. Deformation during either the Yambah Event or Chewings Orogeny, and high-grade (upper amphibolite-facies) metamorphism, associated with zircon growth during the Chewings Orogeny in the Redhackle Granite, are not expressed in the Woodalla Member of the Lander Rock Formation. However, exposures are extremely poor and it is likely that the Chewings Orogeny is essentially thermal in this area. The Redhackle Granite and Lander Rock Formation may have been juxtaposed along thrusts that may have been active during the subsequent Alice Springs Orogeny, eg in the vicinity of Giles Range. The Alice Springs Orogeny is probably expressed in E–W- to NW-striking, sheared phyllonite zones in southwestern MOUNT PEAKE, eg in the Koonoonyeri Granite. However, similar zones in the Esther Granite are unlikely to have been generated during the Alice Springs Orogeny. A Rb-Sr isochron (whole rock and mineral separates), determined by G Luther (La Trobe University, pers comm 2004) for the Esther Granite, gave a Model 2 age of 1535 ± 53 Ma, which is herein interpreted to be a post-Chewings Orogeny cooling age. This indicates that greenschist-facies conditions were probably not subsequently realised in southeastern MOUNT PEAKE (eg, during the Alice Springs Orogeny).

\textbf{NEOPROTEROZOIC STRATIGRAPHY (GEORGINA AND NGALIA BASINS)}

Neoproterozoic rocks outcrop in MOUNT PEAKE but not in LANDER RIVER. Exploration drilling (Archibald 1996) has also intersected Neoproterozoic rocks subsurface in southwestern MOUNT PEAKE. Probable Central Mount Stuart Formation has been interpreted from seismic data underlying the eastern Lander Trough in LANDER RIVER (Kennewell \textit{et al} 1977, Kennewell and Huleatt 1980).

Walter (1980) divided the Neoproterozoic stratigraphy of the southwestern Georgina Basin into four tectosomes (supersequences) separated by stratigraphic breaks, corresponding to the Areyonga, Rinkabeena and Toomba
movements. Dunster et al (2007) summarised existing, and proposed new group names for the lithostratigraphic successions encompassed by these tectosomes in the southern Georgina Basin. They recommended that the use of supersequence nomenclature should be restricted to sequence stratigraphy. The new group names are used herein, but reference is made to supersequences in the context of correlation with other elements of the Centralian Superbasin.

The Vaughan Springs Quartzite is part of Supersequence 1 of the Centralian Superbasin (Walter and Veevers 2000) and is correlated with the Heavitree and Amesbury quartzites (Dunster et al 2007). An unnamed metabasalt near 333000mE 7580500mN, 3.5 km northwest of Mount Browne, predates the Central Mount Stuart Formation. Its age is not known. However, it may correlate with ca 825 Ma Gairdner Event mafic rocks of Hoatson et al (2007), and therefore with basalts in the Bitter Springs Formation of the Amadeus Basin. It is tentatively included as part of this pre-Areyonga Movement succession. The Vaughan Springs Quartzite and the unnamed basalt are not assigned to a group; the Amesbury Quartzite is included in Dunster et al's (2007) Plenty Group.

No lithostratigraphic representatives of the Cryogenian (Sturtian) glacial succession are recognised in MOUNT PEAKE. Thus, there are no representatives of the stratigraphic succession between the Areyonga and Rinkabeena movements (ie Supersequence 2) outcropping in MOUNT PEAKE. Supersequence 3 and 4 pre- and postdate the Toomba Movement and equate with the Keepera and Mopunga groups, respectively. The Keepera Group is represented in MOUNT PEAKE by the Boko Formation (correlated with the Marinoan glacioclasts). The Mopunga Group is represented in MOUNT PEAKE by the Grant Bluff and Central Mount Stuart formations. It is possible that, as currently mapped in MOUNT PEAKE, the former formation includes rocks of the Elyuah Formation and the latter, rocks of the Elkeria Formation.

Walter (1980) indicated the probable occurrence of the previously unmapped Elkeria Formation, and possibly also the Grant Bluff and Elyuah formations within the Central Mount Stuart Formation succession in MOUNT PEAKE. This view is accepted herein. The Neoproterozoic stratigraphy of the southern Georgina Basin is described in some detail below to provide the background to the changes that have consequently been made to the mapped geology in MOUNT PEAKE. Additional, future specialist studies may further elucidate the details of the Neoproterozoic stratigraphy in MOUNT PEAKE.

Vaughan Springs Quartzite

The Vaughan Springs Quartzite was named and defined by Wells et al (1968). The unit is named after Vaughan Springs in northwestern MOUNT DOREEN (690501mE 7530370mN). The type locality is about 3 km southeast of Yuendemu at approximately 791126mE 7533170mN, in MOUNT DOREEN. Wells et al (1968) also measured a type section in this area. However, Wells and Moss (1983) subsequently nominated a type section in the Vaughan Springs Syncline in northwestern MOUNT DOREEN, where they measured a maximum thickness of 1750 m, compared to a measured thickness of >930 m in Wells et al's (1968) original type section.

The Vaughan Springs Quartzite is the basal unit of the Ngalia Basin succession. It outcrops over a distance of greater than 400 km along the northern and southern margins of the Ngalia Basin, where it forms upstanding ranges, particularly in MOUNT DOREEN, and more localised topographic features in NAPPERBY and western LAKE MAKAY. It forms the Nanga, Yindjirub and Bau ranges in MOUNT PEAKE (Figures 24a, b). Isolated outcrops of the Vaughan Springs Quartzite also outcrop at 271000mE 7577500mN and 283250mE 7578000mN, in MOUNT PEAKE.

The Vaughan Springs Quartzite is predominantly a massive to thickly bedded and cross-bedded, medium-grained orthoquartzite (Wells and Moss 1983). The uppermost 1000 m of the quartzite includes some fine- and some coarse-grained sandstone, and is generally well sorted and well rounded. Detrital tourmaline, zircon and sericite are minor mineral constituents of the quartzite, and minor coarse-grained feldspathic sandstone also occurs. Common pitting, particularly in quartzite below the Treuer Member, were attributed to weathering out of possible euhedral pyrite by Wells and Moss (1983).

Wells and Moss (1983) defined the Treuer Member as a succession of siltstone and fine- to medium-grained, thinly bedded, flaggy sandstone, with a component of micaceous, haematitic and feldspathic grains, together with some glauconitic sandstone and possible evaporites between approximately 300 and 760 m in the type section.

Sedimentary structures in the Vaughan Springs Quartzite include cross-beds, ripple marks, flow casts and mud-pellet casts. In addition, orthoquartzite in the Treuer Member shows oscillation ripple marks and small-scale, probable worm tracks.

Conglomerate is widespread at the base of the Vaughan Springs Quartzite, although it is absent from the type section. The conglomerate typically comprises granules, pebbles and cobbles of quartzite and vein quartz. Granitic clasts are rare, despite the fact that the quartzite overlies granite or granitic gneiss in many places. However, Young et al (1995a) described granitic phenoclast-bearing pebble conglomerates in the basal Vaughan Springs Quartzite (Bigly member), overlying the Southwark Granitic Suite in MOUNT DOREEN. Similarly, Stewart et al (1980a) reported gneissic clasts in conglomerate at the base of the quartzite in the Emmagan Mountains in NAPPERBY. Wells and Moss (1983) reported some green illitic clasts that they attributed to a weathered granitic source. Concentrations of corroded magnetite crystals occur locally at the base of the conglomerate and are apparently responsible for the widespread magnetic character of basalt Vaughan Springs Quartzite in LAKE MAKAY. Where the lower Vaughan Springs Quartzite (Biglyly Member) is missing in western VAUGHAN, conglomerate occurs locally at the base of the Treuer Member (Young et al 1995a).

Young et al (1995a) defined the succession underlying the Treuer Member in the Treuer Range and extreme northwestern MOUNT DOREEN as the Biglyly Member, and the Eva Springs Member overlies the Treuer Member in the same ranges.
The Vaughan Springs Quartzite does not outcrop, and is not interpreted subsurface in LANDER RIVER. In MOUNT PEAKE, the white, pink or grey Vaughan Springs Quartzite has been divided into three informal members. The lowermost is predominantly a monomictic orthoconglomerate, with pebbles and cobbles of quartzite supported in a predominantly quartzose matrix (designated \(L_{Puv}\)). Locally, the matrix tends to clay and probably includes degraded feldspar, and also tourmaline and muscovite. Conglomeratic clasts are well rounded (Figure 24c) but are locally inequidimensional and show a well developed imbrication (eg at 255510mE 7586200mN) subparallel to bedding. This conglomeratic member is overlain by predominantly thickly bedded and planar, or low-angle cross-beded, or massive orthoquartzite and tourmaline- and/or muscovite-bearing orthoquartzite. This interval, designated \(L_{Puv}\), includes interbedded quartzite and vein quartz pebble conglomerate and granule-bearing quartzite. Scattered pebbles occur in otherwise clean homogeneous sandstone. Weathered-out shale clasts (mud-pellet casts) are common. According to Wells and Moss (1983), conglomeratic interbeds above the base of the Vaughan Springs Quartzite are uncommon. However, they are widespread in the Nanga Range in MOUNT DOREEN. Undulose partings between beds may reflect sand waves.

The upper interval of the Vaughan Springs Quartzite in MOUNT PEAKE is designated \(L_{Puv2}\). It comprises thinly bedded quartzite and muscovite-bearing quartzite, and is characterised by well sorted and well rounded, clay-cemented, medium- to coarse-grained quartzite that is intensely ripple marked and cross-beded. Sedimentary structures include markedly asymmetric pointed crested, slightly curved asymmetric, symmetric pointed crested (oscillation), and interference ripples, including cuspsate ripples. Sandstone in this upper interval includes fissile variants with a well developed parting. Stewart et al (1980a) reported scour-and-fill structures in the Nanga Range succession.

The basal conglomerate and overlying thickly bedded quartzites (\(L_{Puv}\)) are tentatively correlated with the Bigrlyi Member, and \(L_{Puv}\) with the Eva Springs Member, suggesting that the Treuer Member is absent or very thin in MOUNT PEAKE. Stewart et al (1980a) reported red and purple shale in the succession in the Yindjirbi Range. It is possible that these rocks correlate with the Treuer Member. Similarly, in the absence of conglomerate, a rather shaly facies of the Vaughan Springs Quartzite overlies basement near 255129mE 7583170mN, south of the Nanga Range. There is apparently a sharp contact between \(L_{Puv}\) and \(L_{Puv2}\) at, for example, 255268mE 758592mN.

The Vaughan Springs Quartzite thickens from about 300 to 2500 m from east to west in the Ngalia Basin and is (as noted above) about 1750 m thick in the type section, where both the bottom and top contacts are exposed (Wells and Moss 1983). The thickest succession is at Mount Carey in LAKE MACKAY. Stewart et al (1980a) estimated that the unit is at least 700 m thick in the Nanga Range in MOUNT PEAKE.

Figure 24. Vaughan Springs Quartzite. (a) View northwest to Nanga Range (highest point is Mount Leichhardt: 1024 m), with lowermost conglomeratic facies (\(E_{va}\)) of Vaughan Springs Quartzite in foreground (256770mE 7583162mN). (b) Benched topography \(E_{va}\), reflecting cyclically repeated fining-upward facies in this coarse clastic succession (223455mE 7572200mN). (c) Basal monomictic orthoconglomerate (\(E_{va}\)). Locally, inequidimensional pebbles and cobbles in conglomerate show well developed imbrication (255268mE 7585192mN).
The Vaughan Springs Quartzite unconformably overlies, or is faulted against granite or Arunta Region metamorphic rocks, and is unconformably overlain by the Yuendemu Sandstone and Mount Eclipse Sandstone, and probably also by the Mount Doreen Sandstone in MOUNT DOREEN. Diamictite, probably of the Naburula Formation, was reported by Wells and Moss (1983) to also unconformably overlie the Vaughan Springs Quartzite. The Albinia Formation is most probably disconformable on the quartzite in MOUNT DOREEN.

In the Nanga Range in MOUNT PEAKE, the Vaughan Springs Quartzite apparently unconformably overlies the Koonoonyeri Granite, although the contact is very planar. The overlying, conglomeratic, basal Vaughan Springs Quartzite maintains a very uniform thickness of 10 to 15 m over a strike length of about 20 km at this contact according to Stewart et al. (1980a). The contact is at least locally sheared. Local absence of the conglomeratic lithofacies at, for example, 255129mE 7583170mN, where a thin shaly interval of Vaughan Springs Quartzite immediately overlies basement, may indicate some local topography on the underlying palaeosurface. This palaeosurface had previously been interpreted by Stewart et al (1980a) to be a peneplain. The Vaughan Springs Quartzite unconformably overlies the Lander Rock Formation in the Yindjirbi Range. No contacts are exposed between the quartzite and basement in the Bau Range. There is no outcropping stratigraphy overlying the Vaughan Springs Quartzite in MOUNT PEAKE.

The Vaughan Springs Quartzite is correlated with the Heavitree Quartzite, although there may be no correlative of the Treuer Member in the Heavitree Quartzite. Wells and Moss (1983) reported that the Vaughan Springs Quartzite has also been correlated with the Townsend Quartzite of the Officer Basin, the lower part of the Yackah Beds in the Georgina Basin and with the Munyu Sandstone of the Murraba Basin (formerly included as part of the Birrindudu Basin). Walter and Veevers (2000) considered that the Vaughan Springs Quartzite is part of the ca 840 Ma and younger Supersequence 1 of the Centralian Superbasin and the Adelaide Fold Belt, and therefore, also correlates with the Mount Kinahan Sandstone of the Wolfe Basin, the Coondra Formation of the Savory Basin, and with the lower part of the basal Shanahan Conglomerate Member of the Paralana Quartzite of the Arkarooola Subgroup, in the Adelaide Fold Belt.

A sample of the Vaughan Springs Quartzite, from the ranges about 6 km northeast of North Bore in MOUNT PEAKE, is conservatively interpreted to have a maximum age of sedimentation of 1632 ± 11 Ma (Worden et al 2008). The youngest individual zircons from this sample are 1594 ± 30 Ma and 1594 ± 100 Ma. The majority of zircons in the sample record ages between ca 1800 and 1700 Ma, with a small number of grains having latest Neoarchaean or Siderian ages. These data suggest a predominantly Arunta Region provenance. The ca 1630 Ma population of zircons in the Vaughan Springs Quartzite may reflect a provenance that includes the Warumpi Province, or these zircons could be derived from scattered granites within the Aileron Province, for example the 1622 ± 7 Ma Enmungan Mountains granite. Young et al (1995a) reported unpublished data of CM Fanning indicating that possible volcaniclastic siltstone in the Treuer Member has zircons with U-Pb ages of 1400 Ma and older.

The timing of deposition of the correlative Heavitree Quartzite is not well constrained. It postdates deposition of the 1090–1040 Ma Tjauwata Group rift succession in the southwestern Amadeus Basin (Close et al 2003). A maximum deposition age is also provided by detrital zircon data, with a youngest population in the range 1280–1120 Ma (Maidment 2005). A minimum age constraint is given by the interpreted age of 820 Ma for basalt within the Loves Creek Member of the overlying Bitter Springs Formation (Zhao and Mc Culloch 1993).

Sedimentary characteristics and structures recognised in MOUNT PEAKE are consistent with deposition of the lower interval of the Vaughan Springs Quartzite in a shallow-marine environment. Sedimentary structures in the upper interval indicate an even more shallow-water, in part intertidal, depositional environment. This interpretation concurs with that of Stewart et al (1980a), who further interpreted that the uniform thickness of the basal conglomeratic facies in MOUNT PEAKE reflected deposition on a planation surface, and attributed the rounded quartzite clasts to a high-energy environment.

Evidence for alluvial sedimentation is not recognised in the succession in MOUNT PEAKE.

However, in the regional context, Wells and Moss (1983) and Walter and Veevers (2000) concluded that the Vaughan Springs Quartzite represents initial sedimentation in an alluvial fan; and that this was followed by intertidal and shallow-marine deposits that record (in common with the Heavitree Quartzite) two (or possibly three) transgressions. Ripple marks, mud-pellet clasts, and mud cracks (in addition to cross-beds) are, for example, common in the succession in MOUNT DOREEN (Young et al 1995a). Glaucolite and probable evaporite minerals or more specifically gypsum in the Treuer Member (Young et al 1995a) are consistent with partially restricted conditions of sedimentation within the succession, which were also reported by Wells and Moss (1983) and Stewart et al (1980a).

Lindsay (1991) recognised cyclicity in the Heavitree Quartzite, a correlative of the Vaughan Springs Quartzite. In each cycle, a channelled erosion surface is overlain by conglomerate and braided-river sand deposits, or by laminated lacustrine shale, in turn overlain by mixed fluvial and aeolian sandstone, and finally by cross-bedded tidal sandstone. The Heavitree Quartzite may include a greater proportion of proximal, alluvial fan sediments than the Vaughan Springs Quartzite.

The Vaughan Springs Quartzite is locally intensely folded, for example in the Nanga and Yindjirbi ranges in south-central MOUNT PEAKE. This deformation is attributed to the Alice Springs Orogeny.

Plenty Group

The Plenty Group has recently been defined by Kruse in Dunster et al (2007). The group is distributed in HUCKITTA, HAY RIVER, BARROW CREEK and MOUNT PEAKE, and comprises the Yackah beds and the Amesbury Quartzite. Only the latter unit is represented in MOUNT PEAKE, where it has a maximum outcropping thickness of ca 20 m, and extends onto adjacent BARROW CREEK. Haines in
Haines et al (1991) correlated the Amesbury Quartzite with the lower siliciclastic interval of the Yackah beds.

The Amesbury Quartzite is unconformably overlain by the Boko and Central Mount Stuart formations in BARROW CREEK (Haines et al 1991). It was previously considered a constituent, conformable, lowermost member of the Central Mount Stuart Formation (Offe 1978, Stewart et al 1980a). The unit is nonconformable or unconformable on granitic basement.

**Amesbury Quartzite**

The Amesbury Quartzite was originally named as a member of the Central Mount Stuart Formation by Offe (1978). Haines et al (1991) recognised that the Amesbury Quartzite is unconformably overlain by the glacial Boko Formation, which is, in turn, disconformably or unconformably overlain by the Central Mount Stuart Formation. Haines et al (1991) accordingly upgraded the Amesbury Quartzite to formation status. The unit is named after Amesbury Bore in MOUNT PEAKE (317600mE 7593900mN), and is restricted to scattered outcrops in central-eastern MOUNT PEAKE and central-western BARROW CREEK.

In MOUNT PEAKE, the Amesbury Quartzite comprises predominantly well sorted and well rounded, coarse-grained quartz arenite. Locally, the grains appear more angular (eg 335709mE 7604097mN), but this is due to quartz overgrowths on the original detrital grains. The sandstone is mainly orthoquartzite. However, at some localities, the sandstone is sugary weathering and may have a pink clay component. These characteristics are attributed to minor clay cement derived from degraded feldspar. Where the unit is more recessive, it is suggested that the sandstone may be more feldspathic.

At 334350mE 7605787mN, approximately 30 m of the exposed Amesbury Quartzite succession forms two distinct benches (and a possible third bevelled bench), suggesting some cyclicity in sedimentation. Some thin (ca 8 cm), granule conglomerate beds are present at the base of this succession. Higher in the Amesbury Quartzite succession, granular lag gravels are present, infilling ripple troughs. Typically, the quartzite is laminated to thinly bedded, with shallow-angle, planar cross-beds forming medium to thick bed sets, and at some localities, the sandstone is flaggy. Possible, large-scale hummocky cross-stratification occurs at 330987mE 7604505mN (Figure 25a). Weathered-out, flat shale clasts are common. Ripple marks are widespread and include straight-crested symmetric, sinusoid-crested asymmetric, bevelled, sinusous interference, and lunate ripples; long wavelength (ca 30 cm) ripples or waves are preserved at 330987mE 7604505mN. Channel features, 10–15 m wide, occur at 335200mE 7605869mN. Possible trace fossils of the Planolites type were recognised at 330987mE 7604504mN (Figure 25b, c). Haines et al (1991) described desiccation features in the sandstone in BARROW CREEK. These authors further reported that a thin basal conglomerate is locally present in BARROW CREEK, together with granular or pebbly sandstones, which have well rounded and well sorted quartz granules or pebbles in a medium-grained matrix.

Offe (1978) measured 20 m of succession in the type section, which is approximately 16 km east-northeast of Amesbury Bore at 330000mE 7599000mN, and up to 30 m of succession is estimated to outcrop at 334350mE 7605788mN.

The Amesbury Quartzite unconformably overlies basement. It is nonconformal on granite at, for example, 335200mE 7605869mN. Haines et al (1991) recognised that the quartzite is unconformably overlain by the Boko Formation and reported that this relationship is best exposed at LS509202 in BARROW CREEK; locally, the quartzite is also unconformably overlain by the Central Mount Stuart Formation. The Amesbury Quartzite and Central Mount Stuart Formation are in faulted contact at, for example, 333258mE 7612882mN, and drag folding is seen locally in the quartzite.

Stewart et al (1980a) reported an apparently conformable relationship between the Amesbury Quartzite and laminated siltstones and fine micaceous sandstones with clay galls near 333100mE 7613000mN. These latter rocks are now considered to be Grant Bluff Formation and to have a faulted contact with the Amesbury Quartzite at this locality. However, the extent of the Grant Bluff Formation in this area is too small for it to have been designated separately on the MOUNT PEAKE outcrop map.

The age of the Amesbury Quartzite is poorly constrained. It is unconformably overlain by the Boko Formation, which is correlated with the ca 600 Ma, Marinoan, Late Palaeozoic glacial deposits of the Adelaide Fold Belt. The maximum depositional age, based on detrital zircon populations in the correlative Vaughan Springs and Heavitree quartzites, does not preclude Mesoproterozoic sedimentation.

It is interpreted that the Amesbury Quartzite represents sedimentation in a high-energy nearshore to intertidal environment. Correlation with the basal sandstones of Supersequence 1 of the Centralian Superbasin, for example the Vaughan Springs and Heavitree quartzites, has been suggested by Haines et al (1991). The Amesbury Quartzite may correlate with the lower, siliciclastic interval of the Yackah beds (Dunster et al 2007).

**Keepara Group**

This group was redefined by Kruse in Dunster et al (2007). The group name was originally taken from the Keepara Ridges in southwestern TOBERMOREY by Walter (1980). The group is distributed in BARROW CREEK, ALCOOTA, HUCKITTA, TOBERMOREY, HAY RIVER, MOUNT WHELAN and DUCHESS, and is now recognised to extend into MOUNT PEAKE. Constituent units of the group throughout much of its range are the Black Stump, Oorabroa and Sun Hill arkoses, and the Wonnadinna Dolostone, Little Burke Tillite and Boko Formation. In MOUNT PEAKE, the group is represented by the Boko Formation, which includes a diamicite and possible cap carbonate, and by probable clastic equivalents of the Oorabroa Arkose.

**Boko Formation**

The Boko Formation was defined by Haines et al (1991). The name is derived from Boko Bore in MOUNT PEAKE (334200mE 7609500mN). According to the original definition, the Boko Formation was restricted to only four
Figure 25. Amesbury Quartzite. (a) Thin interval of dark, ferruginised and feldspathic fine-grained sandstone (330986mE 7604505mN). These sedimentary rocks may reflect original heavy-mineral-laminated sands in intertidal zone. This unit immediately overlies rippled sandstone with possible biogenic structures illustrated in Figure 25b–c. (b–c) Possible trace fossils of Planolites affinity (330986mE 7604505mN). Alternatively, these features could reflect desiccation, possibly associated with drying-out and rolling-up of cryptomicrobial films in an intertidal environment (cf Rhysonetron).
outcrops in BARROW CREEK, although it was correlated with a similar diamictite (at the base of the Central Mount Stuart Formation), exposed at two localities a few kilometres to the north of New Bore in WOODGREEN. The latter outcrops are now mapped as Boko Formation (Haines 2005). Furthermore, Haines and Scrimgeour (2007) recognised that low hills and rises covered by loose cobbles and boulders of diverse, faceted and striated rock types represent erosional remnants of the Boko Formation. Similarly, diamictite at the base of the Central Mount Stuart Formation is known at six localities (approximately 387128mE 7573170mN, 392128mE 7573370mN, 337129mE 7575370mN, 340129mE7575170mN,320129mE7579470mN,318129mE 7580170mN; see Stewart et al 1980a) in MOUNT PEAKE (Figure 26). Boko Formation is shown in the current MOUNT PEAKE mapface at the first two of these localities. The other exposures are too small to be depicted. Diamictite that can probably be assigned to the Boko Formation also outcrops in TEA TREE (Evans and Glikson 1969, Preiss et al 1978, Stewart et al 1980a).

According to Haines et al (1991), the Boko Formation comprises massive diamictite with a red-brown mudstone matrix that is only rarely preserved in exposures. Clasts are commonly faceted and striated, and include quartzite, granite, volcanic and metamorphic rocks, ranging in size up to 2 m, with the largest erratics typically being granite. Haines and Scrimgeour (2007) also identified conglomerate clasts in the Boko Formation in WOODGREEN. Stewart et al (1980a) have described the composition of the minor outcrops of diamictite in ANNINGIE and TEA TREE in detail. These descriptions indicate that, in addition to muscovite-quartzite and granite, lithic clasts include retrogressed amphibolite and mica schist. These clast types are consistent with a provenance including Lander Rock Formation that has been invaded by granite, with further detritus possibly derived from the Reynolds Range Group or Vaughan Springs Quartzite. Subangular grains include quartz, microcline, plagioclase, tourmaline, opaque minerals and calcite in a fine groundmass of authigenic biotite and sericite. The diamictite is cleaved and associated laminated silstone and shale comprise quartz and detrital muscovite in a groundmass of well crystallised (2M₁) muscovite. The indications are, therefore, that the Boko Formation in MOUNT PEAKE has undergone zeolite- or greenschist-facies metamorphism.

In addition to diamictite, varved siltstone and limestone/dolostone are also included in the Boko Formation in MOUNT PEAKE. A coarse-grained, thickly bedded to massive pebbly arkose, outcropping locally between Mount Chisholm and Murray Creek Dam (Stewart et al 1980a), may correlate with the Oorabra Arkose. Haines (2005) considered that recrystallised limestone/dolostone, at the top of the Boko Formation at the foot of Central Mount Stuart in MOUNT PEAKE, is probably diagenetic and is therefore a doubtful contender for a cap carbonate. The diamictite, varved siltstone and carbonate reach an exposed maximum thickness of up to a few metres in MOUNT PEAKE. Stewart et al (1980a) reported that ca 80 m of laminated siltstone and slate overlie diamictite near 334375mE 7575625mN, and contain traces of alunite, jarosite and gypsum. Alternating red and grey or green laminae reflect the presence of haematite or sericite, respectively. These rocks are here tentatively included in the Grant Bluff Formation. Haines et al (1999) estimated that the preserved thickness of diamictite at the type locality in BARROW CREEK is 20 m; however, the top is not exposed and poor outcrops elsewhere indicate a significantly greater thickness. The Boko Formation unconformably overlies Palaeoproterozoic basement in MOUNT PEAKE and BARROW CREEK, and also the Amesbury Quartzite in the latter. Haines and Scrimgeour (2007) described a probable glaciated pavement where the Boko Formation overlies the Utopia Quartzite in WOODGREEN. The formation interdigitates with probable equivalents of the Oorabra Arkose, and is disconformably (or unconformably?) overlain by the Elyuah Formation in MOUNT PEAKE. It is overlain, apparently conformably by the Oorabra Arkose and unconformably by the Elyuah Formation, in WOODGREEN, and is disconformably overlain by the Tops Member of the Central Mount Stuart Formation in BARROW CREEK. Details of stratigraphic relationships further to the east can be found in Dunster et al (2007).

Figure 26. Boko Formation: diamictite immediately overlain by thin carbonate (brown) at 316226mE 7580197mN.
The Boko Formation was correlated with ca. 600 Ma Marinoan glacial rocks of the Adelaide Fold Belt by Haines et al. (1991) and Haines and Scrimgeour (2007); previously, Walter (1980) had made a correlation with the earlier Sturtian glacigenic deposits of the Amadeus Basin and the Adelaide Fold Belt. Dunster et al. (2007) recorded that the Yardida Tillite (of the Aroota Group) in the southeastern Georgina Basin may correlate with the diamictite at the base of the Central Mount Stuart Formation in MOUNT PEAKE, or that the latter may be a correlative of the Boko Formation; ie the diamictite in MOUNT PEAKE may be either Sturtian or Marinoan. Haines et al. (1991) interpreted the Boko Formation diamictite to be a non-marine tillite. Varved shales are considered to represent a marked seasonal change in temperature. The Oorabra Arkose is interpreted to be a fluvo-glacial deposit in HUCKITTA and locally includes a wide range of phenoclast lithologies, whereas a basal conglomeratic facies to the north of Mount Thring has been interpreted as a fluvio-glacial deposit in HUCKITTA, and equivalent arkosic sandstones probably locally interdigitate with the Boko Formation in MOUNT PEAKE.

**Discussion**

Contemporary hypotheses for a widespread late Neoproterozoic (late Cryogenian and Ediacaran) interval of glaciation that involved glaciogenic deposition close to sea level at low latitudes are (1) the snowball earth and (2) low obliquity models, recently reviewed by Young (2004) and Williams (2004), respectively. The close temporal and spatial association of glacial and carbonate sediments remains perplexing. However, it is probable that the carbonates (and minor evaporites) may be more a consequence of aridity associated with cold, glacial conditions than a rapid warming of the climate from that associated with the glacial deposits.

Young (2004) considered that neither the number of Neoproterozoic glacial episodes nor the contemporaneity of any individual episode worldwide has been established.

Williams (2004) cited a number of lines of evidence that are apparently inconsistent with the snowball earth hypothesis. Regarding the Marinoan glaciation, for example, he reported that Grey (2001) concluded that the similarity of acritarch assemblages in pre- and post-Marinoan times (ie Cryogenian and Vendian / Ediacaran) does not lend biotic support to the hypothesis, which should be associated with rapid climatic change during this time interval. Similarly, Young (2004) concluded that the rapid onset and amelioration of glacial conditions is not consistent with evidence from the Palaeoproterozoic Huronian succession for progressive climatic deterioration prior to, and slow amelioration following glacial sedimentation in the Gowganda Formation in Canada. Furthermore, the existence of tidalites in Marinoan glaciogenic successions apparently necessitates that cold conditions prevailed near sea level and, according to palaeomagnetic data, at low latitudes. Young (2004) discussed that glacial conditions near sea level at low palaeolatitudes are difficult to reconcile with a marked seasonality in sedimentation.

**Mopunga Group**

The Mopunga Group is of Ediacaran age (Haines 2005, Kruse in Dunster et al. 2007). This group comprises the Elyuah, Grant Bluff, Elkera, Central Mount Stuart and Andagera formations, together with the Gnallan-a-gea Arkose, according to the redefinition by Kruse in Dunster et al. (2007). The group was originally defined by Noakes (1956) and was subsequently redefined by Smith (1964) and Walter (1980). Rocks originally mapped (Offe 1978, Stewart et al. 1980a) as Central Mount Stuart Formation in MOUNT PEAKE are here considered to encompass the Elyuah, Grant Bluff and Central Mount Stuart formations. The Gnallan-a-gea Arkose is seen to locally interdigitate with the Elyuah Formation in the Keepera Ridges in southwestern TOBERMOREY. Possibly equivalent clastic sediments interdigitate with the Elyuah Formation in MOUNT PEAKE, but have not been mapped separately.

Rocks of the group are widely distributed in the southern Georgina Basin in MOUNT PEAKE, NAPPERBY, BARROW CREEK, ALCOOTA, HUCKITTA, TOBERMOREY, HAY RIVER and MOUNT WHELAN. Previously, all Ediacaran-aged rocks in MOUNT PEAKE were assigned to the Central Mount Stuart Formation; however, the Elyuah, Grant Bluff and Central Mount Stuart formations are now mapped in southeastern MOUNT PEAKE and probable equivalents of the Gnallan-a-gea Arkose have also been recognised in this area.

Freeman (1986) suggested that a transgression, following localised erosion of the Oorabra Arkose during the Toomba Movement, was followed by deposition of the Mopunga Group. Kruse in Dunster et al. (2007) reported that the group overlies the Wonnadinha Dolostone with an inferred disconformity, and the Oorabra Arkose with a disconformity or a slight angular unconformity. Where the Keepera Group is absent, the Mopunga Group unconformably overlies Palaeoproterozoic rocks (basement). The group is overlain disconformably by Early or Middle Cambrian strata. These relationships constrain the age of the group to Ediacaran.

In MOUNT PEAKE, the Mopunga Group variously unconformably overlies Palaeoproterozoic (basement) rocks, or apparently disconformably overlies (or is faulted against) the Amesbury Quartzite (of the Plenty Group), Boko Formation and possible Oorabra Arkose equivalent stratigraphy of the Keepera Group. Locally, in the vicinity of 333000mE 7580500mN, 3.5 km northwest of Mount Browne, the Central Mount Stuart Formation overlies weathered unnamed basalt. This basalt is tentatively correlated with the Bitter Springs Formation in the Amadeus Basin. No stratigraphy has been identified to overlies the Mopunga Group in MOUNT PEAKE.

Haines (2005) interpreted that deposition of the Mopunga Group was controlled by east-south-east-trending synsedimentary faults that defined a graben or half graben extending from Central Mount Stuart to Mount Skinner. Along the southwestern margin of this graben, the Mopunga Group is dominated by deltaic clastic rocks of the Grant Bluff and Central Mount Stuart formations. Haines further reported that towards the graben axis, black mudstone of the Elyuah Formation underlies and is transitional to the Grant Bluff Formation, whereas carbonate, clastic and evaporitic
rocks of the Elkera Formation interdigitate and are overlain by the Central Mount Stuart Formation.

**Elyuah Formation**

The Elyuah Formation was defined in HUCKITTA (Smith 1964, Walter 1980, Freeman 1986) and also occurs in ALCOOTA and in MOUNT PEAKE. The formation is apparently confined to the Northern Territory portion of the Georgina Basin. The Elyuah Formation predominantly comprises laminated, fissile shale and is typically recessive or non-outcropping. Locally, a basal arkosic pebble conglomerate was called the Oorabra Arkose Member (Smith 1964), but this interval is now of formation status, in accordance with its unconformable relationship with the redefined Elyuah Formation. A few metres of basal pebble conglomerate are often all that is exposed of the Elyuah Formation in HUCKITTA, according to Freeman (1986). These pebble conglomerates could correlate with either the Oorabra or Gnallan-a-gea Arkose. In WOODREEN, Haines and Scrimgeour (2007) reported that the Elyuah Formation has been intersected in diamond drillholes CMS1–4, with a maximum thickness of 94 m in DDH CMS2. In drill core, the shale is black and micaceous with thin, fine-grained sandstone interbeds.

The formation has an estimated thickness of 60 m in MOUNT PEAKE; Smith (1964) estimated that the shale interval averages 90 m in thickness in HUCKITTA, and Freeman (1986) reported that 100 m of Elyuah Formation were intersected in diamond drillhole NTGS HUC3 in the Elua Range.

In MOUNT PEAKE, the Elyuah Formation comprises a succession of interlaminated, fissile, chocolate brown and green shale. Intervals of calcrete suggest that there are interbedded carbonate rocks within the succession. Interbedded, fine-grained, flaggy sandstone also occurs and dark chocolate-brown, channel cross-bedded feldspathic and granular sandstone outcrops at the interpreted top of the unit. The shale is described as brown and green in the stratigraphic definition, and Freeman (1986) similarly reported that it is of these colours, together with grey, in HUCKITTA. The colours indicate variable Fe²⁺ / Fe³⁺ + Fe⁰ ratios, and the black colour subsurface indicates significant organic carbon content.

Thin, dark chocolate-brown, pebbly to granular arkose intervals are intercalated with calcrete immediately beneath the shale dominated succession. Clasts in the granular beds consist of quartz, 2–3 mm across, and flat-shale or fine-grained sandstone, which is up to 2 cm across and of probable intraformational derivation. A metre-thick carbonate interval overlies Boko Formation tillite and interbedded sandstone and shale at 339750mE 7575750mN, and is similarly overlain by interlayered sandstone and shale. Interbedded shale and sandstone, above and below this possible cap dolostone, probably correlate with the Gnallan-a-gea and Oorabra arkoses, respectively. The Oorabra Arkose includes conglomerate, pebbly arkose, arkose, siltstone and shale (Walter and Veevers 2000).

These associations of rock types suggest a transitional relationship between the Boko Formation (which currently includes the local ‘cap carbonate’) and the Elyuah Formation. There is probable interdigitation of the Boko Formation and Oorabra Arkose-equivalent stratigraphy, and a similar interdigitation of the Elyuah Formation and the Gnallan-a-gea Arkose equivalents. Dunster et al (2007) reported that the Elyuah Formation laterally interdigitates with the Gnallan-a-gea Arkose, but conformably overlies this unit in the Keepera Ridges in southwestern TOBERMOREY. The Elyuah Formation and the Gnallan-a-gea Arkose are apparent correlatives in the southwestern Georgina Basin.

Calcrete intervals within Elyuah Formation shale and thin sandstone in MOUNT PEAKE suggest probable ongoing intercalation of clastic and carbonate lithofacies in the Elyuah Formation. Limestone is a rare constituent lithology of the predominantly micaceous siltstone and shale with thinly interbedded sandstone of the correlative Pertatataka Formation in the Amadeus Basin (Walter and Veevers 2000). In Walter’s (1980) redefinition, the Elyuah Formation was considered to disconformably overlie the Oorabra Arkose or the Wonnadinna Dolostone, and Haines and Scrimgeour (2007) suggested the Elyuah Formation is locally unconformable on the Oorabra Arkose or Boko Formation.

Haines and Scrimgeour (2007) recognised that the Grant Bluff Formation directly unconformably overlies basement in northern and western WOODGREEN (in ALCOOTA); ie, the Elyuah, Oorabra and Boko formations are absent. Smith (1972) reported that the Mopunga Group is only complete in HUCKITTA. However, all constituent stratigraphic units of this group, with the possible exception of the Elkera Formation, are apparently represented in MOUNT PEAKE, although not all are separately mapped at this stage. The presence of fairly complete Mopunga Group succession suggests that there may be little or no tectonic expression of the Toomba Movement in MOUNT PEAKE. Walter (1980) correlated the diamicite in MOUNT PEAKE that is now included in the Boko Formation with the older Neoproterozoic, Sturtian glaciene deposits of the Adelaide Fold Belt. This would imply a substantial hiatus (ca 300 my) in the succession in MOUNT PEAKE. As noted above, the Boko Formation was correlated with Marianoan glacial rocks by Haines et al (1991). The base of the Mariano cap carbonate (Nuccaleena Formation) is defined as the base of the Ediacaran System in the Flinders Ranges in South Australia. The Elyuah Formation in MOUNT PEAKE is therefore Ediacaran. It is correlated with part of the Pertatataka Formation in the Amadeus Basin, and the Brachina Formation in the Adelaide Fold Belt, respectively (Walter and Veevers 2000).

**Grant Bluff Formation**

The Grant Bluff Formation was defined by Walter (1980). The formation extends from the Queensland border to ALCOOTA according to Freeman (1986). It is now recognised to be more widespread in ALCOOTA than originally mapped. Haines and Scrimgeour (2007) reported that a number of outcrops of the Grant Bluff Formation in ALCOOTA were formerly mapped as the Central Mount Stuart beds by Shaw and Warren (1975). Similarly, the Grant Bluff Formation was previously mapped as a local basal unit of the Central Mount Stuart Formation, the Forster Member, in BARROW CREEK.
by Haines *et al* (1991). The Grant Bluff Formation is now recognised to extend into southeastern MOUNT PEAKE, where it forms minor outcrops to the south of Central Mount Stuart. Stewart *et al* (1980a) recognised that, lithologically, the lower part of the Central Mount Stuart Formation in MOUNT PEAKE was comparable with the upper part of the Grant Bluff Formation in the Elyuah Range in HUCKITTA. Walter (1980) suggested that up to about 400 m of the lower Central Mount Stuart succession in southeastern MOUNT PEAKE may be Elkera Formation (see Stewart *et al* 1980a: 214), although Walter's correlation chart also indicated the possible presence of the Elyuah and Grant Bluff formations at the very base of the Central Mount Stuart succession in MOUNT PEAKE. In the present mapping, both these latter formations are recognised in MOUNT PEAKE on lithostratigraphic grounds; however, the Elkera Formation has not been mapped separately and has been included in the Central Mount Stuart Formation, pending further work. The Elyuah and Grant Bluff formations comprise thicker intervals of the Central Mount Stuart succession than indicated in Walter's (1980) correlations. The Grant Bluff Formation is correlated with the middle to upper Pertatataka Formation of the Amadeus Basin (Dunster *et al* 2007).

Lithologically, the Grant Bluff Formation in HUCKITTA comprises laminated to thinly bedded, fine-grained quartz arenite and sublitharenite with micaceous partings. A lowermost and uppermost interval of well sorted and well rounded, medium- to coarse-grained, thinly to thickly bedded quartz arenite, forming prominent, laterally persistent horizons, bounds the unit (Freeman 1986). Cross-bedding and ripple marks are common. In ALCOOTA, the Grant Bluff Formation is predominantly a fine-grained, thinly bedded sandstone; it is typically flaggy and commonly ripple marked and has a well developed parting lineation (Haines and Scrimgeour 2007). The former Forster Member (equivalent to the Grant Bluff Formation) in BARROW CREEK is similarly a quartz arenite or feldspathic quartz arenite. However, in this area, a basal polymictic conglomerate is commonly present. The Grant Bluff Formation is locally pebbly in WOODGREEN.

In MOUNT PEAKE, the Grant Bluff Formation comprises micaceous quartzofeldspathic sandstone with abundant ripple marks and is low-angle, tabular cross-bedded. This sandstone is overlain by planar-bedded, alternating fine-grained sandstone and siltstone. Outcrops have a very benchy character, which suggests good lateral persistence and alternation (cyclicity) of facies. Ripple types include straight-crested symmetric and asymmetric; slightly sinuous or markedly sinuous crested; truncated; and interference variants, and desiccation features are seen superimposed on the latter. A basal succession is preserved at, for example, 327919mE 7569595mN and comprises: (a) medium to thick or massive bed sets of conglomeratic or pebbly, poorly sorted and poorly rounded arkose, overlain by (b) better sorted and rounded arkose in thin, medium or thick, tabular cross-bed sets, and (c) high-angle and channel cross-bedded, poorly sorted and poorly rounded arkose, and granular or pebbly arkose in thick to massive sets.

In BARROW CREEK, the Grant Bluff Formation (formerly the Forster Member of the Central Mount Stuart Formation) is apparently confined to planated areas of the weathered unconformity surface on the underlying basement. It is typically about 20 m thick, but varies up to about 40 m (Haines *et al* 1991). The formation has a similar thickness in northern WOODGREEN, although it is 150 m and 127 m thick in diamond drillholes CMS1 and -2, respectively, in southeastern WOODGREEN (Haines 2005). The Grant Bluff Formation in MOUNT PEAKE is estimated to be up to ca 120 m thick.

The Grant Bluff Formation is locally unconformable on basement in BARROW CREEK, as noted above. It is conformable on (and transitional with the) Elyuah Formation in HUCKITTA and MOUNT PEAKE; and is conformable on the Gnallan-a-gea Arkose. It is further considered to be conformable on the Elyuah Formation in WOODGREEN; however, the Elyuah Formation is very recessive and rarely exposed in this map sheet (Haines and Scrimgeour 2007). The Grant Bluff Formation is overlain by the Elkera Formation in HUCKITTA, and by the Central Mount Stuart Formation in BARROW CREEK and MOUNT PEAKE.

The Grant Bluff Formation in MOUNT PEAKE is interpreted to be shallow marine to intertidal. Pebbles in the localised, basal interval show imbrication and these poorly sorted and rounded sandstones are probably fluviatile.

Haines and Scrimgeour (2007) interpreted the Grant Bluff Formation to be shallow marine and deposited predominantly above storm wave base. In HUCKITTA, Freeman (1986) interpreted the formation to be shallow marine and associated with a transgressive cycle. In BARROW CREEK, the former Forster Member was similarly interpreted by Haines *et al* (1991) as being shallow or marginal marine and related to a transgressive cycle.

**Central Mount Stuart Formation**

The Central Mount Stuart beds were originally named by Smith and Milligan (1964) and defined by Offe (1978). The definition was modified by Walter (1980) to exclude a thin basal diamicite (now included in the Boko Formation). Haines in Haines *et al* (1991) recognised that the Amesbury Quartzite Member was unconformable with respect to the remainder of the central Mount Stuart Formation and consequently redefined this quartzite as a separate formation. He further excluded clastic sedimentary rocks in BARROW CREEK and northern ALCOOTA with an Early Cambrian ichnofauna (Octy Formation) from the Central Mount Stuart Formation, recognising that they disconformably overlie the latter unit. Haines and Scrimgeour (2007) excluded the Forster Member from the Central Mount Stuart Formation, reassigning these rocks to the Grant Bluff Formation. Thus, of the three members (Forster, Tops and Adnera) defined by Haines in Haines *et al* (1991), only the last two are now recognised as constituent units of the Central Mount Stuart Formation. The formation outcrops in southeastern MOUNT PEAKE (Figures 27a–c).

The Central Mount Stuart Formation is recognised in MOUNT PEAKE, southwestern BARROW CREEK, northern ALCOOTA and northeastern NAPPERBY. The unit comprises lithic, arkosic and quartzite arenite, siltstone, dolostone and minor conglomerate. The Tops Member comprises a lower interval of evaporitic and chertified dolostone, and dolomite sandstone, over lain by an upper
interval of red-brown arkosic and feldspathic arenite and siltstone, with varying proportions of interbedded grey-green mudstone. The overlying Adnera Member consists of similar, though generally cleaner, sandstone (feldspathic quartz arenite and orthoquartzite) and granular sandstone, both of which are characterised by cross bedding. These sandstones are red-brown or white, and there is a local uppermost interval of interbedded red-brown sandstone and siltstone.

The Central Mount Stuart Formation has an estimated thickness of 780 m in north-central ALCOOTA. The Tops Member is 114 m in the type section in south-central BARROW CREEK, but thickens southward to 580 m in DDH CMS1 in north-central ALCOOTA. The Adnera Member is 310 m thick in the type section near the boundary with ALCOOTA in southeastern BARROW CREEK and 200 m in central-northern ALCOOTA (in WOODGREEN), but is only 72 m in central-southern BARROW CREEK. Locally, erosion has removed the entire Adnera Member prior to deposition of the Lower Cambrian Octy Formation (Haines 2005). The boundary between the Tops and Adnera members in MOUNT PEAKE is poorly constrained by mapping to date. The occurrence of the medusoid *Halildaya brueri* in scree at about the 450 m level in the succession at Central Mount Stuart in southeastern MOUNT PEAKE (Stewart et al 1980a) suggests that the Tops Member extends to at least this level. Haines (2005) recognised that the Mount Skinner fauna dominated by *Halildaya brueri* is confined to a narrow interval of the Tops Member near the top of the succession in the south, but is higher in the member to the north, suggesting progressive northward onlap. Rare, typically Ediacaran trace fossils are found in the Tops and Adnera members, but the latter lacks body fossils. The Central Mount Stuart Formation conformably overlies the Elkera Formation in DDH CMS1 in southeastern WOODGREEN (Walter 1980), and conformably (and transitionally) overlies the Grant Bluff Formation in WOODGREEN (Haines and Scrimgeour 2007). The Central Mount Stuart Formation is locally disconformably or unconformably overlain by the Lower Cambrian Octy Formation (Haines 2005). However, in central and eastern WOODGREEN, the Octy Formation has been eroded and probable Chabalowe Formation directly overlies the Central Mount Stuart Formation (Haines and Scrimgeour 2007).

The contact between the Grant Bluff and Central Mount Stuart formations in MOUNT PEAKE is similarly apparently transitional. However, it is probable that there is a more clastic lithofacies of the Elkera Formation included in the lowermost Central Mount Stuart Formation, as currently mapped in MOUNT PEAKE. The top of the Central Mount Stuart Formation has probably been removed in MOUNT PEAKE and no units currently overlie it. The formation is estimated to be about 600 m thick in southeastern MOUNT PEAKE, after excluding approximately 60 m of the Elyuah Formation and 20 m of the Grant Bluff Formation from an 800 m succession exposed in the original type section (measured by Stewart et al 1980a), at Central Mount Stuart. It is possible (as noted above) that a further ca 200 m of this succession may be a more coarsely clastic equivalent of the Elkera Formation. However, this interval has been included in the Central Mount Stuart Formation in current mapping. The majority of the succession at Central Mount Stuart is

**Figure 27.** Central Mount Stuart Formation. (a) Central Mount Stuart Formation forming Mount Chisholm in southeastern MOUNT PEAKE (photograph by Alison Dean (formerly NTGS), 292561mE 7666834mN). (b) Western side of Central Mount Stuart looking north-northwest, with hill in middle distance comprising unnamed Precambrian basalt and Central Mount Stuart Formation non-conformably overlying granite. Mount Judith (331500mE 758300mN, in background), in common with summit of Mount Esther (approximately 333500mE 757550mN, but not in view) is also Central Mount Stuart Formation overlying granite. (c) Central Mount Stuart Formation on the southern flanks of Central Mount Stuart near 338500mE 7573750mN.
probably the more arkosic Tops Member, whereas markedly shallow-angle or trough cross-bedded, well sorted, coarse-grained and granular arkosic sandstone in medium to thick bed sets near the top of the succession is probably the Adnera Member.

Haines (2005) interpreted that the Central Mount Stuart Formation was deposited in a fluviodeltaic system, with an increasing marine influence to the east and upward through the succession, and interpreted a gradational contact between the Tops and Adnera members. It is probable that the change in bedding characteristics, and the coarse-grained and granular character of the upper interval of the Central Mount Stuart Formation (ie probable Adnera Member) in southeastern MOUNT PEAKE represents an influx of immature detritus from the northwest, as a consequence of tectonic rejuvenation of the source area. Fluvialite sandstone may have prograded across underlying shallow-marine to intertidal sandstone and siltstone. The Central Mount Stuart Formation is correlated with the Andagera Formation, and the Elkera Formation (in the southern Georgina Basin) (Dunster et al 2007).

PALAEOZOIC AND MESOZOIC (GEORGINA AND WISO BASINS)

The Palaeozoic and Mesozoic stratigraphic succession in LANDER RIVER comprises scattered sparse outcrops of the Wiso Basin. In particular, the Hanson River beds, Lake Surprise Sandstone and undivided Palaeozoic rocks outcrop in the north of the map area. Outcropping Mesozoic stratigraphy is restricted to the Buchanan Hill beds. As Second Edition mapping reported here was directed towards the Palaeoproterozoic geology of LANDER RIVER and MOUNT PEAKE, these outcrops of Wiso Basin stratigraphy were not revisited. Refer to Kennewell and Huleatt (1980) for a more complete discussion.

The Palaeozoic geology in MOUNT PEAKE is restricted to one small outcrop of the Devonian Dulcie Sandstone at 344500mE 7604250mN, on the extreme central-eastern boundary of the map. This outcrop comprises medium to thickly bedded, cross-bedded quartz arenite. The Dulcie Sandstone is part of the Georgina Basin succession. There is no exposure of Mesozoic rocks in MOUNT PEAKE.

CENOZOIC

The Cenozoic in LANDER RIVER and MOUNT PEAKE consists of surficial deposits, duricrusts, including ferricrete and calcrete, and intensely weathered rock. Silcrete also occurs in both mapsheets, but is relatively minor and has not been mapped separately.

Surficial deposits can be divided into: (1) those relating to the current cycle of weathering and erosion, and denoted Q, eg Qs (sheet and dune sand) and Qc (colluvium); and (2) those probably relating to an earlier cycle and correspondingly designated Cz, eg Czs and Czc. The distinction is made on the basis that the latter deposits, although generally poorly consolidated, either show evidence of dissection (Czc), reflecting more recent erosion in active watercourses, or are localised around topographic rises (Czs and Czg). Where outwash gravels and scree that are adjacent to quartz veins have a substantial quartz component, they are mapped as Qcq or Czq.

As noted in the introduction, lateritisation with the formation of ferricrete (Czf) and weathering of bedrock (Czd) was interpreted by Hays (1967) to postdate the Tennant Creek Surface of planation. Hays (1967) argued that there are no known early Paleogene sediments in the north that can be attributed to post-Cretaceous stripping of the Ashburton Surface. This suggests that stripping and consequent formation of the Tennant Creek Surface was contemporaneous with Cretaceous sedimentation to the north. Thus, lateritisation could be of Late Cretaceous to early Paleogene age (Kennewell and Offe 1979, Offe 1978, Huleatt 1978). Kennewell and Huleatt (1980) suggested that minor silcrete occurrences, particularly on the Hanson River beds in their type area in LANDER RIVER, probably relate to a late Oligocene episode of weathering (Canaway Profile) rather than to an earlier Late Cretaceous to Eocene episode (Morney Profile) in Queensland. Both of these profiles were dated by Idnurm and Senior (1978), but Bourman (1993) noted that the error on the age determined for the Canaway Profile (ie 30 ± 15 Ma) allows for the possibility that lateritisation may have extended through a considerable time interval.

Ferricrete and ferruginous lag gravels, the latter often flanking the former, outcrop as low rises, particularly in northwestern and eastern MOUNT PEAKE and southern LANDER RIVER. Where sand covered, low rises are mapped as Czs. Ferricrete forms low hills or mesas in MOUNT PEAKE (Offe 1978), and is also associated with a northwest-trending scarp in ANNINGIE, which probably reflects post-lateritisation reactivation of a northwest-trending fault system that has been active since the Palaeoproterozoic. Remnant ferricrete (and silcrete) hills are found, for example, in the Mount Peake and Conical Hill areas, and an extensive area of intensely weathered leached rock is found in the vicinity of the latter.

Qas, Qap and Qra are composite units, reflecting a probable genetic sequence or chronology. Note that the code Qra has been changed from the original Qar, as used by Stidolph et al (1988), in order to match labels in recently published, immediately adjacent mapsheets of the Aileron Province. Thus, Qas and Qap designate old watercourses, floodplains and poorly drained clay-filled depressions, occurring along relict drainage channels or in the lower reaches of floodplains that have been partially covered by subsequent sheet sand. Qra constitutes more mature alluvial soils, stabilised by mulga, and reflecting old floodplains and relict abandoned drainage channels. Calcrete (Qc) is also associated with relict palaeodrainage.

The distribution of mapped Cenozoic deposits and residua is based largely on the interpretation of aerial photographs and Landsat imagery. The interpretation mainly reflects textural and vegetational characteristics of the units mapped, eg swaled mulga is characteristically developed on red soil (Qr).

MOUNT PEAKE can be divided into predominant, aeolian sheet sand deposits in the west and alluvial deposits in the east. A northwest-trending breakaway in ANNINGIE, locally defined by scattered ferricrete, in part separates these areas of distinct surficial deposits. LANDER RIVER is
dominated by sand cover. Sand plains are prominent in the south and east, and alluvial deposits are inter-associated with sand, particularly in the southeast. The northern two-thirds of the mapsheet mainly comprises stabilised west-northwest-trending dunes. The extant channels of the Hanson and Lander rivers on the eastern boundary and in the southwest of LANDER RIVER, respectively, are marked by alluvial deposits and relict channels, including deposits designated Qas and Qra (see above). Similar deposits mark the current and former channels of the Hanson and Lander rivers, and Ingallan Creek in MOUNT PEAKE. Calcrete (Qc) is well represented proximal to Ingallan Creek. Lacustrine clastic and evaporitic deposits, which are widespread in interdune areas in LANDER RIVER, are designated QI.

A number of company reports present a more rigorous, genetic subdivision of the regolith over significant areas of MOUNT PEAKE, as a framework for geochemical sampling. Examples include: (1) regolith maps (provisional), based on the interpretation of RC9 black-and-white aerial photographs by Chenoweth in Lulofs and Wedekind (1996a) and Norris (1994); (2) regolith maps based on the interpretation of black-and-white aerial photographs and satellite TM imagery by Bolster in Caswell (1995); (3) regolith interpretations by Australian Photogeological Consultants Pty Ltd in southwestern MOUNT PEAKE and portions of the adjacent mapsheets; these are presented in Archibald (1996).

Cenozoic basins and probable, deeply incised palaeochannels also occur in MOUNT PEAKE. The Willowra Basin extends north-northeast from central-southern MOUNT PEAKE along Ingallan Creek to its junction with Lander River and parallels the course of this latter watercourse into southern LANDER RIVER. This basin occupies about 2200 km². The Ngalabaljirji Basin joins the Willowra Basin in central-southern MOUNT PEAKE (see Senior et al 1995: figure 1) and extends northwest into MOUNT THEO. This has a total area of about 4500 km² (a little more than half of this area is in MOUNT PEAKE). According to Howard (1982), the ‘Barkly Basin’ occupies an area of about 2500 km² in the vicinity of the old Mount Barkly homestead (235000 m E 7608000 m N). This basin appears to join the Willowra Basin to the north, and to overlap with the southeastern Ngalabaljirji Basin, where a palaeochannel extends along the northern flank of Mount Leichhardt between Ingallan Creek and Lander River. This basin is informally referred to herein as the eastern Ngalabaljirji Basin, and it appears that this basin may extend over a larger area than is indicated in Senior et al (1995: figure 1), ie between Mount Leichhardt and Bau Range. Howard (1982) reported that the basin appears to be divided by a north-trending basement high. According to Howard, a maximum thickness of 300 m of Cenozoic sediments in the western Willowra Basin overlie weathered bedrock and duricrust (silcrete and ferricrete) on Precambrian basement. This basin fill comprises about 15 m of unconsolidated late Cenozoic to Quaternary fluviatile deposits overlying consolidated material that includes earlier Cenozoic fluvial channel deposits. Locally, Ingallan Creek and the Lander River incise Cenozoic sediments to a depth of about 5 m. Senior et al (1995: figure 1) indicated that the Ti-Tree Basin just extends into extreme southeastern MOUNT PEAKE.

**GEOPHYSICS AND INTERPRETED GEOLOGY**

Paucity of outcrop in MOUNT PEAKE and LANDER RIVER necessitates the interpretation of geophysical data to extrapolate under cover (surficial deposits and Phanerozoic stratigraphy) and to elucidate a probable Palaeoproterozoic framework over a large part of the area. Preliminary interpretations of these mapsheets were presented by Offe and Stewart (1974), Kennewell and Matveev (1980), Stewart et al (1980a), Donnellan and Johnstone (2003) and Vandenber et al (2004). Australian Photogeological Consultants Pty Ltd (1995) produced a photogeological, lithostructural synthesis map, on behalf of North Flinders Exploration, over the latter's exploration leases in the 'North West Aruntas', an area that extends over ca 14 000 km² in southwestern MOUNT PEAKE, and adjacent NAPPERBY and MOUNT THEO. This map facilitated the recognition of a few faults in southeastern MOUNT PEAKE that were not immediately obvious in the remotely sensed datasets used in the present interpretation. Furthermore, the shear sense and (informal) names of a number of faults mentioned herein are also derived from the Australian Photogeological Consultants (1995) map.

Geological interpretations are extrapolated from known outcrops and are based on 400 m and 500 m line-spaced (semi-regional) airborne magnetic data for LANDER RIVER and MOUNT PEAKE, respectively, and 11 km-spaced Bureau of Mineral Resources (BMR) regional gravity data. Interpretation is further constrained by exploratory drilling to bedrock over many areas in MOUNT PEAKE and in southwestern LANDER RIVER. Subsurface data are also available from limited exploration drilling in northeastern LANDER RIVER. Some important reports with drillhole information that is relevant to validating the interpreted geology map include Hughes et al (1996), Hughes and Thompson (1996), Hughes (1996), Lulofs and Wedekind (1996a, b), Archibald (1996), Adrichem and Roberts (1999), Ashby and Schusterbauer (1998), Kettlewell and Longmire (1999) and Whittaker (2002). The recognition of the Central Mount Stuart and Boko formations in the subsurface in southwestern MOUNT PEAKE is based on this last source of information.

Early interpretations (Offe and Stewart 1974, Stewart et al 1980a) indicate that ca 70% of MOUNT PEAKE is underlain by Lander Rock Formation, and that this lithostratigraphic unit underlies the southern third of LANDER RIVER (Kennewell and Offe 1979, Kennewell and Matveev 1980 in Kennewell and Huleatt 1980, and Stewart et al 1980a). According to these interpretations, granite, together with small areas of outcropping Neoproterozoic stratigraphy make up the remainder of MOUNT PEAKE, and Wiso Basin stratigraphy underlies the northern two-thirds of LANDER RIVER.

The interpreted geology maps accompanying this report (Donnellan 2007b, 2008b) attempt to maximise understanding of the Palaeoproterozoic geology of the area. Accordingly, for example, Ooradidgee and Hatches Creek group geology is interpreted to underlie significant areas in the north and west of LANDER RIVER, although it is recognised that these rocks are overlain by Palaeozoic sediments of the Wiso Basin. Furthermore, the emphasis has
been on an attempt to extrapolate the known stratigraphy from the adjacent Tennant Region. The style of interpretation in LANDER RIVER and MOUNT PEAKE is somewhat different from that of adjacent mapsheets further to the west. A local increase in metamorphic grade and very poor outcrop to the west reduce the effectiveness of a more stratigraphic approach to geophysical interpretations in these mapsheets.

Gravity data indicate a major, probable crustal-scale feature in southwestern MOUNT PEAKE. This feature approximately coincides with the boundary between the Willowra Regional Gravity Ridge to the north, and the Caroline Gravity Ridge to the east of the Yuendumu Regional Gravity Low (Offe 1978: figure 2). These gravity features are long-wavelength, crustal-scale features. Magnetic data indicate that Lander Rock Formation stratigraphy continues across the boundaries between these different gravity domains. Consequently, these gravity features are not considered to represent a fundamental terrane boundary at the current level of exposure. However, fundamental terrane boundary is now recognised from seismic data between the Aileron Province and the Tanami Region further to the west (Huston et al. 2005). The juxtaposition of these two provinces predated deposition of the Lander Rock Formation. In this context, it is also noted that there is no evidence for a terrane boundary between the Aileron Province in LANDER RIVER–MOUNT PEAKE and the Tennant Region during the time interval from ca 1860–1790 Ma.

The majority of LANDER RIVER and MOUNT PEAKE south of the Wiso Basin is herein interpreted to be underlain by granite and the Lander Rock Formation. Offe (1978) suggested that the gravity contrast between the Willowra Regional Gravity Ridge and the Yuendumu Regional Gravity Low is a consequence of a smaller proportion of granite intruding the metamorphic basement rocks in the former area, by comparison with the latter area. However, a greater proportion of granite is now interpreted in the area corresponding with the Willowra Regional Gravity Ridge (Donnellan and Johnstone 2003, Donnellan 2007b) than had been suggested by previous workers. The ridge is probably a consequence of dense rocks in the deeper crust underlying these granites and the Lander Rock Formation, into which they intrude.

The magnetic Lander Rock Formation stratigraphy describes approximately a northwest trend and this is interpreted to reflect the predominant orientation of (F₁) fold hinges. Overprinting, northeast-trending (F₁) folds are interpreted to be locally expressed in the magnetic data, particularly in central-eastern MOUNT PEAKE. Shorter wavelength (F₂) folds have been mapped in the Walabanba Hills and are associated with an (S₁) axial planar cleavage or schistosity throughout the Lander Rock Formation. This generation of folding is not apparently interpretable in the magnetic data (at least at 1:250 000 scale). The Lander Rock Formation is interpreted to be preserved as (anticlinal) screens between granite, and as roof pendants within granite. Available gravity data do not allow the three dimensional geometry of the granites to be ascertained. However, geophysical modelling and the interpretation of seismic data in the Tanami Region has indicated that some of the granites in that area are comparatively thin (5–6 km) sheets (L.Vandenberg, NTGS, pers comm 2005). It is plausible that many of the granites in the Aileron Province (including those in MOUNT PEAKE) may have similar geometries. The granitic phase of the Anmatjira Orthogneiss in south-central MOUNT PEAKE has previously been considered to comprise sub-concordant, relatively thin sheet-like bodies (Vernon et al. 1990, Collins and Williams 1995). It is increasingly recognised that granites may form relatively thin sheets, although Pitcher (1993) considered this form is most readily attained in continental 'mobile belts'. Goleby et al. (2005) and Lyons et al. (2005) have reported that granite plutons imaged by a seismic survey in the Tanami Region, including the Coomarie and Frankenia granites, are thin bodies in the order of 1 km maximum thickness.

Faults similarly define a predominantly northwest-trending structural grain in MOUNT PEAKE and southern LANDER RIVER. Thus, the predominant orientation of folding and faulting, as interpreted from the magnetic data, apparently parallels the dominant structural grain in NAPPERBY to the south, and that of the Tennant Region and, in particular, the Davenport Province to the east. Individual major faults have been active at several times during the geological history of the area. Some of these faults can be demonstrated to have a north-over-south sense of movement and are reverse faults. Faults, for which the shear sense is most readily determined, were probably active during the Alice Springs Orogeny. They are generally localised in southwestern MOUNT PEAKE, and some are associated with phyllonite. Major faults approximately parallel the boundary of the Tennant and Arunta regions (see Donnellan and Johnstone 2004) but (as noted above) do not appear to represent a fundamental terrane boundary at the Lander Rock Formation, Bullion Schist and Ooradidgee Group level of stratigraphy. These units are in part correlated using the magnetic data.

There is very little outcrop of rocks of the Ooradidgee and Hatches Creek groups in LANDER RIVER and MOUNT PEAKE. However, they have been interpreted from geophysical data in the subsurface. The southern, fault-bounded margin of the Lander Trough in LANDER RIVER is a convenient (but apparently arbitrary) boundary between mapped and interpreted Lander Rock Formation stratigraphy of the Aileron Province and Ooradidgee Group (Tennant Region) stratigraphy in northern LANDER RIVER. Similarly, there is apparent continuity between the Ooradidgee Group and Lander Rock Formation across the boundary between northwestern BARROW CREEK and southwestern BONNEY WELL, on the one hand, and northeastern MOUNT PEAKE and southeastern LANDER RIVER on the other. Hatches Creek Group stratigraphy has been extrapolated across these same mapsheet boundaries from the Tennant Region to the Arunta Region. Although substantially invaded by granite across the mutual boundary of BARROW CREEK and MOUNT PEAKE, the Lander Rock Formation, Bullion Schist and Ooradidgee Group have been interpreted to be, at least in part, correlative. Their magnetic character further suggests that the Lander Rock Formation and Bullion Schist may be, in part, equivalent to the Junalki Formation in the Warramunga Province and that they probably, therefore, include a component of an older stratigraphy than is recorded in the Ooradidgee Group.

Field mapping differentiated a number of different packages of the Lander Rock Formation. A predominantly
The geological history of MOUNT PEAKE began with deposition of the Woodalla Member of the Lander Rock Formation. Lithostratigraphic correlation suggests that deposition of the Mount Stafford Member was penecontemporaneous with, or immediately postdated deposition of the turbiditic Lander Rock Formation in MOUNT DOREEN and MOUNT PEAKE. The Mount Stafford Member has a maximum depositional age of sedimentation of ca 1860 Ma (Claoué-Long et al 2008a).

Widespread deposition of the Lander Rock Formation probably occurred in the time interval ca 1860–1810 Ma, according to currently available geochronological constraints. The Lander Rock Formation is considered to be more proximal in eastern and northern MOUNT PEAKE than in the southwest, where it is probably a continuation of the turbiditic facies that is well represented in MOUNT DOREEN.

The Lander Rock Formation was intruded by predominantly gabbro and dolerite, but also by some probable ultramafic rocks. Outcrop data indicate that stratiform magnetic units are probably predominantly mafic units. These may include both intrusive sills and volcanic rocks. Gabbro in the vicinity of Waldrons Hill intruded prior to the emplacement of the 1814 ± 6 Ma unnamed granite, $\text{Pg}_1$.

Deposition of non-outcropping Ooradidgee Group rocks in northern LANDER RIVER is interpreted to be, at least in part, contemporaneous with Lander Rock Formation sedimentation.

The Lander Rock Formation (including the Mount Stafford Member) was deformed and metamorphosed during the ca 1805–1790 Ma Stafford Event. Metamorphism is variably of greenschist to granulite grade. Deformation involved three phases of folding, associated during a single progressive event.

Granite emplacement (eg Anmatjira Orthogneiss and Esther Granite) was penecontemporaneous with the Stafford Event and constrains the age of this event to 1805–1790 Ma. Events 1–5 above are considered to represent the Orosirian geological history of MOUNT PEAKE and LANDER RIVER, and the Stafford Event is approximately coincident with the Orosirian/Statherian boundary.

Emplacement of granite continued late in the Stafford Event, eg, the 1793 Ma Koonoonyieri Granite.

Deposition of the Reynolds Range Group, Mount Thomas Quartzite and Pine Hill Formation, apparently postdated the Stafford Event. Deposition of the essentially non-outcropping Wauchope Subgroup of the Hatches Creek Group in northern MOUNT PEAKE and LANDER RIVER was probably contemporaneous with that of the Reynolds Range Group, but see Claoué-Long et al (2008a) for a discussion of possible alternative correlates of the latter group.

Granite emplacement, eg the 1772 Ma Redhackle Granite, was penecontemporaneous with a second deformational event that is equated with the 1780–1770 Ma Yambah Event.

Granite emplacement immediately prior to, or contemporaneous with the Strangways Event is represented by the ca 1730 Ma Windajong Granite and unnamed equivalents.

A final phase of granite and associated porphyry magmatism, probably penecontemporaneous with the ca 1620 Ma Ennugan Mountains Granite, occurred prior to the ca 1590–1560 Ma Chewings Orogeny. This is the final stage of the Palaeoproterozoic (Statherian) geological history recognised in MOUNT PEAKE. It has not been identified in LANDER RIVER. The Chewings Orogeny is interpreted to be expressed in localised deformation of these late granites in southern-central MOUNT PEAKE, and in upper amphibolite-facies metamorphism of the Redhackle Granite, which resulted in new zircon growth. The Esther Granite was also affected by this event, as expressed by a Rb-Sr whole and mineral separate model 2 isochron age of 1535 ± 53 Ma, which is interpreted to represent post-Chewings Orogeny cooling. The Chewings Orogeny is apparently fairly close in time to the Statherian/Calymmian boundary.

Following the Chewings Orogeny, the expression of which is apparently confined to southern MOUNT PEAKE, there was a long hiatus prior to the deposition of the Vaughan Springs Quartzite and the probable correlative Vaughan Springs Quartzite in MOUNT PEAKE.
The youngest zircon population in the Vaughan Springs Quartzite is ca 1632 Ma. However, these quartzites are correlated with the Heavitree Quartzite and therefore have a 'preferred' age of ca 850 Ma or younger (Cryogenian).

13. An unnamed metabasalt, confined in outcrop to the flanks of a hill, 3.5 km northwest of Mount Browne in southeastern MOUNT PEAKE, may approximately correlate with mafic volcanic rocks of the ca 825 Ma Gairdner Event of Hoatson et al (2007).

14. Deposition of diamicrite, varved siltstone and limestone/dolostone of the Boko Formation ensued. This episode of glacigene sedimentation is correlated with the latest Cryogenian, Marinoan glacial deposits.

15. An unconformity between the Boko Formation and the overlying Mopunga Group is implied in the definition of the Mopunga Group as an unconformity-bounded succession. However, there is an apparent transitional relationship between the "Cap Dolostone" (included in the Boko Formation in MOUNT PEAKE) and the Elyuah Formation. Thus the Toomba Movement may not be expressed in MOUNT PEAKE.

16. Unnamed metabasalt in southeastern MOUNT PEAKE (see event 11) is unconformably overlain by the Central Mount Stuart Formation (ie, the Boko Formation is absent locally). This unconformity is considered to be the local expression of the Rinkabeena and/or Areyponga movements.

17. Mopunga Group sedimentation in MOUNT PEAKE includes the Grant Bluff and Central Mount Stuart formations. These formations comprise shallow-marine and fluvio-deltaic clastic rocks of Ediacaran age.

18. Formation of the Ashburton Surface (of planation) in the late Neoproterozoic or early Cambrian. Analogy with the Davenport Province indicates that this was dissected during the lower Middle Cambrian (Stewart et al 1986).

19. Scattered outcrops of the Palaeozoic Wiso Basin succession outcrop in LANDER RIVER. These comprise the early Middle Cambrian (Ordian to early Templetonian-aged Hooker Creek Formation), and the Lake Surprise Sandstone. The age of the latter has not been established, although it postdates the Ordovician (Arenigian) Hanson-aged Hooker Creek Formation), and the Lake Surprise Sandstone. The age of the latter has not been established, although it postdates the Ordovician (Arenigian) Hanson River beds (Kenneyellow and Huleatt 1980).

20. Formation of the Tennant Creek Surface (of planation) probably occurred in the late Lower Cretaceous or early Cenozoic, and subsequent lateritisation occurred prior to the mid-Miocene.

21. Cenozoic sediments are locally preserved beneath recent cover, and there are scattered outcrops of calcrete. A laterite profile or partial profile is preserved, particularly in the east and northeast of MOUNT PEAKE. Dissection of this profile suggests late-stage fault reactivation and uplift to the northeast, and a ferruginised northwesterly-trending breakaway parallels a major fault that records a protracted history from the Palaeoproterozoic to the Cenozoic.

**ECONOMIC GEOLOGY**

Recent exploration activities in MOUND PEAKE and LANDER RIVER have largely been directed towards U, Au and Ni. Exploration models suggest that potential styles of mineralisation might include: (1) Tennant Creek-style Au-Cu-Bi; (2) shear-hosted Au; (3) Dead Bullock/Granites style Au; (4) granite-related pegmatite, greisen, skarn and replacement-style Sn mineralisation; (5) unconformity-related Au-Pt-Pd-U (associated with the Vaughan Springs Quartzite); (6) sediment-hosted U in fluvialite sandstone in Cenozoic basins; (7) Yeelirrie-type U; (8) mafic-hosted vanadiferous magnetite and (9) orthomagmatic base metal mineralisation.

**Tin**

The only record of mineral production from LANDER RIVER and MOUNT PEAKE is that of a small quantity of tin from the Anningie tin field in the Walabanba Hills, particularly from the Reward Claim. Tin occurs at Reward as cassiterite in tourmaline- and muscovite-bearing pegmatite. It has also been recovered from alluvial/eluvial sediments at Reward; from about 800 m to the south-southeast and south at Halls Claim and Clarkes Application respectively; and also from Bismarks Show, about 1.5 km to the north of Reward. Kojan (1980) reported that there are widespread indications of tin in the Anningie tin field, associated with scattered pegmatite bodies, within which the tin is irregularly distributed. About 35 t of tin concentrate were produced from the Reward mine over the period 1935–1973. The alluvial deposits were shallow and of limited extent, but grades of up to about 24 kg/m³ were reported.

The tin-bearing pegmatites (and associated greisen) are deformed and, therefore, apparently intruded metasedimentary rocks of the Lander Rock Formation and interlayered amphibolites prior to regional deformation. The 1789 Ma Esther Granite is similarly syn-tectonic, has an anomalously high tin content and is considered to be probably parental to the Anningie tin-tantalum-bearing pegmatites.

The following brief summary of the Anningie tin field is derived from Frater (2005). Frater concluded that the tin at Anningie is associated with pegmatites of LCT (lithium-caesium-tantalum) type (see Černý's (1993), as is typical of tantalum, niobium and tin mineralisation throughout the Northern Territory. These pegmatites are in turn associated with peraluminous granites, in which tantalum, niobium and tin are thought to substitute as oxides for (TiO₄)⁴⁻. Both granite and pegmatite are pervasively greisenised by a late-stage, aqueous-rich, magmatic-pneumatolytic fluid. Mineralisation occurs in local pods within the typically barren granite, in pegmatic phases within the granite and in highly fractionated pegmatites surrounding the granite.

There are two, parallel, north-northeast-trending, tourmaline-bearing pegmatite dykes at Reward. The more easterly of these is spatially associated with a prominent quartz blow (apparently called the Black Angel; Powell 1981) and is unmineralised. The pegmatites intrude schist and amphibolite of a large roof pendant of the Walabanba Member in the Esther Granite. Mineralogical details, complex zoning and textural features of the pegmatites were described by Frater (2005) who recognised at least three generations of feldspar, the first of which is coarse grained and deformed (strained and fractured), in common with the
associated quartz. It is these early formed minerals that are interlocked with fractured tantalite and cassiterite.

**Copper-gold-bismuth**

Western Mining Corporation identified a number of coincident ground IP and gravity anomalies in a northwest-trending magnetic corridor in extreme southeastern MOUNT PEAKE (Mount Esther prospect). Two outcropping ironstones with anomalous Cu-Bi-(Au) were considered to be indicative of potential Tennant Creek-style targets. However, Wedekind (1995) reported that eleven holes drilled to test these targets intersected sheared and quartz-veined granite carrying disseminated magnetite and minor sulfides.

Exploration in extreme northeastern LANDER RIVER has targeted Tennant Creek-style, ironstone-associated copper-gold mineralisation in the Warramunga Formation (or time equivalents?), underlying Palaeozoic rocks of the Wiso Basin. Low-level aeromagnetic data have been used to identify magnetic targets, some of which have been drill tested. Geopeko’s Navigator anomalies (NAV 12–17) lie within LANDER RIVER, but are near the boundary with the adjacent TENNANT CREEK, GREEN SWAMP WELL and BONNEY WELL mapsheets. Williams (1978) reported that drill testing of the Navigator 12 and 14 anomalies demonstrated that they result from dorate and feldspar porphyry, respectively, and are unrelated to IOCG mineralisation. The interpreted geology map presented here suggests that Ooradidgee Group rocks probably immediately underlie the Palaeozoic succession in northeastern LANDER RIVER and that the Navigator anomalies are near the boundary between this stratigraphy and granite; the latter is interpreted to belong to the Treasure Suite.

**Mafic-hosted mineralisation (Ni, Cr, Cu, V, Fe)**

The Murray Creek prospect in MOUNT PEAKE was originally drilled by CRA in 1982, and Discovery Nickel in 2006, with both drillholes (1.5 km apart) intersecting magnetite-rich gabbro. Re-evaluation of Discovery Nickel’s hole ARD02 by TNG Ltd identified homogeneous magnetite-rich gabbro over at least 100 m, ending in olivine-rich ultramafic rocks. A sample from 34 m depth assayed 34.5% Fe, 0.59% V₂O₅ and 9.8% TiO₂, and surface drill spoil yielded similar grades (TNG Ltd, ASX Announcement 1 July 2008). Widespread anomalous vanadium has been recorded within a large magnetite-rich mafic granulite body at the Capricorn prospect beneath the Burr Plain north of Alice Springs. Six drillholes into this unit intersected broad zones of anomalous vanadium (400–1000 ppm V₂O₅) over an area of 9 km² (Western Desert Resources Ltd, ASX Announcement 15 January 2008).

Wedekind (1995) also reported that drill testing of five, high-amplitude airborne magnetic (and coincident surface Ni, Cr and Cu geochemical) anomalies at Tompkins prospect, in the vicinity of Conical Hill in central MOUNT PEAKE, intersected variably serpentinitised and metamorphosed, discrete, ultramafic intrusive bodies including olivine cumulates; below the depth of weathering, olivine and pyroxene were very fresh. At the same prospect, weak gold anomalies, associated with northwest-trending quartz veins (that have apparent boxworks after sulfides) were also drill-tested and variably quartz-veined gabbro was intersected below these anomalies (Wedekind 1995). This suggests similarities with dolerite-associated gold mineralisation in the Kurinelli goldfield in the Davenport Province of the Tennant Region, and also with that at Waldrons Hill in LANDER RIVER and Prospect D in BARROW CREEK.

Lulof and Wedekind (1996a, b) reported that dipole anomalies in both the Conical Hill area and in an area about 7 km north-northwest of Anninie Homestead were tested as possible kimberlites. BHP Minerals (1984) identified a ca 850 nT magnetic and coincident 6–7 mgal gravity anomaly east-northeast of Duck Hole (at about 278700mE 7634050mN). These anomalies were attributed to hornblende-bearing, quartz-feldspar-biotite gneiss, containing traces of magnetite and pyrite. In the MOUNT PEAKE interpreted geology map, this magnetic high is attributed to mafic rocks, including quartz diorite.

Hoatson and Stewart (2001) investigated the mafic sills and dykes intruding the Mount Stafford Member in NAPPERBY and south-central MOUNT PEAKE, in the context of a regional study of mafic and ultramafic rocks of the Arunta Region and their economic potential. They concluded that these particular mafic rocks are too evolved for platinum group element and/or chromium mineralisation, and, at least at the current level of exposure, are volumetrically too small to host significant base-metal sulfide mineralisation.

**Gold**

North Flinders Mines Ltd (NFM) undertook exploration in an area of the northwestern Arunta, extending over contiguous areas of MOUNT PEAKE, NAPPERBY, MOUNT DOOREN and MOUNT THEO. From airborne magnetic data, they interpreted that this area was on a major linear feature extending from the Granites–Tanami region (Archibald 1996). This structure is now interpreted to represent an old terrane boundary, related to the juxtaposition of the Arunta and Tanami regions prior to deposition of the Lander Rock Formation (Huston et al 2005). NFM’s principal exploration target in this area was the Lander Rock Formation, and they considered that possible mineral occurrences may include the following styles: (1) shear hosted; (2) Dead Bullock style, i.e. controlled by anticlinal folding and iron-rich lithologies; (3) granite-related (greisen, skarn, replacement and pegmatitic) mineralisation; and (4) unconformity-related Au-Pt-Pd-U, associated with the Vaughan Springs Quartzite. Archibald (1996) identified shear-hosted gold-anomalism/mineralisation characterised by haematite-chlorite alteration and brecciated textures. This is associated with the northwest-trending Lander Fault, which they interpreted as separating low-metamorphic-grade Lander Rock Formation from the high-metamorphic-grade Mount Stafford Member. Mineralisation is polymetallic and occurs particularly at the intersection of the Lander Fault and west-northwest- or west-striking major faults (eg Giles Range and Anzac Dam faults), which were interpreted to be high-angle reverse faults with a sinistral strike-slip component. These faults are associated with quartz veins and were probable major fluid pathways. An alteration
map for the Bailey Creek area in the Yindjirri Range was presented in Greenaway (2000) and shows broad zones of chloritic (-pyritic) alteration. Greenaway described these alteration zones as being surrounded by sericitic and silicic sedimentary rocks, with mineralisation localised at the contact between chloritic and sericitic alteration zones.

Adrichem and Roberts (1999) reported that a small amount of surface gold was seen during a journey of exploration from Barrow Creek to the Granites–Tanami region by Chewings in 1909, presumably in the vicinity of Waldrons Hill in LANDER RIVER. These authors further reported that a small, but unknown quantity of gold was mined from a shallow shaft and cosestan in the 1930s by Waldron, in the vicinity of the hill that bears his name. Exploration in the Jarrah Jarrah Range in southeastern LANDER RIVER (which is now of essentially historical interest) was reported by Brown (1973). He recognised that the Davenport Province geology of the Taylor and Crawford ranges (in BARROW CREEK) extended into southeastern LANDER RIVER, and reported that low-grade base metals are known from shear zones in the area. Brown (1973) also reported discontinuously outcropping calc-silicate rocks (locally with boxwork textures), comprising garnet, diopside, vesuvianite, titanite and minor apatite, with scheelite and rare earth elements, to the south of the quartz-filled shear zone comprising the Jarrah Jarrah Range.

In a series of reports from 1996–1999, Normandy NFM Ltd presented details of extensive exploration undertaken as a part of their Willowra Project, in an area extending over parts of MOUNT SOLITAIRE, MOUNT THEO, northeastern MOUNT PEAKE and southwestern LANDER RIVER. Three scenarios that were considered prospective for gold in the Arunta Region in MOUNT PEAKE by Adrichem and Roberts (1999) were: (a) discordant stockworks of what was described as 'relatively' late quartz veins; (b) gold-bearing shear-hosted veins with marked associated alteration; and (c) iron-related magnetic aureoles. During the course of this exploration program, zones of multi-element anomalism were defined and were referred to as the Emperor 1–7 prospects. These include Emperor 3, a discontinuous zone of Au, Bi, Zn, Ag, Cu, Ni, As and Mo, extending over more than 30 km in a broadly WNW orientation, and extending into MOUNT PEAKE and probably also into LANDER RIVER. Similarly, in Emperor 4, Au, As, Bi and Ag anomalism extends discontinuously west-northwest over about 20 km from MOUNT SOLITAIRE to LANDER RIVER.

Uranium

A number of the granites in MOUNT PEAKE have (at least locally) elevated uranium contents (eg Esther and Koonoonyeri granites). This is also true of the granites in northern NAPPERBY (see Stewart et al 1980a). Howard (1982) reported that granites in the Nanga Range (herein mapped as Koonoonyeri Granite) average 10 ppm U$_3$O$_8$, but range up to 110 ppm, and the granites in southern MOUNT PEAKE and northern NAPPERBY were considered a potential source of uranium for redistribution and concentration in Cenozoic basins (eg the Willowra and Ngalabaldjiri basins) in MOUNT PEAKE. Greisen at the Reward tin mine contains 0.024% U$_3$O$_8$ (Daly and Dyson 1963). Anomalous levels of uranium have also been recognised in water bores, for example, at Nintabrina Bore in north-central NAPPERBY, according to Kojan (1980), who further reported that uranium concentrations drop off markedly over 15 km to the northwest, towards Big Bore in southern MOUNT PEAKE. Kojan (1980) considered that previous drilling by CRAE and Tanganyika Holdings in the early 1970s, exploring for calcrete-hosted Yeelirrie-style U-deposits, was inconclusive. Kojan (1983) reported that although water samples from drillholes were highly anomalous in U, intensive exploration had failed to identify a uranium deposit, and uranium anomlasm in groundwater was attributed to the release of uranium from xenotime during greisenisation. The Anzac Dam uranium prospect is associated with calcereated granite and secondary carnitite, which was similarly attributed to derivation from (xenotime in) biotite-rich shear zones. This granite is greisenised and kaolinised. Small concentrations of uranium, associated with calcrete, developed on granite in the immediate subsurface, and associated with the Enmugan Mountains Granite, were reported from drill intersections by Kojan (1983).

Scott (1974) interpreted calcrete, developed immediately west of Ingallan Creek in the vicinity of Crows Nest Well and Ajax Bore, to be probably pedogenic and reported that it apparently has no potential for significant uranium mineralisation.

Howard (1982) reported on exploration for sediment-hosted uranium mineralisation in fluviatile units in the western Ngalabaldjiri Basin, which covers an area of about 2500 km$^2$ in western MOUNT PEAKE, between the Nanga and Bau ranges. A reconnaissance resistivity survey was used to delimit a broad, deep (up to about 300 m) Cenozoic basin. Consolidated sediments within the basin overly an intensely weathered and lateritisied Proterozoic basement. Inflow and outflow channels were identified, the latter including the Willowra channel to the north, which contains unconsolidated sediments, attributed to late Cenozoic and early Quaternary fluvial activity, at the top of the Cenozoic basin succession. Howard (1982) reported that the level of surface oxidation is deep and that evidence for reducing conditions, reflected by carbonaceous shale and pyrite, was identified in only three drillholes.

Water resources

The following brief summary of the water resources of LANDER RIVER and MOUNT PEAKE is based on Read (2005).

Cenozoic strata host the best aquifers in MOUNT PEAKE, where these surficial deposits are thick enough to extend below the water table in both contemporary creeks and palaeochannels, and particularly in the Willowra and Ngalabaldjiri basins. In the Ngalabaldjiri Basin (previously informally called the Barkly Basin), Read (2005) noted the occurrence of saline water and reported that the extent

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2 At Yeelirrie (WA), uranium mineralisation is hosted in calcrete in palaeodrainages, rather than in laterally more extensive sheets.
of fresh water is unclear. In LANDER RIVER, the only known Cenozoic aquifer is immediately adjacent to the contemporary channel of the Lander River, and the three bores known to tap into this have produced yields of 0.4 to 1.8 L/s.

Read (2005) reported that an aquifer tapped by bores within the Wisio Basin is of uncertain significance, because, although these bores have a well defined stratigraphy, the depth from which water was obtained was not recorded. The Lake Surprise Sandstone of the Wisio Basin has produced yields of 1.5 to 6 L/s, with a wide range of total dissolved salts (150 to 3100 mg/L TDS). Read suggested that this stratigraphic unit may host a potentially major groundwater resource; however, an assessment of the extent of low-salinity water cannot be made from the data that are currently available. The Hanson River beds have yielded flow rates of between 1 and 5 L/s, with between 800 and 9100 mg/L TDS, with water apparently derived from both carbonate rocks and sandstone within this succession.

There are no known bores into the Central Mount Stuart Formation. A small number of bores into the Amesbury Quartzite suggest that flow rates of about 1 L/s can be obtained from depths of about 40–60 m within this unit. Read (2005) reported seventy-seven other bores in MOUNT PEAKE as penetrating rocks of the Arunta Region, with aquifers comprising both intensely weathered rock or saprolite, or little-weathered but fractured rock, with the fractures enhanced by weathering. Seventy-four of these bores have recorded yields from a median depth of 51 m, but the median flow rate is 0.1 L/s and only five bores had yields above 2 L/s; the median TDS for these seventy-four bores was 3500 mg/L.

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**APPENDIX 1: STRATIGRAPHIC DEFINITIONS**

**Esther Granite**

**Proposer:** N Donnellan  
**Derivation of name:** After Mount Esther (53K 3313750mE 7573200mN) in southwestern ANNINGIE.  
**Synonymy:** None.  
**Distribution:** The Esther Granite outcrops sporadically over an area of ca 650 km² in southern ANNINGIE from Mount Esther to Mount Judith, Central Mount, Amadeus Bore and the Walabanka Hills. Geophysical data indicate the granite does not extend widely beyond the limits of these scattered outcrops, but suggests the granite may extend locally onto northeastern NAPPERBY, northwestern ALCOOTA and southwestern BARROW CREEK.  
**Type / reference areas:** The type area is in the vicinity of Old Yards Well at 53K 312242mE 7595271mN (which is also the sample site for SHRIMP single-crystal zircon U-Pb geochronology). Three reference areas are nominated as examples of three further principal textural variants (see below) of the Esther Granite, these are: (1) around Central Mount (53K 318248mE 7573912mN); (2) to the north of Mount Esther (53K 329249mE 7574747mN); and (3) near Amadeus Bore (at 53K 314339mE 7596767mN).  
**Lithology:** The Esther Granite is a grey, biotite granite and typically has a K-feldspar megacrystic texture. The type Esther Granite is characterised by extremely large (to 15 cm), elongated K-feldspar megacrysts, and outcrops around Old Yards Well and the Walabanka Hills. The first textural variant is well represented around Central Mount and is characterised by inequidimensional, but much smaller (1.5–2 cm) K-feldspars. A second textural variant has equidimensional K-feldspar megacrysts to approximately 5 cm and is represented around Mount Esther. A third textural variant is coarse to very coarse equigranular (or seriate porphyritic) and occurs in the vicinity of Amadeus Bore. Pegmatite is an additional phase of the granite.  
**Relationships and boundary criteria:** The Esther Granite intrudes the Lander Rock Formation and is unconformably overlain by Boko, Grant Bluff and Central Mount Stuart formations and by unnamed, probably Neoproterozoic basalt. Coarse andalusite porphyroblasts in the Lander Rock Formation proximal to the Esther Granite are attributed to probable contact metamorphism.  
**Geomorphic expression:** The Esther Granite typically outcrops as low whalebacks and boudery nubbins.  
**Correlatives:** None known.  
**Age and evidence:** The Esther Granite has a SHRIMP single-crystal zircon U-Pb igneous crystallisation age of 1789 ± 6 Ma (Cross et al 2005).  

**Koonoonyeri Granite**

**Proposer:** N Donnellan  
**Derivation of name:** Koonoonyeri Bore 53K 258775mE 7592200mN.  
**Synonymy:** None.  
**Distribution:** The Koonoonyeri Granite outcrops to the north of the Anzac Dam Fault Zone in southern-central MOUNT PEAKE, particularly proximal to the Nanga Range. The
granite is interpreted from geophysical data to extend over an area of ca 1500 km².

**Type area:** In the vicinity of 53K 263263mE 7574234mN.

**Lithology:** Grey, biotite granite characterised by equant K-feldspar megacrysts. Locally mylonitic or phyllonitic. A discrete, high-U phase of the granite is mapped separately (Pgk.), and is characteristically deeply weathered in outcrop. This phase outcrops immediately to the east of Nanga Range (eg at 263250mE 7586000mN).

**Geomorphic expression:** Whalebacks and bouldery nubbins.

**Correlatives:** The Koonooyni Granite is comparable in age to the Anmatjira Orthogneiss, which has an igneous crystallisation age of 1795 ± 4 Ma (Worden et al 2008), but unlike the Koonooyni Granite, the Anmatjira Orthogneiss is a rapakivi granite.

**Relationships and boundary criteria:** Locally, intrudes probable Lander Rock Formation (in the vicinity of 53K 262500mE 7577250mN). Unconformably overlain by Vaughan Springs Quartzite.

**Age and Evidence:** The Koonooyni Granite has a SHRIMP single crystal zircon U-Pb igneous crystallisation age of 1793 ± 3 Ma (Worden et al 2006).

**Lander Rock Formation**

**Proposer:** C Edgoose, after Vandenberg et al (2005).

**Derivation of name:** Lander Rock (NAPPERBY) 53K 282250mE 7537125mN.

**Synonymy:** Lander Rock beds (Shaw and Stewart 1975), Lander Group (Meixner et al 2004b), Lander beds (Donnellan 2004).

**Constituent units:** Unnamed unit Plt, (MOUNT THEO; Vandenberg et al 2005); Walabanba Member and Anningie Member (MOUNT PEAKE, LANDER RIVER); Mount Stafford Member (NAPPERBY, MOUNT PEAKE); Woodalla Member (MOUNT PEAKE).

**Distribution:** Sporadically exposed, but interpreted to be extensive throughout northwestern Aileron Province of Arunta Region (MOUNT THEO, MOUNT SOLITAIRE, HIGHLAND ROCKS, MOUNT DOREEN, LAKE MACKAY, MOUNT RENNIE, MOUNT LIEBIG, NAPPERBY, MOUNT PEAKE, LANDER RIVER).

**Type area:** Greenschist facies: around 22°2'29.76"S, 131°14'14.64"E, in low hills northeast of Moyles Dam, MOUNT DOREEN; rocks include tightly upright-folded, fine-grained muscovite-chlorite psammitte, pelite and rare quartzite, with strongly developed cleavages associated with multiple folding events.

**Reference areas:** Amphibolite facies: around 22°6'21.6"S, 131°34'9.12"E, in low hills in area of Mount Hardy Mines, MOUNT DOREEN; rocks include biotite-muscovite-andalusite schist and psammitte, tightly upright folded with strongly developed cleavages. Transitional granulite facies: in vicinity of 22°12'12.6"S, 131°37'51.24"E, in low hills at southern end of Ngadarunga Hills, west of Yuendumu, MOUNT DOREEN; rocks include garnet-sillimanite-cordierite-biotite migmatic pelitic and psammitic gneiss, with minor mafic to intermediate metaigneous rocks and rare calc-silicate rocks.

**Thickness:** Generally unknown, as succession is tightly multiply folded, but estimated to be 3–4 km in MOUNT PEAKE.

**Geomorphic expression:** Generally low hills and rises.


**Depositional environment:** Dominantly marine; turbiditic, but with lateral variants, eg, probable shallow water (Walabanba Member) and shallower marine (unnamed unit Plt.).

**Relationships and boundary criteria:** Lower contacts not observed. Unconformable upper contact with overlying Mount Thomas Quartzite of Reynolds Range Group preserved in Reynolds Range (NAPPERBY) and Wabudali Range (MOUNTDOREEN). In many places, stratiform mafic rocks occur within the sedimentary and metasedimentary succession, at corresponding metamorphic grade, eg mafic granulite within granulite-facies metasedimentary rocks. It is not known whether these mafic rocks are extrusive or intrusive, or whether they represent more than one phase of igneous activity prior to tectonometamorphic events. The Lander Rock Formation is extensively intruded by granites with ages in the range 1805 Ma, 1790–1760 Ma (most voluminous group), 1730 Ma, 1640 Ma and 1570–1550 Ma.

**Age and Evidence:** Palaeoproterozoic, Orosirian. Maximum deposition ages in range 1860–1830 Ma obtained from across area of distribution by SHRIMP U-Pb zircon dating (eg Kinny 2002, Cross et al 2005, Worden et al 2006).

**Correlatives:** Killi Killi Formation of Tanami Group (Tanami Region). Probable correlative of lower Ooradidgee Formation (Tennant Region). Correlates (at least in part) with Bullion Schist (BARROW CREEK).

**Comments:** Formation is metamorphosed at varying grades, but is dominated by greenschist-facies rocks. Transition to amphibolite-facies rocks is generally gradational, but is, in some cases, associated with fault contacts. Granulite-facies rocks are of restricted extent and appear to be related to local thermal spikes during regional metamorphic events. Age of metamorphic and tectonic overprint is largely attributed to 1810–1800 Ma Stafford Event, but in some places, high-grade metamorphism is related to younger events eg 1600–1590 Ma Chewings Orogeny in Reynolds Range area (NAPPERBY).

**Redhackle Granite**

**Proposer:** N Donnellan

**Derivation of name:** Redhackle Dam 53K 218400mE 7573000mN.

**Synonymy:** None.
Distribution: The Redhackle Granite outcrops sporadically in southwestern MOUNT PEAKE, in the vicinity of Giles Range and Western Creek Yard. Minor outcrops to the west-southwest and southwest of Woodalla Bore are also included in the Redhackle Granite. Locally, the granite extends in outcrop into northwestern NAPPERBY. Geophysical data and company drilling indicate that the granite probably extends over an area of about 1000 km² in southwestern MOUNT PEAKE, over a further 150 km² in northwestern NAPPERBY, and extends locally into southeastern MOUNT THEO.

Type area: A small group of granites extending over an area of about 6 km² centred on 53K 222000mE 7576500mN.

Lithology: The Redhackle Granite is a grey, K-feldspar megacrystic biotite-orthogneiss or granite and includes aligned tabular, coarse equant and minor rapakivi (sensu lato) feldspar megacrystic textural variants. Rapakivi feldspar tends to be euhedral, rather than classically rounded, although locally, the texture is more typically wiborgitic.

Geomorphic expression: Gneissosity results in a generally tabular outcrop morphology, although locally less deformed granite forms bouldery nubbins.

Correlatives: None.

Relationships and boundary criteria: Intrudes Lander Rock Formation.

Age and Evidence: The Redhackle Granite has a SHRIMP single crystal zircon U-Pb igneous crystallisation age of 1772 ± 3 Ma (Worden et al 2006).

Windajong Granite

Proposer: N Donnellan

Derivation of name: Mount Windajong 53K 279750mE 7672675mN.

Synonymy: None.

Distribution: The Windajong Granite occurs as a few outcrops scattered over an area of ca 40 km² in north-central MOUNT PEAKE. The granite has a distinctive geophysical expression and defines a subcircular non-magnetic gravity low, extending over an area of ca 160 km², which extends from MOUNT PEAKE to extreme south-central LANDER RIVER.

Type area: 53K 281500mE 7671500mN, approximately 2 km southeast of Mount Windajong.

Lithology: Even grained (to seriate porphyritic) two-mica granite.

Geomorphic expression: Low whalebacks.

Correlatives: Possible member of the Devils Suite of the Tennant Region.

Relationships and boundary criteria: Inferred on geophysical evidence to intrude Lander Rock Formation, but contacts are not exposed.

Age and Evidence: The Windajong Granite has a SHRIMP single crystal zircon U-Pb igneous crystallisation age of 1730 ± 3 Ma (Cross et al 2005).

Walabanba Member

Proposer: N Donnellan

Derivation of name: Walabanba Hills in the vicinity of 52K 302500mE 7560300mN in northwestern ANNINGIE.

Parent unit: Lander Rock Formation.

Distribution: Outcrops over an area of about 40 km² in the Walabanba Hills and about 15 km² to the north of Old Mount Peake centred on 53K 284500mE 7624000m, and at 53K 294250mE 7669500mN in MOUNT PEAKE. The unit also outcrops locally in southern LANDER RIVER. Interpretation of geophysical data indicates it is a component of the Lander Rock Formation succession throughout northern and eastern MOUNT PEAKE and in LANDER RIVER south of the Wiso Basin.

Type area: The Walabanba Hills, and particularly in the vicinity of 53K 303000mE 7660000mN.

Thickens: Polydeformation precludes precise determination, but estimated to be ≥850 m.

Lithology: Alternating metapelite, typically with a well developed slaty cleavage, and metapsammite, representing an original succession of siltstone and cross-bedded quartz arenite, the latter with localised heavy mineral laminations; and layer parallel amphibolite. Pelitic rocks are locally more schistose, particularly proximal to granite contacts, where they contain large retrogressed andalusite porphyroblasts. Psammitic rocks are similarly hornfelsed proximal to granite, and contain a small proportion of plagioclase, microcline, biotite, muscovite and titanite.

Structural attitude: The Walabanba Member is polydeformed, with generally moderately dipping, but locally overturned strata.

Relationships and boundary criteria: Contacts with immediately under- and overlying intervals of the Lander Rock Formation are not generally exposed. In the Walabanba Hills, the unit is locally bounded by stratiform metamafic rocks. Poorly or non-outcropping non-magnetic intervals of Lander Rock Formation metasedimentary rocks also bound the unit and separate it from the underlying Anningie Member. Intruded by the Esther Granite, gabbro and dolerite.

Age and evidence: From SHRIMP U-Pb zircon dating (Claoué-Long et al 2008a), the Walabanba Member has a maximum age of sedimentation of ca 1863 Ma, based on the average of the youngest coherent group of zircons (1863 ± 5 Ma); the youngest zircon is 1822 ± 56 Ma. Intruded by the 1789 ± 6 Ma (Cross et al 2005) Esther Granite, which provides a minimum age of deposition.

Synonymy: None.

Correlatives: Probably partially correlates with the Woodalla and Mount Stafford members of the Lander Rock Formation, but comprises more proximal, shallow-marine sedimentation, in contrast with these deep-water (turbiditic) metasedimentary rocks. Correlated with part of both the Bullion Schist and the Ooradidgee Group.

Anningie Member

Proposer: N Donnellan

Derivation of name: Anningie Creek and ANNINGIE 1:100 000 mapsheet.

Parent unit: Lander Rock Formation.

Distribution: Outcrops over an area of about 70 km² in the vicinity of Central Mount and more sporadically over an area of about 90 km² north of Conical Hill in eastern MOUNT PEAKE. Minor outcrops occurring locally in southern LANDER RIVER (eg at 53K 257600mE 7704750mN)
are also probable Anningie Member. Interpretation of geophysical data indicates member is a component of the Lander Rock Formation succession throughout northern and eastern MOUNT PEAKE and LANDER RIVER south of the Wiso Basin.

**Type area:** Northwest of Central Mount in the vicinity of 53K 315250mE 7577500mN.

**Thick ness:** Polydeformation precludes precise determination, but estimated to ≤1200 m.

**Lithology:** Predominantly micaceous, fine-grained quartzofeldspathic schist, local sillimanite schist apparently proximal to contacts with intrusive mafic rocks; layer-parallel amphibolite.

**Structural attitude:** The Anningie Member is polydeformed with a generally moderately dipping S1 foliation, or, locally, bedding.

**Relationships and boundary criteria:** Contacts with the immediately under- and overlying intervals of the Lander Rock Formation are not exposed. Geophysical interpretation indicates that the Anningie Member is at a lower stratigraphic level in the Lander Rock Formation than the Walabanba Member. Intruded by the Esther Granite, unnamed granite and Anmatjira Orthogneiss.

**Age and evidence:** The Walabanba Member, a conformable unit at a higher stratigraphic level in the Lander Rock Formation, has a maximum age of sedimentation of ca 1863 Ma based on the average of the youngest coherent group of 18 zircons (1863 ± 5 Ma); the youngest zircons is 1822 ± 56 Ma (Claué-Long et al 2008a). Intruded by the 1789 ± 6 Ma (Cross et al 2005) Esther Granite.

**Synonymy:** None.

**Correlatives:** Probably partially correlates with the Woodalla and Mount Stafford members of the Lander Rock Formation. Correlated with part of both the Bullion Schist and the Ooradidgee Group.

**Woodalla Member**

**Proposer:** N Donnellan  
**Derivation of name:** Woodalla Bore 53K 193000mE 7575250mN in southwestern MOUNT PEAKE.  
**Parent unit:** Lander Rock Formation.  
**Distribution:** The principal areas of outcrop are immediately north of Giles Range in southwestern MOUNT PEAKE, and near Tin Bore (53K 249700mE 7562100mN) in central-northern NAPPERBY.  
**Type area:** Around 53K 225300mE 7571300mN to the north of Giles Range.  
**Thickness:** Polydeformation precludes precise determination; estimated to be at least 500 m, but is probably substantially thicker.

**Lithology:** Metasedimentary feldspathic-quartzarenite, and (cleaved) siltstone and schistose equivalents. Stratiform amphibolite is associated with schistose Woodalla Member near Tin Bore in NAPPERBY.

**Structural attitude:** Polydeformed, with generally moderate to steeply dipping bedding or S1 foliation.

**Relationships and boundary criteria:** The base of the Woodalla Member is not exposed. There is an apparent conformable relationship with the Mount Stafford Member near Tin Bore in Napperby. However, the Mount Stafford Member is considered to be predominantly a higher metamorphic grade equivalent of the Woodalla Member.

**Age and evidence:** The correlative Mount Stafford Member has a maximum age of 1869 Ma based on its youngest coherent group of detrital zircons, 1866 ± 3 Ma (Claué-Long et al 2008a). The correlative Lander Rock Formation in MOUNT DOREEN has a similar maximum age of sedimentation, ie 1868 Ma based on a youngest coherent group of detrital ages of 1862 ± 6 Ma (Claué-Long et al 2008a).

**Synonymy:** None.

**Correlatives:** Correlated with turbiditic (and locally high-grade equivalents) Lander Rock Formation in MOUNT DOREEN and Mount Stafford Member in MOUNT PEAKE and NAPPERBY. The Woodalla Member may equate with widespread (probably turbiditic) Lander Rock Formation in the western Aileron Province of the Arunta Region.

**Mount Stafford Member** (variation of published name)

**Proposer:** N Donnellan, originally named the Mount Stafford Beds by Shaw and Stewart (1975), and redefined as the Mount Stafford beds by Stewart et al (1980b).

**Derivation of name:** Mount Stafford 53K 257700mE 7563350mN.

**Parent unit:** Lander Rock Formation.

**Distribution:** In the Yundurbulu Range in north-central NAPPERBY and adjacent south-central MOUNT PEAKE, where it extends into the Bilba Hills.

**Type area:** Well exposed in the Yundurbulu Range, where a section from approximately 53K 252500mE 7559300mN northeast to approximately 53K 260800mE 7565750mN crosses a succession of prograde metamorphic isograds, described by Vernon et al (1990).

**Thickness:** Probably ≤1300 m.

**Lithology:** Locally quartz-mica schist and phyllite (now largely included in Woodalla Member); spotted and layered predominantly metapelitic and subordinate metapsammitic hornfels (andalusite-cordierite-K-feldspar; spinel-cordierite-K-feldspar; orthopyroxene-garnet-cordierite-K-feldspar); migmatite; amphibolite.

**Structural attitude:** Polydeformed, major outcrop area comprises northwest-trending open anticlines and synclines.

**Relationships:** Conformable, and laterally transitional contact with Woodalla Member. Top not exposed. Intruded by dolerite, unnamed granite and Anmatjira Orthogneiss.

**Age and evidence:** The Woodalla Member, which is a low-metamorphic-grade equivalent of the Mount Stafford Member, has a maximum depositional age of 1866 ± 3 Ma, based on its youngest coherent group of detrital zircons, (Claué-Long et al 2008a). Intruded by the Anmatjira Orthogneiss, which has an igneous crystallisation age of 1795 ± 3 Ma (Worden et al 2008). Rubatto et al (2006) established that metamorphism was essentially coeval with granite intrusion at 1802 ± 3 Ma.

**Synonymy:** Formerly Mount Stafford Beds and Mount Stafford beds.

**Correlatives:** Woodalla Member in part, and therefore probably also Lander Rock Formation in MOUNT DOREEN.
APPENDIX 2: GEOCHEMICAL DATA FOR FELSIC ROCKS

Excel spreadsheet MtPeake_LanderRiver_Appendix_2.xls tabulating major and minor oxide, and trace element contents for granites from MOUNT PEAKE and LANDER RIVER.

Major and minor oxide data for sample numbers prefixed 7211 and 7411 are from Stewart et al (1980a), and corresponding trace element data from Geoscience Australia’s geochemistry database, OZCHEM. Data for sample MP02ND108 are also from OZCHEM.

All other samples were analysed by Amdel Laboratories.

NA signifies not analysed.

Note that the Proterozoic symbol P is displayed as P in unit codes (eg Pg1m = Pg1m).